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Ravindra Goonetilleke
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Ravindra Goonetilleke · Waldemar Karwowski
Editors

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Advances in Human Factors and Ergonomics 2016

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7th International Conference on Applied Human Factors and Ergonomics

Proceedings of the AHFE 2016 International Conference on Physical Ergonomics and Human Factors, July 27–31, 2016, Walt Disney World®, Florida, USA

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Preface

The discipline of human factors and ergonomics (HF/E) is concerned with the design of products, process, services, and work systems to assure their productive, safe and satisfying use by people. Physical ergonomics involves the design of working environments to fit human physical abilities. By understanding the constraints and capabilities of the human body and mind, we can design products, services and environments that are effective, reliable, safe and comfortable for everyday use.

A thorough understanding of the physical characteristics of a wide range of people is essential in the development of consumer products and systems. Human performance data serve as valuable information to designers and help ensure that the final products will fit the targeted population of end users. Mastering physical ergonomics and safety engineering concepts is fundamental to the creation of products and systems that people are able to use, avoidance of stresses, and minimization of the risk for accidents.

This book focuses on the advances in the physical HF/E, which are a critical aspect in the design of any human-centered technological system. The ideas and practical solutions described in the book are the outcomes of the dedicated research by academics and practitioners aiming to advance theory and practice in this dynamic and all-encompassing discipline.

A total of eleven sections were presented. Each section contains research that has been reviewed by members of the international editorial board. Our sincere thanks and appreciation to the following board members:

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We hope that this book, which is the international state-of-the-art in physical domain of human factors, will be a valuable source of theoretical and applied knowledge enabling human-centered design of variety of products, services, and systems for global markets.

Kowloon, Hong Kong — Ravindra Goonetilleke
FL, USA — Waldemar Karwowski
July 2016

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Part I
Prevention of Work-Related Musculoskeletal Disorders

Physical Load Among Construction Workers and Analysis with Objective Ergonomics Research Method

Zenija Roja, Henrijs Kalkis, Ingars Reinholds and Inara Roja

Abstract There is growing number of work related musculoskeletal disorders among workers in construction industry. Employees in construction professions admit physical load and discomfort in various body parts after the work. Accordingly to Eurostat statistical data 60 % of total work related diseases are attributed to musculoskeletal disorders in Latvia. The aim of this study was to determine physical load of construction auxiliary workers and bricklayers using objective ergonomics research method HR monitoring and subjective ergonomic risk assessment methods. The research involved full time 8 auxiliary construction workers and 7 bricklayers. Analysis of the heart rate monitoring data proved that objective physical load analysis method is more precise than subjective workload evaluation methods. Results showed that construction workers workload falls into hard and moderate work heaviness category. More experienced workers with longer length of service were subjected to lower work heaviness category.

Keywords Bricklayers · Auxiliary workers · Heart rate · Physical load · Ergonomics

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1 Introduction

Excessive physical exposures such as heavy lifting or working with bended or twisted back, long working hours, unfavorable microclimatic conditions, poor control of executed work and decision-making, management and colleagues' lack of support often is reason what causes work related musculoskeletal disorders [1, 2]. These occupational risk factors may contribute to the development of musculoskeletal disorders—either alone or in varying combinations are described in many findings [1, 3–8]. Additionally, studies have shown that a heavy workload is associated with reduced work ability, increased risk of sick leave, and early retirement. Serious health problems are caused by workers smoking. Smoking reduces blood flow to the vertebral body, adversely affecting the metabolic balance of the discs, thereby accelerating degenerative processes and making the spine more susceptible to mechanical deformities and injury [9]. Hazards are categorized as those inherent in the performance of specific work tasks, those due to work and job design factors, those due to characteristics of the workplace environment, and those associated with the personal characteristics of people in the workplace, including supervisors and managers. Work related musculoskeletal disorders (WRMSD) can arise not only physical-employed, it can be a harrowing illness also for office workers and other monotonous work performers [10].

The aim of this study was to determine physical load of construction auxiliary workers and bricklayers using objective ergonomics research method HR monitoring and subjective ergonomic risk assessment methods. The research involved full time 8 auxiliary construction workers and 7 bricklayers, that found to be healthy in the mandatory health checks and had no complaints about acute or chronic pains in various parts of the body. Their type of work included heavy raising manual work in different compulsory postures. Exclusion criteria were: life-threatening diseases, hypertension >140/90 mmHg, acute rheumatic problem. The study was approved by the Human Ethics and Institutional Review Board of Riga Stradins University in 2015. All workers were males and agreed to take part in the objective measurements.

2 Methods

2.1 Participants

Research group consisted of 8 auxiliary construction workers and 7 bricklayers (aged 21–65 yrs.). Background factors of the research group are shown in Table 1.

All workers agreed to participate in the survey on exploring existing work conditions and workload. The participants filled up a questionnaire revealing their age, length of service in the profession, body weight, and activities during work, occupational risks, lifestyle, and habits. It should be noted that only bricklayers had

Table 1 Background factors of the subjects: length of service, age, height, weight, body mass index (BMI)

Occupation (length of service)	n	Mean age ± SD	Range	Mean height, cm ± SD	Mean weight, kg ± SD	Mean BMI, kg/m^2 ± SD
Auxiliary construction workers	8	34.2 ± 8.5	18–63	178.0 ± 9.6	79.5 ± 7.1	25.1 ± 3.3
(1–10 years)	6	26.6 ± 6.1	18–32	177.4 ± 8.3	78.3 ± 6.7	24.4 ± 3.5
(>10 years)	2	45.3 ± 4.7	39–63	176.7 ± 6.6	79.0 ± 6.2	25.0 ± 3.1
Bricklayers	7	37.6 ± 8.0	22–61	176.9 ± 6.3	76.2 ± 8.1	24.1 ± 2.1
(1–10years)	5	29.4 ± 5.3	22–38	177.1 ± 4.1	76.0 ± 5.3	23.6 ± 3.4
(>10 years)	2	51.2 ± 6.3	41–61	175.3 ± 6.4	75.2 ± 8.4	24.3 ± 2.8

special vocational education in construction work, but for auxiliary workers there is no special education in construction work.

2.2 Heart Rate (HR) Monitoring

Heart rate (HR) monitoring is one of the most popular indirect objective methods to estimate energy expenditure (EE) as it is a practical and low-cost method that brings little inconvenience to the subject. Heart rate monitoring was carried out using Polar S810iTM Heart Rate Monitor device and data processing software Polar Precision Performance. When determining heart rate the device sums up the acquired data and transforms them into metabolic energy consumption (kcal/min). Data processing software Polar is used to determine the energy consumption and work ability (degree of hardness). Maximal heart rate was calculated as the most common formula $HR_{max} = 220 - \text{age}$, although there exist most accurate formulas, for example: $HR_{max} = 205.8 - (0.685 \times \text{age})$ [11]. Work heaviness in terms of energy expenditure was classified accordingly to classification scale shown in Table 2.

Table 2 Work heaviness classification in terms of energy expenditure [12]

Workload categories		Energy expenditure	
NIOSH (USA) standard, ISO 28996		Male, kcal/min	Female, kcal/min
Light work	I	2.0–4.9	1.5–3.4
Moderate work	II	5.0–7.4	3.5–5.4
Hard work	III	7.5–9.9	5.5–7.4
Very hard work	IV	10.0–12.4	7.5–9.4
Ultimate work	V	more 12.5	more 9.5

2.3 The Rating of Perceived Exertion (RPE)

The rating of perceived exertion (RPE) of individuals depending on their age, physical conditions, subjective view of increased heart rate was assessed using Borg rating scale, ranging from 6 to 20 [13]. Data were gathered via questionnaires and interviews.

2.4 The Key Indicator Method (KIM)

The Key Indicator Method (KIM) for assessment of the manual handling of heavy loads developed by the German Federal Institution for Industrial Safety and Occupational Medicine was used to assess workers ergonomics risks [14]. Key indicators (criteria) takes into account: object mass rating points (M); the employee's posture rating points (P); working conditions rating points (C); working time/intensity value points (I). Risk evaluation is carried out by physical workload risk score (RS) using the following formula: RS = (M + P + C) × I. According to this method work hardness categories R_P (or risk range) are as follows: I—light work or low load situation (RS < 10); II—moderate work or increased load situation (RS = 10 … 25); III—hard work or highly increased load situation (RS = 25 … 50); IV—very hard work or physical overload (RS > 50).

2.5 National Institute for Occupational Safety and Health (NIOSH) Lifting Equation

National Institute for Occupational Safety and Health (NIOSH) lifting equation is an assessment method for lifting and lowering tasks [15]. The equation provides a recommended weight limit (RWL) based upon task parameters and the duration the task is performed. The RWL is obtained through the following equation [16]: $RWL = 23[25/H][1 - (0.003|V-75|)] \times [0.82 + 4.5/D] \; [1 - (0.0032 \; A)] \; FM \times CM$, where H is the horizontal location in cm, V is the vertical location in cm, D is the distance in cm, FM is the frequency multiplier, A is the asymmetry angle in degrees, and CM is the coupling multiplier. The actual load lifted or lowered divided by the RWL provides the lifting index LI. LI values greater than 1.0 are assumed to represent tasks posing risk to the worker population.

3 Results and Discussion

Questionnaire data analysis showed that all participants were in the age group 18–63 years and most frequently complained on feeling discomfort after the work, particularly, low back pain and pain in the neck, shoulders, arms and legs. More

complains about pain in the neck, shoulders and back was among workers with longer length of service (>10 years). Determined frequency of heavy lifting and moving in one shift depends on the type of work. Five auxiliary construction workers indicated that they are lifting and moving heavy materials (over 40 kg) 200 times per shift, but 5 bricklayers reported heavy weight (30–40 g) lifting and moving 40–100 times per shift. Only 2 bricklayers and 3 auxiliary construction workers reported that they have to lift and move heavy loads less than 20 kg only up to 40 times per shift. It should be noted that all workers are passionate smokers and in average they smoke 20–40 cigarettes per day that can influence their health and wellbeing in future.

The work severity (risk) degree was assessed with Key Indicator Method (KIM) for auxiliary construction workers and bricklayers. The main tasks for auxiliary workers were: lifting and carrying construction and building materials, for bricklayers—bricklaying, including brick building by hands and forced work positions, manual lifting of construction objects.

Using the before mentioned connection total assessment of workplace was done and risk degree R_P determined (see Table 3).

Assessing physical workload of the above mentioned occupations during tasks of lifting or moving heavy loads, Table 3 shows that auxiliary workers are exposed to most severe workload (corresponds to the risk degree IV), but bricklayers are subjected to hard work risk category (III) in accordance with NISOH workload standard categories.

The estimated recommended weight limit for all employees in the research group for both professions was calculated. Results are illustrated in Table 4.

The results in Table 4 shows that the recommended weight lifting and moving limit exceeds 1.4–1.5 times for auxiliary construction workers, but for bricklayers in the group of length of service from one to ten years results are even higher (from 2.6 to 3.1 times).

Hence it can be concluded that workers in various construction processes are subjected to physical overload at the workplaces, the moved and lifted weight especially for bricklayers exceeds the norm in various manual lifting of construction objects operations. It can negatively influence cardiovascular system and muscular-skeletal system. The selection of heart rate measurements was based on

Table 3 KIM method evaluation scores (M, P, C, I), standard deviation (SD), risk score (RS), risk degree (R_P) for construction workers (n = 15)

Occupation		M ± SD	P ± SD	C ± SD	I ± SD	RS	R_P
	n = 15	Scores					I–V
Auxiliary construction workers	8	4.4 ± 1.2	4.6 ± 1.2	0.4 ± 0.2	7.3 ± 1.6	65.4	IV
(1–10 years)	6	4.3 ± 1.6	4.2 ± 1.5	0.5 ± 0.2	6.1 ± 1.3	51.2	IV
(>10 years)	2	3.6 ± 1.4	6.7 ± 1.3	0.4 ± 0.4	7.3 ± 1.4	63.9	IV
Bricklayers	5	4.3 ± 1.5	4.4 ± 1.6	0.3 ± 0.3	3.6 ± 0.8	31.6	III
(1–10 years)	7	3.8 ± 1.6	7.3 ± 1.2	0.4 ± 0.2	2.3 ± 1.7	27.0	III
(>10 years)	2	4.2 ± 1.2	4.2 ± 1.8	0.3 ± 0.2	4.2 ± 1.4	37.7	III

Table 4 Recommended mass limit (RML), lifting and moving load (M), lifting index (Li) and standard deviation (SD) for construction workers (n = 15)

Occupation	n = 15	M ± SD, kg	RML ± SD, kg	Ci
Auxiliary construction workers	8	5.2 ± 1.5	3.5 ± 2.5	1.5
(1–10 years)	6	15.1 ± 2	9.8 ± 2.2	1.5
(>10 years)	2	4.5 ± 1.5	3.3 ± 1.4	1.4
Bricklayers	7	22.4 ± 2	8.1 ± 1.1	2.7
(1–10 years)	5	9.6 ± 2	3.1 ± 1.4	3.1
(>10 years)	2	17.8 ± 2	7.4 ± 2.3	2.4

necessity of objective workload analysis of auxiliary workers and bricklayers. In order to find out the work load under shift work, HRM for the auxiliary construction workers and bricklayers was done in day shift work (8:00–16:00).

Research results of HRM are summed up in Table 5. Results of HRM are shown by taking into account average heart rate and energy expenditure of each person, standard deviation (SD), Pearson's correlation (r), and Cohen's Kappa coefficient (κ).

Heart rate monitoring data analysis confirmed that auxiliary construction workers as well as bricklayers work is referable with hard and moderate work heaviness category energy expenditure in their tasks varies from E = 3.0 till 7.6 kcal/min. More experienced workers (length of service >10 years) were subjected to II work heaviness category. That can be explained that these workers have more work experience and already have adopted to workload than workers with less length of service in the construction operations.

Research results are in accordance with other findings. Lifting and carrying are manual work for construction workers, and the loads often exceed the recommended limits [17]. Accordingly to Koningsveld and Van der Molen [17] the internationally accepted limit (30 % of maximal oxygen consumption) for energetic load is exceeded by many construction workers. Maritz et al. [18] suggested that an average working HR for standard for 8 h industrial job should be 105 beats/min, with a range of 95–115 beats/min. Accordingly to Brouha [19], the HR in the industry should not exceed 110 beats/min, as cumulative fatigue would likely to ensue beyond this HR level. Matos and Arezes [10] proved that severe workload may not be related to the poor available equipment but with the need to optimize their use by the workers. Also in our research workers with higher experience have developed more comfortable and individual work techniques and hence also the workload severity falls into lighter risk category.

There is high prevalence of back pain and neck-shoulder pain, pain in the arms and legs, and tiredness among auxiliary construction workers. Excessive ergonomic stresses can cause a variety of occupational health problems such as musculoskeletal disorders [1] including fatigue, discomfort and disability [20] as well as cardiovascular diseases [21]. Workload stresses may result from awkward posture, excessive force demands, highly repetitive actions and/or excessive energy expenditure [2]. In such circumstances workers are at a higher risk of work related

Table 5 Workers' heart rate (HR), objective energy expenditure from HRM data (E), the rate of perceived exertion (RPE, scale 6–20), work heaviness category (WHC), Pearson's correlation (r) and Cohen's Kappa (κ)

		Heart rate monitoring data				Objective E ± SD, kcal/min*	Mean RPE ± SD (range)	WHC
Occupation	n	Mean HR ±SD, beats/min	Range HR, beats/min	r	κ			
Auxiliary construction workers	8							
(1–10 years)	6	139 ± 12	56 … 126	0.95	0.85	7.6 ± 0.7	8 ± 2 (6–10)	III
(>10 years)	2	126 ± 15	77 … 135	0.95	0.80	5.5 ± 2.5	9 ± 2 (7–11)	II–III
Bricklayers	7							
(1–10 years)	5	147 ± 16	68 … 138	0.95	0.75	7.5 ± 0.6	10 ± 2 (8–12)	III
(>10 years)	2	133 ± 14	84 … 151	0.95	0.68	5.7 ± 1.6	11 ± 2 (9–13)	II

*day shift

injury or muscular skeletal problems. Most physical demands are emphasized in lifting procedures, which drastically loads the musculoskeletal system [22]. Hence the additional research is necessary to carry out workload analysis on various body parts and determine muscle fatigue levels, for example with objective evaluation methods like myothonometry or electromyography.

4 Conclusions

Combined use of subjective and objective research methods proved high physical workload for construction workers. HRM as objective method showed lower workload heaviness categories as subjective methods. It was proved that work heaviness falls into lighter workload categories for workers with longer length of service in construction industry. Construction auxiliary workers and bricklayers are subjected to long and intensive work in compulsory work positions and workload exceed the NIOSH workload norms that has significant impact on workers cardiovascular system, muscular and skeletal system and fatigue level. Further research will be carried out in order to analyze muscle fatigue levels in different worker's age groups with objective research methods.

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An Ergonomics Research for Developing Senior Citizens' Mobile Devices Gesture Display

Shou Fang Liu, Ming Hong Wang, Ming Chyuan Lin and Tsung Sheng Huang

Abstract The advanced countries in Europe, US, and Japan start to focus on the design problems of aging society from the point of social welfare because of the global trend towards the aging society. However, there are a variety of mobile devices on smart phones and tablets showing the flashy and high-tech effect to attract the users' attention but it is confusing to the elderly for searching and judging important information. An industrial designer should know the elderly requirements, follow the principles of the universal design, be able to design suitable gestures for the interface operation of the mobile devices, and promote the value of products. This research applies the concept of ergonomic methods in building ergonomic decision evaluation system, modeling development and demonstrating the developed designs to help improve the gesture of interface operation on the mobile devices for the elderly people.

Keywords Elderly people · Smart mobile device · Interface design · Customer-oriented design

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1 Introduction

Due to the change of social population, the elderly with the improvement and completion of the medical equipments and care are becoming more and more life span. The relevant research issue of facing the elderly adaption is what many scientific experts want to understand further. Situated in the era of fast modern technology development, people often carry the smart mobile device, which has become part of the human life. Under the situation of seating in such a high-fast modern technology, the elderly are forced to use the relevant 3C technological products of intelligent interface devices. Learning through the initial observation on the popularity rate of intelligent interface devices, people can find the life-style of the elderly is beginning to be changed. Life can't be escaped from the high-technological products with the audience dependent on the smart phones. As such it will take much higher quality for users to use.

Our living societies are now in the surroundings of the high-fast technological development that need the visual and touch display to be the way of spreading messages, which instead cause a big burden for the elderly. A multiple functional mobile device has become the available spreading message equipment, the close-related product, mastering the precise information instantly and releasing information at any time in the modern life, etc., so it's become the most important service content item of the current modern technological products.

Cuhaman [1] thought that the users' interface composed of the interaction of software and hardware among the products is grouped into three categories: hardware operation, touch operation and software operation. The common interface of hardware operation is called content interface operation including the traditional controller, the control panel of the display, and the position of the content product for users to operate. The touch interface operation of the touch panel combined with the software and hardware users' interface that allows users to use fingers to operate. The soft interface operation toward the development of diagrams is called diagram interface operation, which enhances the users' comprehension to make the operation easy. Primarily finding from the author's past relevant research, the operation of the smart device interface, for which people's demand will produce a different-level change when the age is growing.

The young aged people, with better physical status than the medium-high aged people, are good at mastering the technological products either familiarity with operation or the speed of reaction to the interface operation. The study has shown the elderly are unable to retain the attention for a long time, which might cause some problems, especially for the task of the prompt and continuous scan, the elderly will feel so tired [2]. They are likely to be absent-minded, for the trivial details, lowering the ability of gaining information [3, 4].

Their abilities become lowering when they focus on two complicated tasks at the same time [5, 6]. No matter how the old people are, their attention can be distributed to employ at the same time. For example, when driving, their attention will be distributed; only when facing more complicated tasks is the elderly attention

weaker than those of the young. The study has shown the distribution of attention can decline with the age increasing. It is an essential issue for the future toward the aging society that the elderly should be more intuition and efficiency for the operation of the smart interface device product. The modern high technological products have developed more and more advanced functions, and all brands promote the smart mobile interface products, which can be all kinds, and they emphasize their own value of products correspondent with the environment, safety, equipment efficiency, and the introduction of all kinds of novel entertaining functions.

For the color of words on the interface, the organism of the product feedback, the way of the screen display and illumination, the size of floating windows, and gestures, they are forced to learn different ways of operation when using every different product of brands. Besides, they have to try many times because of different gestures and will cause the learning patience exhausted or give up directly and turn to their family or friends for help. The author has primarily united the most common types of smart-phones in the market based on the observation from the above list of the most common gesture operations involving motion, rotation, and contraction, etc. Human-Computer Interface or called Human-Computer Interaction, HCI, is focusing on the ideal users' interface design, showing that the machinery interface is the main interactive role [7]. Usability evaluation includes five sector indexes and is stated as follows:

1. Learnability: be easy to learn and quick to respond.
2. Efficiency: be capable to use and quick to reach.
3. Memorability: be easy to memorize and operate.
4. Inaccuracy: lower error rate.
5. Satisfaction: be comfortable in use and operation.

2 Method

2.1 Previous Studies

In the previous studies, the examiners operated 5 most common products of smart-phones that are obtained from the market, and recorded their gesture operation. The experiment investigated the examiners' operation of smart-phone products to find which gesture operation for the elderly can't be used easily. These statistical data derived from the experiment will be the core of the study. In this experiment, five designers who have over six years of practice experience were asked to take the way of hand-drafting to identify the difficulty that the elderly feel when using smart-phones. It is expected to analyze through the current gesture operation to find a more suitable way for the elderly.

The result of the final research evaluated the experimental solutions and the simulated gestures of innovative designs with the way of traditional operation to compare interactively with the gesture of the innovative design. Note that the Traditional Gesture is illustrated in Figs. 1, 2 and 3. As to new Gesture, they are illustrated in Figs. 4 and 5.

Fig. 1 Zoom in gesture (shrink)

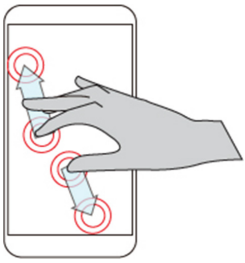

Fig. 2 Zoom out gesture (enlarge)

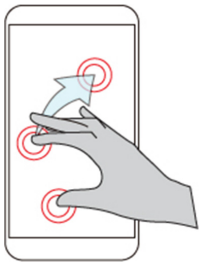

Fig. 3 Rotate gesture

Fig. 4 Zoom in (slide down) and Zoom out (slide up) gesture

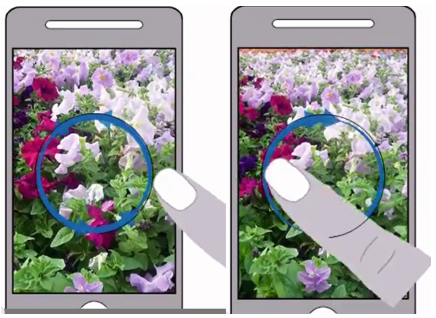

Fig. 5 Zoom in (reverse clock circle) and Zoom out (clock circle) gesture

The study establishes the way of the innovative gesture control. According to the outcome of the focus group, the way of the innovative gesture operation is better than the way of multi-fingered gestures for the elderly. Thus, it can prove the innovative-designed gesture operation is much better than the way of the traditional operation. In the items of the use assessment, efficiency, memory and satisfaction all can achieve the good condition.

From the analysis of the study, the medium-high aged people can take the one touch gesture operation as the way to operate smartphones. The outcome from the research is helpful for the advanced development in the touch device operation of mobile devices for the elderly. Based on Wang's [8] research outcome, it is noted that the best gesture operation of the smart mobile device interface is use the one touch operation for the elderly.

2.2 Focus Grouping

This study focused on over 55 years old people for the smart-phones of hand-touched operation through the review of references, the survey of questionnaires, and the experimental simulated operation. To provide the suitable hand-touched operational interface materials with the elderly, the research increased the elderly' touch feedback of the screen texture design, and evaluated with learning, efficiency, memory, the error rate, convenience, vision, and the whole satisfaction. Note that the standard of the scores are based on a Likert Scale (1 = very awful; 2 = bad; 3 = no opinion; 4 = good; 5 = very good). The comfortable degrees of fingers and eyes are the way to testify the gesture operation.

2.3 Subjects

The tested subjects who involved in the experiment are 10 people aged over 55. To conduct the test, the research arranged 15 min of operation in order to explore the

elderly's requirement for the way of the smart mobile interface device. The tested subjects have at least one-year experience of using smart-phones. The research presented 4 different touch product samples and explored which is most suitable for the elderly to use comfortably.

2.4 Process

This experiment uses the same type smartphone, the type and brand of the smart-phone is HTC M7. Focus the issue of "interface materials" and "the comfortable degree of vision" to be the research exploration. Explore the variable comparison of smart mobile touch interface devices and the comfortable degree of the visual browse to represent all kinds of variations for users' feelings after the usage.

- Step 1: First, ask the examinees to use the smartphone without attaching any materials, with 5 min.
- Step 2: Put the interface materials of the No.1 to the No.4 attached to the smart-phones respectively, and each of the interface material for using 5 min. Figures 6, 7, 8 and 9 illustrated the respective surface materials for the 4

Fig. 6 No.1 Bright surface material

Fig. 7 No.2 Matte surface material

Fig. 8 No.3 Rigidity surface material

Fig. 9 No.4 Anti-blue surface material

samples. The examinees browse the specific pictures of the study with different interface materials, and use the three gesture operations: motion, rotation, and contraction. The above three gestures are the most employment that the research derived from the past research references and the current observation.

- Step 3: After finishing the experiment of No.1 to No.4, the research evaluated the questionnaires of the experiment. Table 1 illustrated the results for the four samples based on the seven evaluation items.
- Step 4: The above experimental steps proceed with a continuous process, and it can just be seen as the procedure of the whole experiment. Based on the experimental data of smart-phones, the data with the interface materials and without the interface materials are forwarded to the ANOVA analysis to observe if there is any obvious difference, and explore which materials are suitable for the elderly.

Table 1 Mean and S.D. in different gesture mode

			Learnability	Efficiency	Memorability	Errors	Convenience	Visual	Satisfaction
Material samples	No1.	Number	10	10	10	10	10	10	10
		Mean	3.0	3.4	3.0	3.8	3.4	1.8	3.8
		S.D	0.9	0.5	0.9	1.0	0.5	0.4	0.4
	No2.	Number	10	10	10	10	10	10	10
		Mean	4.8	4.6	5.0	4.0	4.0	4.8	4.4
		S.D	0.4	0.5	0.0	0.9	0.0	0.4	0.5
	No3.	Number	10	10	10	10	10	10	10
		Mean	3.6	4.4	4.0	4.4	4.0	2.6	4.0
		S.D	0.5	0.5	0.9	0.5	0.0	0.5	0.0
	No4.	Number	10	10	10	10	10	10	10
		Mean	3.2	2.8	2.8	2.8	2.8	2.4	3.2
		S.D	0.4	0.7	0.7	0.7	0.7	0.8	0.4

3 Result

Facing the coming of the aging society, the relevant touch interfaces of technological products are developing rapidly. The users are eager for the requirement of the simple interface operation. However, we can't exactly know the elderly' feelings for the new coming touch technology and the interface from the current references. It is expected that through the experiment of smart-phones and the operative observation, the results can help induce and analyze the elderly for the requirement of the operation of smart-phones and develop the design principles of the smart mobile relevant interface product as a reference for the related design for the future elderly.

3.1 The Comparative Analysis of Each Material

We can clearly see that the No.1 (glare), the No.2 (anti-glare) and the No.3 (reinforced glass) are the common materials for the elderly to use. From the evaluation of usage chart illustrated in Table 1, learning, efficiency, memory, the error rate, vision, and the whole satisfy, all achieve significance ($P < 0.05$).

4 Conclusion

From the analysis of the study, we can understand that based on the previous study, getting the innovative gesture model for the users aged over 55, using the one touch gesture as the way of operating smartphones, connected with the interface materials of mobile devices can be helpful for the elderly to operate the touch device interface. In this period of the experiment, getting the statistic data as the reference of expanding samples in the future is still unable to represent the population for the current experimental result. This study will continue to explore deeply, hoping to analyze the more suitable experimental proof for the elderly to operate and making the interface materials of smartphones much more comfortable for the elderly to use. In the future, the direction of the study will further focus on the analysis of exercise for the tiring of hands muscle, the exercise way of every finger' joint, and the innovative design model of eyes tracking.

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Application of Hidden Markov Model in Human Motion Recognition by Using Motion Capture Data

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Abstract The present study outlines an approach that describes how the statistical pattern recognition tool as Hidden Markov Model (HMM) is used to segment, extract features from different types of human common locomotion data, classify them and make a reliable probabilistic recognition. We have utilized six type of motion (climb, forward jump, jump, run, sit and walk), and each of them was composed of eight AMC data format specifically chosen from the CMU online library. The captured data were transformed from three dimensional (3D) joints trajectories into Matlab analyzable 2-Dimensional matrix using the Singular Value Decomposition (SVD) features factorization algorithm and then trained using the Baum-Welch algorithm, which has performed a classification of each motion's extracted features for computational evaluation. The maximum iterations tolerance according to the number of motion was around 0.001 for highly accurate probability. In spite of the noisiness of the hand and toe trajectories, the recognition level was pretty higher than expected. Although, this investigation doesn't take in account the different motion's trajectories speed. The overall model has shown the probabilistic efficiency of HMM when it is about segmenting and evaluating vectorized motion's features. The proposed study is suitable to any human common locomotion capture in AMC format and can be a great tool for further modeling in motion prediction.

Keywords Singular value decomposition · Hidden Markov model · Motion recognition

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1 Introduction

Through Digital human modeling usually needed for robotics intelligence and work process analysis combined with Motion Capture technologies, the scientific world is reaching a new level in understanding human functionality beyond ergonomics design. As evolution goes, being able to distinctly make the correlation between motion's specific variability and comparable set of extracted features is becoming the core concept of Motion Recognition especially when it is about segmenting unobservable parameters. Already successful in the field of speech recognition and protein modeling because of its capacity in uncertainty compensation, Hidden Markov Model (HMM) became one of the wildly used stochastic approaches to capture motion's structure in order to make reliable matching templates through vector quantization for the corresponding untrained sequence. HMM has three major design basis that are evaluate the probability or likelihood of a sequence of observations given a specific model; the determination of a best sequence of the model states; and the estimation of the model parameters for an effective recognition [1]. Most popular dynamic research is vision-based recognition analysis depending on observed video sequences where each frame describes a particular body-position shape [2–4]. The advantage of those HMM built in dynamic modeling is that the motion's characteristics are extracted by frame creating analyzable symbols, however it requires a large amount of visual data assuming that all of them are noiseless. Given the high complexity of human body motion, alternative systems that do not necessitate explicit image feature detection or segmentation are welcomed.

In favor of solving these limitations, our study proposes an application where HMM is applied to Mocap AMC data format (skeletal joint trajectories displacement data) downloaded from the open CMU online library in order to perform a set of recognition. In our case, it implies to make an efficient classification of the movement type, and to restitute the parameterization of that movement for the evaluation sake. Through a range of frames, the algorithm is turning the motions joints trajectories into a matrix with minimal and maximal values to index the range of variation (if we consider a motion as a succession of signal coming from each joint, we can theorize that the motion's trajectories are turned into recognizable signal variation) computed by utilizing SVD (Singular Value Decomposition), that gives out a least squares estimation of the 3D joints trajectories. Although, the Baum-Welch algorithm is used to estimates the transition and emission probabilities for each Hidden Markov Model matrix sequences to make the probabilistic guess by looping through a specifically defined number of iterations considering the level of tolerance value and a maximum number of iterations defined by the number of motion sample. At the recognition level, which is divided in two sections: the single motion data where only one motion data is tested and the batch motion data where the entire group of motion is tested, the results in term of performance have shown that it is possible to recognize an executed motion based only on 3D joints

displacement data without having to take in account circumstantial appearance like background or weather.

The remainder of this paper is organized as follow: Section 2 covers the research background and related work. Afterwards, the data factorization and the experimentation process are detailed in Sect. 3. In Sect. 4, the results are presented in terms of accuracy and reliability. In Sect. 5, the overall method is discussed. Finally, conclusion and future work are drawn from the experimental results in Sect. 6.

2 Background

In the last two decades, motion recognition and scene analysis [2], have increased in the computer programming vision community, owing in part to more sophisticate use of the tools from machine learning and the availability of open large data sets. One of the pioneer researches has used HMM to recognized human action as described in [3] by distinctly classify and successfully identify the six different tennis strokes. However, in their research when the training and testing data are from different subjects, the performance of the model has the tendency to drop. HMM combined with a rotation-invariant image representation has been also used to recognize hand gestures from video sequences [5]. However, it has not take in account the fact that the variation between instances has to be eliminated. In Kale et al.'s [6] approach, the human shape was extracted from video images and used to conceive a HMM and then make the recognition. However, the system accuracy was limited because its efficiency depends on the style of clothing the subject wears. There are abundant published studies that attempt Motion Recognition based on 3D data, especially with the recent release of the Microsoft Kinect (home base game entertainment device). The research of [7] has been inspired by the previously named approach, but instead of using a person shape, they used 3D motion capture coming from CMU library to apply HMM in the identical system framework. However, their approach was only considering one set of motion (walking). Motion recognition enables modern users to interact with computer in a natural way, even if it is still difficult and expensive to develop effective motion recognition technologies.

3 Experiment

For our study, we have utilized six types of human common locomotion, respectively: climb, forward jump, jump, run, sit and walk defined as the input of our system. Each of these batches is composed of eight amc data (48 in total) with a standard frame per second equal to 120 and most of them have been downloaded from different subjects. The skeletal positions are preprocessed using the function

amc to matrix matlab routines, where the joints trajectories (indexed in 29 IDs referring to the amc data skeleton bone assignments) are transformed into matlab matrix. The previous step is very important considering that the SVD function is a matrix-based factorization algorithm. In the first sub-section, motion specificity and two features sets corresponding to matrix motion features range standardization and matrix features factorization are extracted. Following is the outputs of HMM classifiers using Baum-Welch training algorithm and the recognition process.

3.1 Features Extraction and Factorization

The crucial task here is to identify features that carry equivalent information for data value reduction. When the amc data are turned into 2-Dimensional matrix (Table 1), they are stored in the value $\boldsymbol{I}$ that represent the initialized vector dimension size (62) according to the number of frames. The next step of our approach is the initialization of a random real matrix: $\boldsymbol{m} \times \boldsymbol{n}$ (Table 2), which respectively represent the number of standardized frames (transpose operator) we want to analyze according to the number of amc (column vectors), before moving to Singular Value Decomposition (SVD).

3.2 Features Factorization

SVD is closely related to the conception of diagonal symmetric matrix correlation. According to Kalman theory, finding the SVD of our six motion's matrices represented as the arbitrary matrices noted $A = \{\boldsymbol{a_1}, \boldsymbol{a_2}, \boldsymbol{a_3}, \boldsymbol{a_4}, \boldsymbol{a_5}, \boldsymbol{a_6}\}$, is about combining linearly the sets of extracted features to furnish the best approximation for each motion. It also implies that it exists two orthogonal matrices as U and V and a diagonal matrix denoted S such as $A = USV^T$. In that situation, U is $\boldsymbol{m} \times \boldsymbol{m}$ and V is $\boldsymbol{n} \times \boldsymbol{n}$, so that S is rectangular with the same dimensions as

Table 1 Raw data frame number with DOFs

ID	'Climb'	'Forward jump'	'Jump'	'Run'	'Sit'	'Walk'
1	4346 × 62	439 × 62	497 × 62	148 × 62	2313 × 62	343 × 62
2	4376 × 62	426 × 62	319 × 62	130 × 62	4759 × 62	298 × 62
3	1417 × 62	295 × 62	369 × 62	128 × 62	324 × 62	598 × 62
4	1201 × 62	407 × 62	400 × 62	137 × 62	303 × 62	494 × 62
5	1387 × 62	422 × 62	322 × 62	143 × 62	768 × 62	316 × 62
6	1432 × 62	496 × 62	466 × 62	143 × 62	496 × 62	329 × 62
7	1614 × 62	461 × 62	173 × 62	138 × 62	953 × 62	449 × 62
8	415 × 62	483 × 62	351 × 62	128 × 62	752 × 62	517 × 62

Table 2 Standardized raw data with DOFs

ID	'Climb'	'Forward jump'	'Jump'	'Run'	'Sit'	'Walk'
1	124 × 62	124 × 62	124 × 62	124 × 62	124 × 62	124 × 62
2	124 × 62	124 × 62	124 × 62	124 × 62	124 × 62	124 × 62
3	124 × 62	124 × 62	124 × 62	124 × 62	124 × 62	124 × 62
4	124 × 62	124 × 62	124 × 62	124 × 62	124 × 62	124 × 62
5	124 × 62	124 × 62	124 × 62	124 × 62	124 × 62	124 × 62
6	124 × 62	124 × 62	124 × 62	124 × 62	124 × 62	124 × 62
7	124 × 62	124 × 62	124 × 62	124 × 62	124 × 62	124 × 62
8	124 × 62	124 × 62	124 × 62	124 × 62	124 × 62	124 × 62

A represented in our method by a matrix of length 62×62, which is the dimensions of each analyzed motion. The diagonal entries of S, illustrated by $S_{ii} = \sigma_i$, are manage to be nonnegative in order to decrease the magnitude. The positive ones are called singular values of A. The columns U and V left and right singular vectors for A [8]. The least square fit here is represented by the maximum and minimum values measured by SVD during the features extraction process (matrix factorization).

3.3 Classification

We aim to model human common locomotion recognition using HMM with discrete hidden states and continuous observations from each state. An HMM has the ability to learn standardize motion pattern, in the way that it round up easily to avoid zero probability and identify sequential stochastic states where the likelihood of a state predicate the previous state. During the learning process, which was an unsupervised learning, we used the Baum-Welch algorithm so that the transition with very low likelihood will not interfere in the overall sequence classification. For that purpose, we have first of all defined a standard derivation constant named *eps* equal to $1e^{-6}$ and multiplied it by the sequences 1/6 probability to find the estimation likelihood matrix of the transition guess. Since we have used different type of motion, we observed joint displacement correlation values as the one producing the hidden state because an HMM parameters are composed of:

- Transition probability a_{ij}, $1 \leq i, j \leq N$, which are the probabilities of transitioning from state q_i to state q_j in successive time slices,
- Initial probabilities π_i, $1 \leq i \leq N$, which are the probabilities of a sequence starting in any state qi, and
- Observation probabilities $b_i(x)$, $1 \leq i \leq N$, which are the probabilities of observing x given being in state q_i.

Table 3 HMMs models database

'Climb'	'Forward jump'	'Jump'	'Run'	'Sit'	'Walk'
124 × 8 cell	124 × 8 cell	124 × 8 cell	124 × 8 cell	124 × 8 cell	124 × 8cell
124 × 8 cell	124 × 8 cell	124 × 8 cell	124 × 8 cell	124 × 8 cell	124 × 8 cell
124 × 8 cell	124 × 8 cell	124 × 8 cell	124 × 8 cell	124 × 8 cell	124 × 8 cell
1 × 8 cell	1 × 8 cell	1 × 8 cell	1 × 8 cell	1 × 8cell	1 × 8 cell
1 × 2 cell	1 × 2 cell	1 × 2 cell	1 × 2 cell	1 × 2 cell	1 × 2 cell

These parameters can be summarized by $\lambda = (\pi, A, B)$ where π (minmax deviation matrix) is a vector of probabilities and A (transition guess) is a matrix of probabilities. The SVD motion pattern vector matrix represents our B (Table 3) matrix.

4 Results

After carefully extracted each motion HMM model, the first recognition test applied was the motion batch test that uses the Ultra Fast Fourier Transform (UFFT) to increase signal variation compression rate and rapidly give back a recognition percentage with the name of the batch having higher predicted and recognized motion vectors. The UFFT has taken the matrix digital signal corresponding here to the minimum and maximum deviation values coming from the untrained batch and expressed it as the weighted sum of an equivalent number of frequencies. Unexpected results have been obtained using this method knowing that this process is just about giving out the percentage of the motion type with the higher predicted and recognized motion vector rate after that has been turned into a comparable signal sequence (Table 4).

The second recognition test was about evaluating each untrained amc features to the already existing ones stored in the database. At the opposite of the cluster recognition, the isolated gesture analysis performs better because the motion boundaries are clearer and it is possible for the algorithm to detect with better accuracy the points location, even if there is some noisiness. Before pointing out the motion's appurtenance type, the modeled HMM displays the number of vectors it has recognized for the database. The average efficiency was about 66.67 % (Table 5).

Table 4 Recognition rate of jump

Motion's name	Rate (%)
Jump	80 %

Table 5 Recognition rate experiment 2 (batch recognition test)

Number of frames						Average recognition rate
Climb	Forward jump	Jump	Run	Sit	Walk	
32	32	32	32	32	32	66.67 %

5 Discussion

We have presented an application of HMM using skeletal-based data (MoCap) to perform a set of motion recognition. The likelihood of the observed motion parameters are based on a SVD and Baum-Welch for respectively vector quantization and parameters training. Again, we choose designed 124 × 8 matrix structure features characteristics because we have defined the function double to expend the motion's variation matrix so that by multiplying with SVD diagonal matrix, it gives back the best block matrix size structure. The batch-testing process was weakened by the fact that the algorithm has only recognized the jump batch motion as the higher predicted motion's vectors batch but it has left out 20 amc over 48 at the beginning of the experimentation. The same situation happened with the single amc data test, which means that our system needs improvement. However, 28 and 32 are still more than the half of the data batch content and it could also mean that the 20 and 16 left amc's derivation signal was too low to be capture by the signal compression method UFFT. It was also caused by the misleading of the noise coming from the hand and toe data that had decreased the rate of some motion's matrix information. What has been made sure in that study is that the use of MoCap data facilitates the data collection and speed up the data processing part, which implies the urgency to improve the technology. On the other hand, combining SVD vector quantization to HMM has improved the efficiency of the algorithm such as from the predicted derivation features extracted vectors it had been possible to identify correctly the motion's category. However, we realized that SVD has extracted the least square values derivation of each motion after five iterations, which was designed to be six and during the recognition process, the HMM classifier has only consider the fourth iteration of 1 × 8 structure as the optimal sequence for the recognition. Although, the structure 1 × 2 vector features variation for each type of motion was the best fitting prediction made by SVD. The obviously first relevant par of this study is the fact many HMM-based research talk about the need for a large set of training data information [9], which is true but perhaps we need more sophisticate tools.

6 Conclusion

All chosen motions sequences for the verification of our model were accessed from the CMU online library that they are all from different subjects, which primarily indicates that the model has built a strong recognizable series of pattern for each motions to be able to render out a high recognition rate. Using SVD combined with HMM has been an efficient mixture method because it took those high variables set of 3D motion data points and reduced them into a lower dimensional rate in order to exposed the substructure of the original data more clearly without loosing the motion data main correlation. Consequently, our application has revealed that motion prediction could have been also done by the fact that one of the advantageous properties of SVD is that it always deduces the optimal set of vectors that best predict the motion variation range, based on the conventional matrix similarity measurement. Even though our approach has not take in account the motions trajectories' speed, the relevant inquiry to keep in mind is to figure out how to apply these new applications to improve upcoming technological innovations.

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Estimating the EMG Response Exclusively to Fatigue During Sustained Static Maximum Voluntary Contraction

Jing Chang, Damien Chablat, Fouad Bennis and Liang Ma

Abstract The increase of surface electromyography (sEMG) root-mean-square (RMS) is very frequently used to determine fatigue. However, as RMS is also influenced by muscle force, its effective usage as indicator of fatigue is mainly limited to isometric, constant force tasks. This research develops a simple method to preclude the effect of muscle force, hereby estimates the EMG amplitude response exclusively to fatigue with RMS. Experiment was carried out on the biceps brachiis of 15 subjects (7males, 8 females) during sustained static maximum voluntary contractions (sMVC). Result shows that the sEMG RMS response to fatigue increases to 21.27 % while muscle force decreasing to 50 % MVC, which implies that more and more extra effort is needed as muscle fatigue intensifies. It would be promising to use the RMS response exclusively to fatigue as an indicator of muscle fatigue.

Keywords Surface EMG · Root-mean-square · Muscle fatigue · Sustained static maximum voluntary contraction

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1 Introduction

Muscle fatigue is a complicate phenomenon believed to be closely related to musculoskeletal disorder [1]. In ergonomics, fatigue is usually measured from three aspects: the reduction of force output capability, the self-rating discomfort, as well as the myoelectric activity change. The reduction of force output capability has been well modeled [2], and been used to describe fatigue and calculate fatigue resistance [3, 4]; the self-rating discomfort was reported to be a valid estimator [5], but its usage might be limited due to the subjectivity. The myoelectric activity monitored by surface EMG (sEMG) shows the in situ and real-time changes of the muscles [6]. Therefore, it has been frequently used to determine fatigue [7].

Overall, sEMG signal is the synthesis of myoelectric and anatomic properties: the shape of motor unit action potential (MUAP) waveform [8], the firing rate of MUAP trains, the recruitment of new motor units [9] as well as the subcutaneous tissues which act as a volume conductor and cause a spatial low-pass filtering effect when conducting myoelectric signals [10]. In the process of fatigue, metabolites such as lactic acid concentrate, for which the muscle fibre conduction velocity (CV) decreases. The decrease of CV directly changes the shape of the MUAP waveform and leads to the compression of EMG spectrum towards its lower part [11]. As a result, more energy passes through the tissues which act as a low pass filter, and is detected by the surface electrodes, leading to an increase of sEMG amplitude.

The changes of sEMG characteristic values, such as decrease of the median power frequency (MDF) and increase of the root-mean-square (RMS), are very often used to estimate fatigue [12–14]. But it should be noted that these sEMG indicators are not always applicable. Firstly, sEMG spectral compressions are sometimes slight and insignificant statistically, especially during low force level tasks [5, 15]. As De Luca [7] puts it, the usage of spectral variables should be limited to isometric, constant-load tasks greater than 30 % of subjects' maximal force. In addition, the sEMG amplitude is significantly affected by muscle force: greater force leads to larger amplitude [16, 17]. It seems the RMS should only be used in constant-force fatigue process.

However, the tasks that are cared most are dynamic, inconstant-force ones. These tasks are characterized by time-varying changes in forces exerted variations as well as in working postures [12]. Both of the two factors lead to EMG changes despite of fatigue. To indicate fatigue with sEMG in real operations, it is logistic to start from tasks with fixed posture and inconstant force, such as sustained static maximal exertions. Voluntary sustained static maximal exertions, or sustained maximum voluntary contractions (sMVC), are characterized by rapid muscle fatigue and continuous force decline [18]. In this process, the impact of intensifying fatigue on sEMG amplitude is overwhelmed by the impact of decreasing muscle force. As a result, the RMS turns to decline along with fatiguing progress [19].

In this research, a simple method to preclude the impact of muscle force on RMS is tested during sMVC and the sEMG RMS response exclusively to fatigue is

identified. The possibility of using the identified value as an indicator of fatigue is discussed.

2 Methods

2.1 Subjects

A number of 15 subjects (7 males, 8 females) took part in the experiment. They were healthy, aged between 20 and 35 and free from any upper limb pain during the previous 12 months. All of them are right-handed. Other criteria include moderate (non-extreme) level of self-reported daily physical activity. After being fully informed of the nature of the experiment, they signed an informed consent. Anthropometry data were measured upon their arrival at the laboratory (see Table 1).

2.2 Experiment Setup

The experiment platform consisted of a dynamometer (BET® Primus RS), a customized chair without armrest, an electromyography recorder (TeleMyo 2400T V2®) and an interactive monitor. The muscle force and the surface EMG were recorded by the dynamometer and EMG recorder at frequency of 20–1500 Hz respectively. Real-time muscle force was recorded by and displayed on the monitor.

In the experiment, each subject was told to be seated on the chair with torso and upper arms perpendicular to the ground. The elbow joint angle of the dominant arm was kept at 90° with forearm supine and horizontal. Subject's output strength was transduced to the dynamometer by a lever that is hold in hand (see Fig. 1). Body movement was mechanically restrained by belts restraining legs, trunk and shoulder to the chair. During the whole experiment, subjects were closely monitored to maintain the posture as still as possible. In all the experiments, bar arms were used and the room temperature was maintained around 22 °C by air-conditioning if necessary.

Table 1 Subject physical characteristics

Characteristic	Mean	SD
Age (year)	28.3	4.7
Height (cm)	167.1	9.1
Weight (kg)	67.1	14.0
BMI	23.8	3.5
Maximum voluntary contraction (N)	137.8	47.8

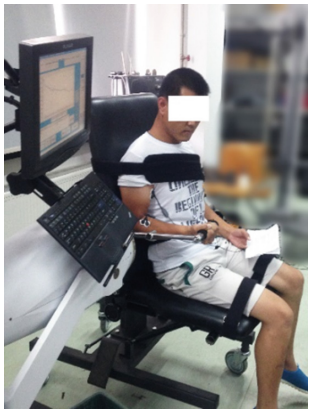

Fig. 1 Experiment posture

2.3 Experiment Protocol

Before experiment, subjects were trained to sustain submaximal muscle force without joint movements.

The experiment includes three sessions. First there was the initial Maximum Voluntary Contraction (iMVC) session. Subject's iMVC was obtained in the position described above. At least three short-time MVC trials (each lasting for 3 s) were performed, with 10 min rest in between. The iMVC trials were continued until there were three measures whose Coefficient of Variation (CV) was less than 5 %. The average value of the three measures was taken as iMVC.

After a recovery break of 10 min, there came the simple contraction sessions, where subjects perform a series of five short-time submaximal exertions, from 50 to 90 % MVC, in steps of 10 % MVC. The sequence of the five exertions was generated by computer randomly for every subject. Each exertion lasted for only 3 s to avoid fatigue. After each exertion, at least 5 min rest was taken until a complete recovery was reported by the subject. In this session, the interactive monitor that displayed the real-time force was set in front of the subjects and the target force level was clearly labelled on the screen.

Finally it was the sMVC fatigue session. After a total recovery of at least 15 min, the subject was asked to exert his maximum strength to lift the transducing lever handle of the dynamometer and to sustain the maximum effort for 60 s. The force decline was recorded by the dynamometer automatically. Subjects received non-threatening verbal encouragement throughout the procedure.

2.4 Data Collection

Surface EMG data was collected from the biceps brachii muscles by a pair of disposable Ag-AgCl electrodes. The electrodes were 1 cm in diameter each, placed

on the belly of the biceps brachii, with a 2.0 cm space in between. The skin was carefully shaved, cleared by alcohol and slightly abraded. Intra-electrodes resistance was kept below 10 KΩ. A ground electrode was placed over the end of the humerus in the elbow flexor joint.

EMG signals were recorded continuously throughout the three test sessions. Raw signals were sampled at 1500 Hz. RMS was calculated using MATLAB.

2.5 Data Analysis

For each 3 s exertion of the simple contraction session, the RMS was calculated from the 1 s-long EMG signals fragment in the central of the 3 s-long signals (from 1 to 2 s), noted as RMS_s.

During the sMVC, the muscle force declines from almost 100 % MVC all the way along. For each subject, the time points when the force reaches 90, 80, 70, 60 and 50 % MVC were determined and the nearby EMG signals (1 s-long) corresponding to these time points were selected. RMSs were calculated from these EMG signals fragments, noted as RMS_f.

By comparing the RMS_f with RMS_s, one may figure out the EMG amplitude changes caused by fatigue, precluding the effect of muscle force. For each subject, all RMS values were normalized by the RMS of EMG signals when he or she reached the peak force during the sMVC fatigue session.

$$RMS_{fe} = RMS_f - RMS_s \tag{1}$$

3 Results

3.1 Simple Contraction Session

Monotonous and significantly linear relationship (Pearson's test: $r = 0.74; p < 0.001$) was found between muscle force and RMS values in the simple contraction session (shown in Fig. 2). Larger muscle force corresponds stronger EMG signals.

3.2 Fatigue Sessions

Under the influence of both muscle force declines and the fatigue increases, the amplitude of EMG decreases along the fatigue process. As shown in Fig. 3, from 90 to 50 % MVC, the RMS_f goes from 95.4 to 70.2 % (normalized by RMS corresponding to maximal force).

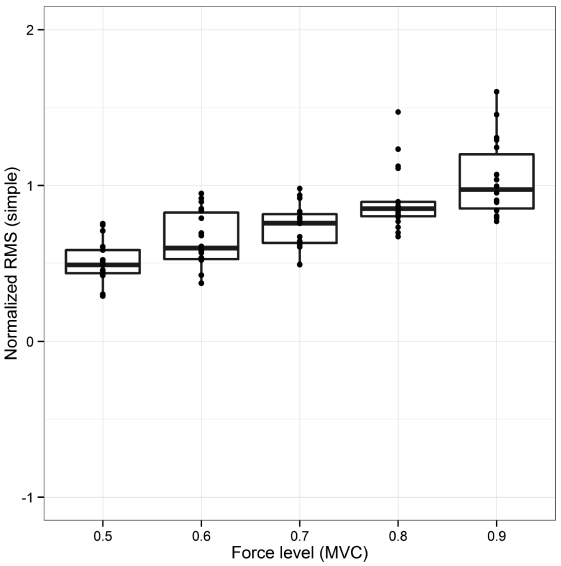

Fig. 2 Subjects' normalized RMS values during simple contraction session

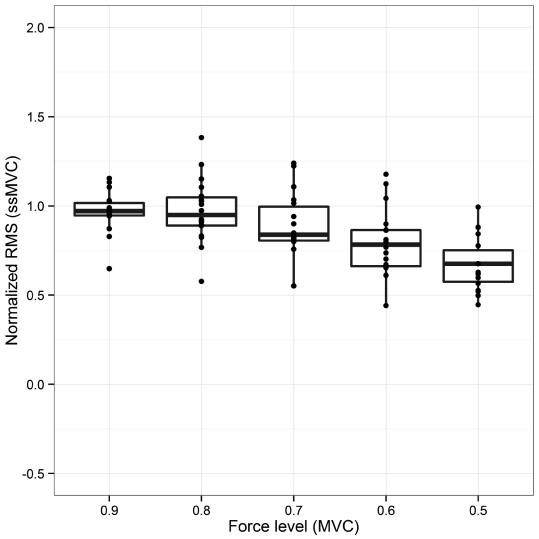

Fig. 3 Subjects' normalized RMS values during sMVC fatigue session

3.3 RMS Response Exclusively to Fatigue

After precluding the influence of muscle force by Eq. (1), sEMG RMS response exclusively to fatigue was determined. Result shows that it increases with fatigue strengthening: RMS_{fe} goes from 0.54 up to 21.27 % while muscle force reduces from 90 to 50 % MVC. Boxplot is shown in Fig. 4.

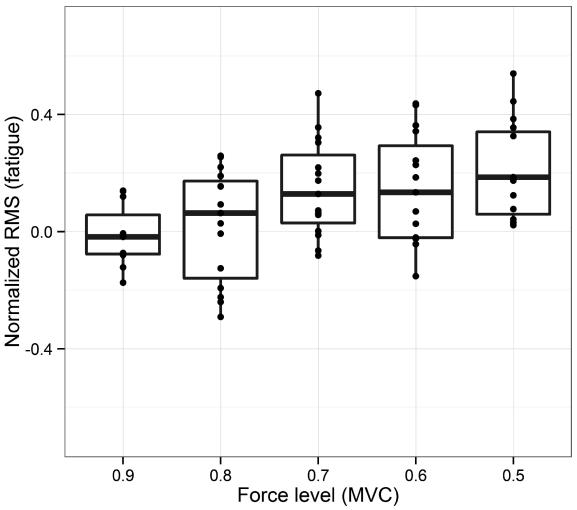

Fig. 4 Subjects' RMS response to fatigue during sMVC. Impact of muscle force is precluded

4 Discussion

4.1 Force—RMS Relationship in Simple Contraction

In this experiment, linear relationship was found between muscle forces and RMS values during the simple contraction session. This clear relationship between mechanical and the electrical responses of human muscle is well documented in previous researches [20–22] under voluntary isometric contractions.

As mentioned above, the RMS value of the sEMG signals is decided by: (1). the percentage of MUAP trains wave that filtered by the tissue and reach the electrodes, designated as p; (2). the average length of the MUAP trains, designated as $\bar{l}$; (3). the firing rate of the MUAP trains, designated as f; (4). the mean amplitude of filtered MUAP trains, designated as $\bar{A}$. Then RMS could be indicated by Eq. (2) (is the Constant coefficient).

$$RMS = \tau_0 \bar{l} p f \bar{A} \tag{2}$$

During the simple contractions when the muscles are fresh, the shape of MUAP waveform and the filtering threshold of the tissue remain unchanged. Therefore p is constant. With the increase of muscle force, MUs with higher firing rate of their amplitude potential trains are recruited and the firing rates of initial MUAP trains increase. These factors lead to the increases of $\bar{A}$ and f, and furthermore an increase of total RMS.

4.2 RMS During Fatigue Process

During the sMVC fatigue progress, the RMS reduces to about 70 % when muscle force reaches 50 % MVC. Similar results have been reported in previous researches, as listed in Table 2. Generally, EMG amplitude reduced by 30–70 % during a maximal voluntary contraction sustained for 60 s, depending on different muscles and protocols.

As mentioned above, the RMS of sEMG has been found to increase in the process of constant-force fatiguing tasks [12, 13, 25]. When the body tries to maintain the target forces, a progressive increase of MUAP trains firing rate take place and MUs with larger amplitude are recruited [27], which increase the f and $\bar{A}$ in Eq. (2). At the same time, the percentage of filtered MUAP trains p grows due to fatigue. As a result, the total RMS increases.

Whereas in the procedure of sustained maximal exertions, both acute muscle fatigue and rapid force decline are identified. The MUAP trains are pushed to change in two directions: on the one hand, in every moment of sMVC, the muscle is trying hard to maintain its original force, which leads to increases of f and $\bar{A}$; on the other hand, as the muscle fails to maintain its original force, muscle force continue to decline, which brings about the decreases of f and $\bar{A}$. As a consequence, the impact of force decline prevails over that of fatigue and decreases of f and $\bar{A}$ are observed [27]. Despite of the increase of the percentage of filtered MUAP trains p, the total RMS declines with time.

4.3 EMG Response Exclusively to Fatigue

After precluding the impact of muscle force changes, the sEMG RMS response to fatigue is found to increase from 0.54 to 21.27 %, along with muscle force decreasing from 90 to 50 % MVC. The underlying implication is that in this

Table 2 EMG amplitude changes during sustained maximal voluntary contraction

Authors	Muscle	Amplitude value	Tendency	Magnitude
Stephens and Taylor [23]	First dorsal interosseous	srEMG[a]	Decrease	To 53 % ± 7 %
Bigland-Ritchie et al. [19]	Adductor pollicis	srEMG[a]	Decrease	By 50–70 %
Kent-Braun [17]	Ankle dorsiflexor	iEMG[b]	Decrease	To 72.6 % ± 9.1 %
Bigland-Ritchie [24]	Adductor pollicis	srEMG[a]	Decrease	About 50 %

[a] srEMG—Smoothed rectified EMG
[b] iEMG—Integreted EMG

Table 3 Normalized RMS values corresponding to five force levels during sMVC session

	90 % MVC	80 % MVC	70 % MVC	60 % MVC	50 % MVC
RMS_f *(%)	95.38 (13.55)	96.37 (19.58)	89.69 (18.30)	80.06 (14.37)	70.19 (16.90)
RMS_{fe} [a](%)	0.54 (11.78)	2.24 (19.18)	14.70 (16.42)	14.67 (18.88)	21.27 (18.66)

[a]Normalized by the RMS values corresponding to maximal force

process, although the firing rate of and average amplitude of MUAP trains decline significantly, increasingly extra effort is made compared with that when the fresh muscle exerts same forces. The more severe the muscle fatigue is, the more extra effort it is needed.

It is notable from Table 3 that no extra RMS increase is detected when force declines from 70 to 60 % MVC. This should be explained by the different percentage held by MU deactivation and firing rate slowing in force reduction at different force output level. As the muscle force increases, MUs are recruited in the order of their firing rate and twitch tension from low to high [9, 28] along with the average firing rate speeding up [29]. The recruitment of new MU was reported to terminate by 60 [30] or 75 % MVC [28] in biceps brachii. Conversely, during sMVC session, before the muscle force reaches about 70 % MVC, the slowing of MU firing rate contributes the largest part to force loss. From 70 to 60 % MVC, the deactivation of MU takes part in. MUs with the largest twitch tension are deactivate, which makes a great contribution to force loss. Hereby, the firing rate slowing and RMS changes are not significant.

5 Conclusions

In this research, a simple way to identify the sEMG RMS response to fatigue was tested on biceps brachii muscles during sMVC process. The impact of muscle force changes on RMS is precluded by simply subtracting the RMS of the fresh muscle when exerting corresponding force from the total RMS. Result shows that the sEMG RMS response to fatigue increases along with the fatigue process to as much as 20 %, which implies that more and more extra effort is needed as muscle fatigue intensifies. It would be promising to use the RMS response exclusively to fatigue as an indicator of muscle fatigue.

Acknowledgments This work was supported by the National Natural Science Foundation of China under Grant numbers 71101079 and 71471095, by the Tsinghua University Initiative Scientific Research Program under Grant number 20131089234, by Chinese State Scholarship Fund, and by INTERWEAVE Project (Erasmus Mundus Partnership Asia-Europe) under Grants number IW14AC0456 and IW14AC0148.

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The Metabolic Rate of Male Adults in Different Garments Under Different Upper Limb Workloads

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Abstract While we are working or living in severe environment, the internal pressure changes of functional garments, the resistance from clothing and the thermal insulation for individual will lead obviously changes of our workload, heart rate and metabolic rate. Working in extreme circumstances and dressing pressure garments make workload increased significantly which limit people's ability to accomplish the tasks and reducing the efficiency of activity. This paper mainly report the study on relationship between different upper limb workloads and metabolic rate when subjects were dressing, undressed or with pressures. Specially, we focus on the relationship between heart rate and metabolic rate in clothes. The main conclusions of this paper is: Wearing different garments the correspondence between heart rate and metabolic rate are far from the same. And Liquid Cooling Garment (LCG) is the most effective garment for human metabolism among the clothes in this research. The pressures inside clothes increased workload, as well as the metabolic rate.

Keywords Metabolic rate · Heart rate · Workloads · Garment · Ergonomics

1 Introduction

Influence of clothing on human metabolism is through the separation of human body from external thermal exchange and the resistance of the clothing which increase workload. Besides, the change of pressures inside airtight garment will lead metabolic rate (MR) to increase. From 1940s, people began to pay attention to the effect of clothing thickness on heat transfer between human body and the environment [1]. In 1960–70s, Woodcock et al. have proposed thermal dynamic

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models about clothing human body heat transfer to the environment [2–7]. However, the effect of different clothing on human metabolism is rare. Typically, the metabolism occurred corresponding change which caused by the clothing heat barrier and pressures change in different attire can often be ignored, and been ignored in the past. But with the continuous expansion of human activity scope, people need to wear special costumes in extreme environment, those effects on human metabolism should not be neglected. For example, in a vacuum and cold space people need to wear the garment with thermal protection and pressure regulation functions, which will prevent our body from hurting by surroundings. Meanwhile, it blocks physical heat dissipation and increases the resistance, so does the metabolic rate.

Extreme environments often requires the clothing have such functions as adiabatic, pressure and thermal regulation, with the change features of peripheral environment and the metabolic heat production, increase the workload significantly. It greatly limits the ability of people to complete the tasks, reducing the activity efficiency. Therefore, research on the relationship between workloads and metabolism in different suits help people understand the relevant issues and provide the reference for human activity in bad environment. This paper study on the effect of different clothes and different clothing pressures on workload, heart rate and metabolic rate by experiment. And the method of metabolism relevant data acquisition mainly come from ISO 8996:2004 Ergonomics of the thermal environment-Determination of metabolic rate. The researchers adjusted the measurement and calculation method of the standard and improved it better meet the Chinese physical condition.

2 Method

Researchers designed the primary coverage of this study which was the measurement of the heart rate and respiratory related parameters while subjects were trying to accomplish different loads of upper limb exercises in different garments or pressures. Calculating the body's metabolic rate and then observing the relationship between metabolic rate and heart rate under the different clothes.

The researchers obtained metabolic rate by measured the parameters related to human breathing, like carbon dioxide production rate and oxygen consumption rate. The metabolic rate is calculated by using these parameters. According to ISO 8996:2004 [8], the computational formula of respiratory quotient (RQ) is as follows:

$$RQ = \frac{\dot{V}_{CO_2}}{\dot{V}_{O_2}} \tag{1}$$

The energetic equivalent EE (W·h/L) and the metabolic rate M (W/m^2) is calculated as:

$$EE = 5.88 \times (0.23\,RQ + 0.77) \tag{2}$$

$$\mathrm{M} = EE \times \dot{V}_{O_2} \times \frac{1}{A_{Du}} \tag{3}$$

Among these formulas, $\dot{V}_{O_2}$ and $\dot{V}_{CO_2}$ respectively represent the oxygen consumption rate and carbon dioxide production rate in liters per hour which these two values can be acquired by measuring, A_{Du} stands for the body surface area which is given by the Du Bios formula which is:

$$A_{Du} = 0.202 \times W_b^{0.425} \times H_b^{0.725} \tag{4}$$

H_b is the body height in meters, W_b is the body weight in kilograms.

Through the consolidation and adjustment of the calculation methods in standard, we obtained the basic formula of metabolic rate M which can computed directly by respiratory parameters as:

$$M = \left[5.88 \times \left(0.23 \times \frac{\dot{V}_{CO_2}}{\dot{V}_{O_2}} + 0.77\right)\right] \times \dot{V}_{O_2} \times \frac{1}{A_{stevenson}} \tag{5}$$

In this equation, $A_{stevenson}$ is the body surface area which is figured by the Stevenson formula as:

$$A_{stevenson} = 0.61\,H + 0.0128\,W - 0.1529 \tag{6}$$

We used $A_{stevenson}$ instead of A_{Du} to calculate body surface area is because it is more suitable with the physical condition of Chinese. The values of metabolic rate in this research are all figured by the formula (5) and (6).

The researchers chose 10 healthy male adults whose body height was between the 161–179 cm and weight was in 52–77 kg, then, conducted participants performed upper limb exercise according to a certain rhythm in different clothes or pressures. At the same time, we recorded the heart rate, oxygen consumption, respiratory quotient and other relevant physical parameters.

The conditions of garment and pressure included as: naked (only wore shorts), wore undergarment, wore Liquid Cooling Garment (LCG) with undergarment at normal temperatures and pressures (Fig. 1), two pressure garments with 130 and 140 kPa absolute pressures, which contained airtight pressure suit with LCG and underwear.

We designed the work situation in nude, underwear and LCG tests which included static standing, shoulder rotation, elbow rotation and upper limb movement which the output power at 20, 30, 40 and 60 W with only some subjects completed 70 W power of upper limb exercise test. Test work in pressure garments

Fig. 1 Status of subjects in undergarment and LCG

is static standing, elbow rotation and two kinds of workload of upper limb exercise. Single mode measurement time is 2–3 min and rest 3–5 min, the rest time based on whether subjects recovered to their basal metabolic rate.

Finally, the test personnel checked the instruments for measurement of respiratory parameters and heart rate, the measurement accuracy reached at 0.01 L/h.

3 Result

The tests obtained subjects' heart rate and metabolic rate during upper limb movement in five kinds of clothes with conditions. The heart rate (HR) and metabolic rate (MR) of Subject No.1 following the change of time in all kinds of clothes and workloads, as it shown in Figs. 2, 3, 4, 5 and 6.

According to the periodic filtering of sample points of heart rate and metabolic rate, subjects in LCG status are the most efficient, which in the same level of heart rate (90–120 b/min) can provide 37.56–104.59 % more power than any other state. The results of other 9 subjects are similar to subjects No.1. Furthermore, researchers figured out the average heart rate and average metabolic rate in a period of time, the fitting curve of the mean metabolic rate and mean heart rate in the condition of different clothes, as shown in Fig. 7.

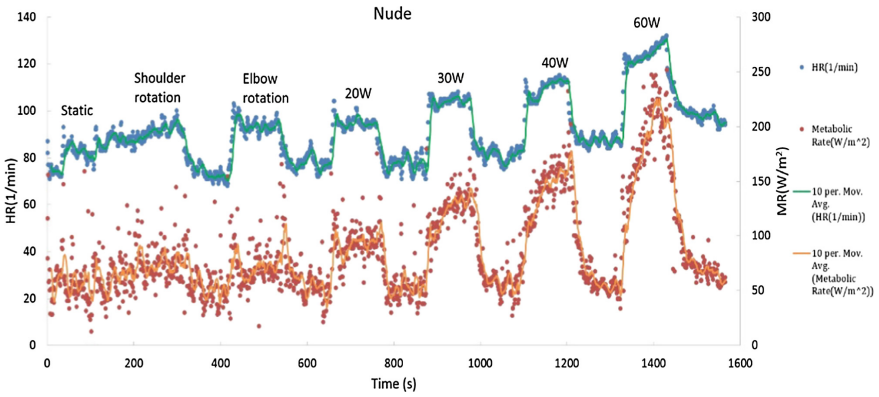

Fig. 2 HR-MR variation over time at nude status

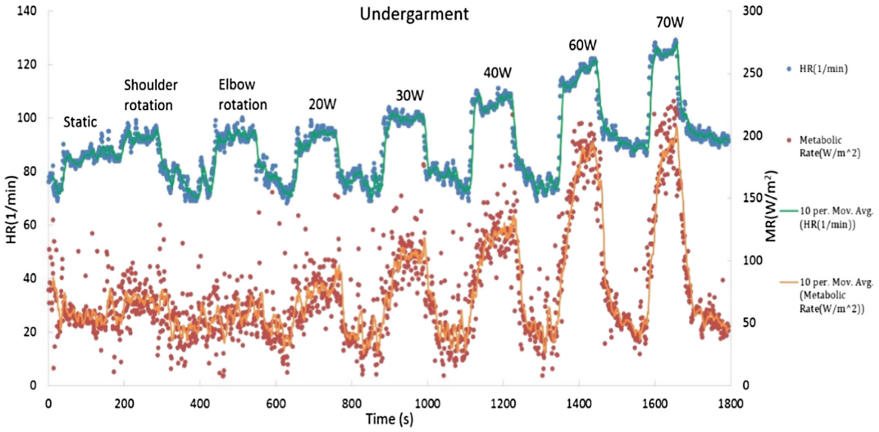

Fig. 3 HR-MR variation over time at undergarment status

Let X denote the average heart rate, Y represents the average metabolic rate. Curve fitting the results obtained average heart rate—metabolic rate relationship of subjects No.1 in different garments:

- Nude: $Y = 2.61X - 152.57$, $R^2 = 0.8171$
- Undergarment: $Y = 2.53X - 153.52$, $R^2 = 0.8011$
- LCG: $Y = 5.05X - 352.13$, $R^2 = 0.8103$
- 130 kPa Suit: $Y = 3.62X - 152.88$, $R^2 = 0.6414$
- 140 kPa Suit: $Y = 2.80X - 146.48$, $R^2 = 0.7053$

Meanwhile, the different subjects in the same suit have different relationship between metabolic rate and heart rate. Figure 8 for instance, it contains 10 subjects'

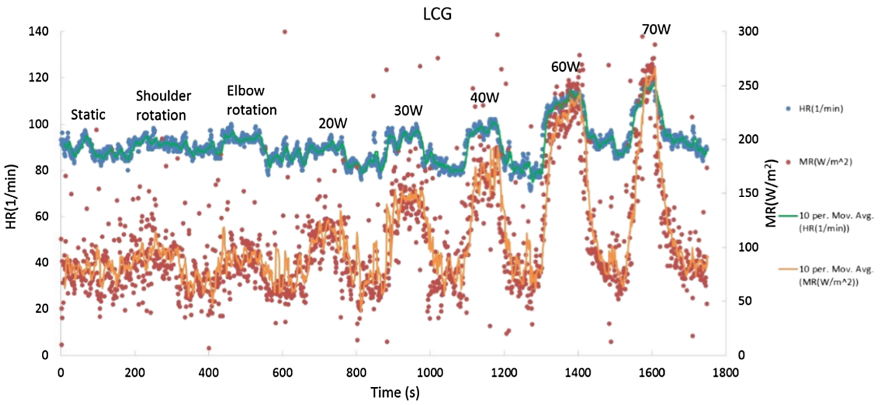

Fig. 4 HR-MR variation over time at LCG status

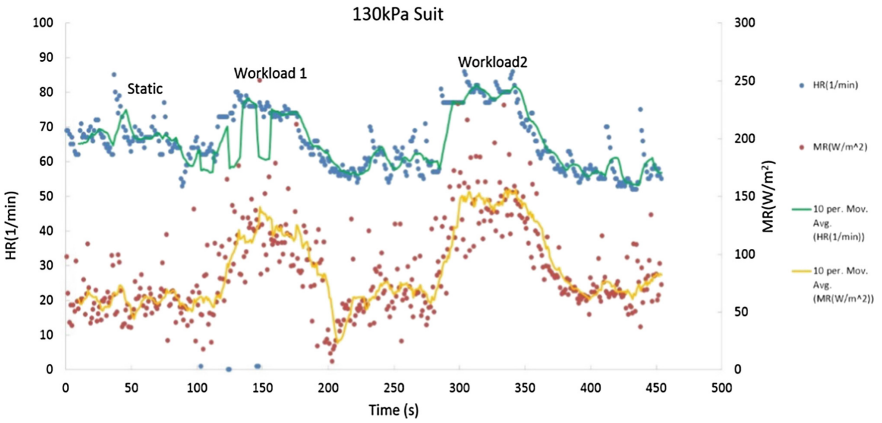

Fig. 5 HR-MR variation over time at 130 kPa pressure suit status

average HR-MR fitting curve in 130 kPa suit, which results is summarized in Table 1.

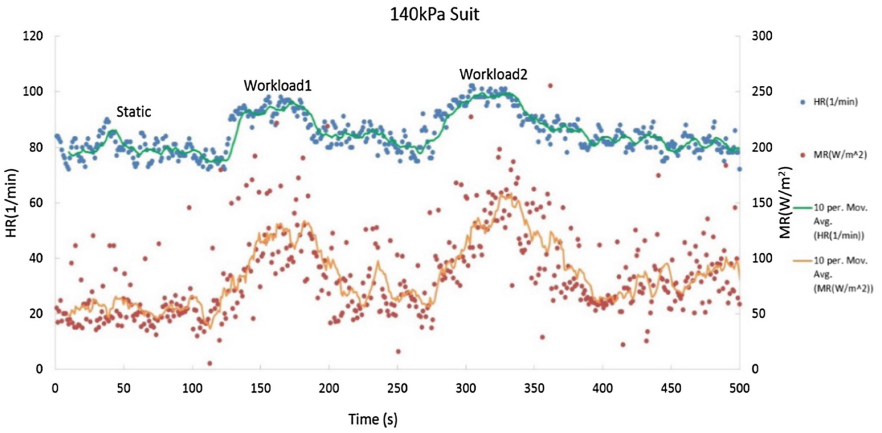

Fig. 6 HR-MR variation over time at 140 kPa pressure suit status

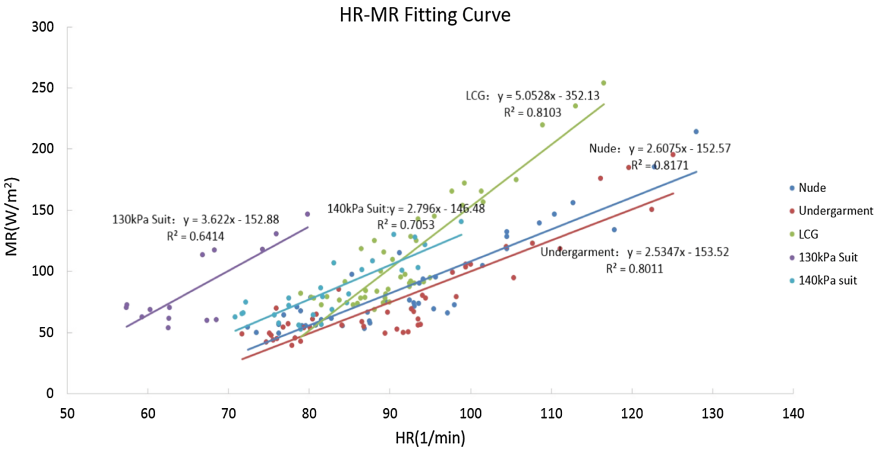

Fig. 7 The fitting curve of average HR-MR in the different clothes

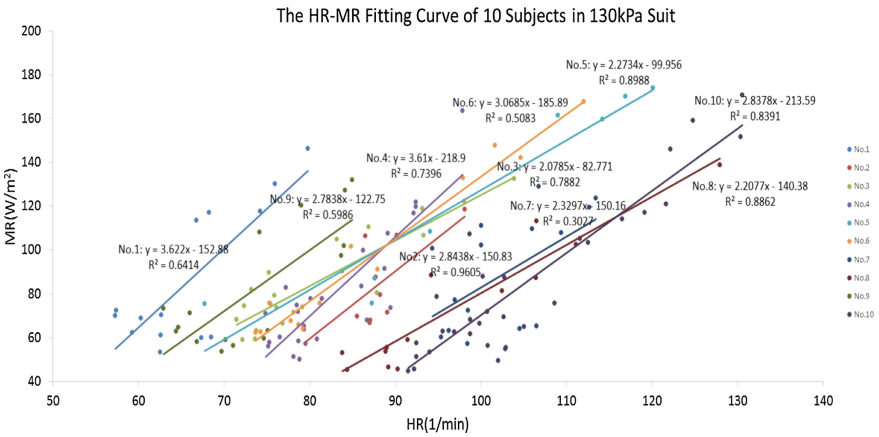

Fig. 8 The fitting curve of 10 subjects' average HR-MR in 130 kPa suit

Table 1 Parameters of HR-MR Fitting Curve from 10 subjects in 130 kPa Suits. Let Y = aX + b

Subject	High/m	Weight/kg	a	b	R^2
1	1.75	76.66	3.62	−152.88	0.6414
2	1.72	56.34	2.84	−150.83	0.9605
3	1.66	64.59	2.08	−82.77	0.7882
4	1.72	67.16	3.61	−218.90	0.7396
5	1.61	52.27	2.27	−99.96	0.8988
6	1.66	60.74	3.07	−185.89	0.5083
7	1.70	65.09	2.33	−150.16	0.3027
8	1.79	63.26	2.21	−140.38	0.8862
9	1.70	60.12	2.78	−122.75	0.5986
10	1.74	64.70	2.84	−213.59	0.8391

4 Conclusion

Researchers draw the following conclusions according to the results:

According to Figs. 2 and 7, the same subject in different garments have different correspondent relations between heart rate and metabolic rate. The stronger resistance of clothes, the smaller slope of HR-MR fitting line (LCG > Nude > Undergarment, 130 kPa suit > 140 kPa suit). The clothing resistance here is not only refer to mechanical obstruction, but also mean the impediment of thermal regulation. In fact, people have a stronger capability of cooling when they are in LCG than only in underwear or nude status. Meanwhile, it has better flexibility than pressure suits. As the result shows to us, when people in LCG they could

provide 37.56–104.59 % more power in the same situation (heart rate at 90–120 b/min) than other garments. Therefore, LCG is the most efficient metabolic suit.

Figures 5, 6 and 7 shows that 130 kPa suit has higher metabolic efficiency than 140 kPa suit. It suggests that with the growing pressures inside the suit, it consumes more power to accomplish the same task. So pressures increase the workload and rise up the metabolic rate to some extent.

The HR-MR relationships of the different subjects in the same clothing are not the same and with no apparent connection to their own naked status. It may be related to the relationships of HR-MR vary from person to person.

Although nude or wearing undergarment status have almost no clothing resistance, they are not the most efficiency state of metabolism. It supposed to that through the body skin directly to exchange the energy with the out world may not the most efficiency way. The equipment like liquid cooling garment can make physical work more efficient.

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Study on Quantitative Evaluation Method of Cooperative Task Operation Process on the Ship

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Abstract Personnel establishment and task type are complex on the ship. In order to guarantee the efficient accomplishment of cooperative task, optimal man-machine function allocation on the premise of limited space and time is in need, which can be used to evaluate the rationality of cooperative task. In this article, typical missions are selected to be evaluated. Three methods are used to assess the task from different aspects. Human cognitive reliability(HCR) model, entropy method and Cooper-Harper method evaluate completion rate, rationality of man-machine function allocation and difficult degree respectively. Human operation error rate based on HCR model accords well with real error rate and there is no significant different between them ($p < 0.05$); The score of work strength and complexity by the entropy method indicate the task complexity. The higher the score is, the longer the finish time becomes. The score by the Cooper-Harper method imply the operation difficulty. The higher the score is, the longer the completion time becomes. Three methods used in this article are practical and effective. The results of these methods correspond well to the real performance. Therefore, they are applicable to serve as quantitative evaluation method of cooperative task on the ship.

Keywords Ship · Cooperative task · Operation process · Quantitative evaluation

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1 Introduction

There are many kinds of tasks in different working condition on the ship and many tasks demand for lots of people because of the large scale of ship equipment, large amount of system device and the complexity of operation. The personnel organization structure according to the ship's command and management requirements is set by the classification form such as function, area, technology and so on. So a lot of complex task need many people from different type of work to cooperate. The whole efficiency of ship system depends on comprehensive performance of various tasks [1]. There are higher demands for cooperation of crew in premises of limited time and space. In complex working condition, several factors, such as quick changing information, sudden increasing amount of work, complicated demand for decision, great weight of recognition and high pressure on time, form a complex pressure on the physiology and mentality of crew, which will influence the result of tasks.

Based on the man-machine-environment system, the reliability and safety of man-machine system, the rationality of the man-machine function assignment, and the difficulty of operation can considered as three aspects of evaluating the rationality of the task process. By these methods, we can make early prediction and evaluation on the rationality of design of cooperative task operation process quantitatively and then found the scheme problem to solve as soon as possible. And this can improve the efficiency of ship system operating, which is useful to the designer and has the strong practical significance.

2 Introduction of Three Methods

2.1 HCR Model

HCR (Human Cognitive Reliability) is designed to value the probability of the operator group failing to finish the mission within the schedule time [2].

$$p = e^{-\left(\frac{t/T_{1/2}-\gamma}{\alpha}\right)^{\beta}} \tag{1}$$

$$T_{1/2} = T_{1/2,n}(1+K_1)(1+K_2)(1+K_3) \tag{2}$$

In this formula, the t means the time for the reaction of the operator; $T_{1/2}$ means the time leaving for the operation of operator; $T_{1/2,\ n}$ means the time of normal operation time; K_1 means operation experience; K_2 means psychological pressure; K_3 means human-machine interface; α, β and γ means the parameter of the operators' behavior types.

There are 3 kinds of behavior types: Skilled, ruled and knowledge.

Error probability only related with the ratio of schedule time (t) and operation time ($T_{1/2}$) as well as following the Weibull distribution with three parameters. And

during the calculation of the error probability, t and T are required in the mission and the value of α, β, γ and K_1, K_2, K_3 are according to the IAEA indicator system [3].

2.2 Entropy Method

This research use entropy to determine the weight of the values. Entropy weighting is an objective weighting method, it use the amount of information provided by the entropy to determine the weight. Using entropy weighting, the disturbance from human factors can be largely avoided and the evaluation result can be more precise [4]. This method can overcome the disturbance of human factors in current weighting process [5].

In this research, human-machine function allocation is achieved mainly by subjective evaluation, which means to list the units that need human-machine function allocation and let some specialists (include ship designers, ergonomic specialists and sailors) make subjective scoring to the list. Detailed subjective scoring indexes include physical labor intensity, brain labor intensity, physical labor complexity and brain labor complexity. There are 10 levels in the scoring, in which 1 represents the lowest intensity and complexity while 10 represents the highest intensity and complexity.

Use x_{ij} (i = 1, 2, … n; j = 1, 2, … m) as the score of index j made by specialists i, the process of entropy weighting is as below:

(1) Calculate the entropy of all units

Use e_j as the entropy of index j, the process of the calculation of e_j is as below:

$$f_{ij} = x_{ij} / \sum_{i=1}^{n} x_{ij} \tag{3}$$

$$e_j = \frac{1}{\ln n} \sum_{i=1}^{n} f_{ij} \ln f_{ij} \tag{4}$$

In the equations above, f_{ij} is the characteristic proportion in the score made by specialists i under index j, and $\sum_{i=1}^{n} x_{ij}$ is the sum of all the scores of index j.

(2) Calculate the entropy weight of all indexes

Use w_j^* as the entropy weight of index j, then the entropy weight of index j is

$$w_j^* = \frac{1 - e_j}{n - \sum_{j=1}^{m} e_j}, j = 1, 2 \ldots, m \tag{5}$$

Once we get each task unit weight of the four indexes, we can calculate task unit weighted score according to the results of the index weight. Use the sum of mental labor intensity and mental operation complexity weight in each task unit as the standard to evaluate the importance of each unit. And then, the weight of each task unit can be sure according to the sum. Last, total score of the task process is the weighted sum score of each task process unit.

A low score of labor intensity and complexity indicates that the man-machine distribution is optimal. So in the man-machine allocation, low score means process is more reasonable.

2.3 Cooper-Harper Method

Cooper-harper method used to be used on evaluation of pilots [6] while it is used on evaluation of ships' operation process. The specific method is that operator or expert make scores according to the feeling of their personally operation. And the mean of the scores in each task unit is the final score of one unit.

The core of this method is to make sure of the weight of each task unit. In this paper, the weight is determined by the final score of each task unit from the entropy subjective scoring table and the final score of Cooper-harper is the weighted sum of each unit score.

In this method, the lower the score is, the easier the operation is. That means the operation process is easier to complete.

3 Experiment Method

The tasks on the ship are nearly all rule-based behavior and the operator are almost are of average training level. Because of the long-time improvement and adaptation, there are not too many complex man-machine interfaces in the mission and we think the man-machine interfaces are favorable. Therefore, this experiment mainly verify the parameter α, β, γ of rule-based behavior, K_1 of average training level, K_3 of favorable man-machine interfaces and different K_2 of different stress situations. Two typical missions on the ship are selected to be evaluated, which are aircraft maintenance and equipment supply. In the aircraft maintenance process, operators mainly choose some unit to test and maintain. In the equipment supply process, operators mainly fill the gas and load the weapon.

3.1 Experimental Facilities

(1) Carrier-based aircraft and attendant equipments
(2) Testing equipments
Camera: Logitech Pro C920
Heart rate monitor: Polar RS400

3.2 Experiment Subjects

This experiment includes 10 groups (each group has 3 students). Subjects are selected professional school students who have been trained for this and each group has the average level of training.

3.3 Experimental Design

Because all the tasks in this experiment is students of average level of training conducting a rule-based behavior, we need to set three different situations to refer to different degree of metal pressure.

- Situation 1: Completing all tasks under normal condition with no limits.
- Situation 2: Setting time limit. Experimenters need to finish their tasks within the required time.
- Situation 3: Simulating a competition. Different groups need to compete with each other to finish their tasks as quick as possible to win.

Situation 1 refers to low-stress situation where the experimenters are in the state of relaxation; Situation 2 refers to normal-stress situation where the experimenters are in normal state; Situation 3 refers to high-stress situation where the experimenters have heavy workload. Considering severe-stress situation only happens in battlefield, we don't need to simulate it in this experiment. The first three situations are in our experimental agenda.

In this experiment, we have two tasks in three different situations. So we need to conduct 6 small tests.

- Test 1: Aircraft maintenance in situation 1.
- Test 2: Equipment supply in situation 1.
- Test 3: Aircraft maintenance in situation 2.
- Test 4: Equipment supply in situation 2.
- Test 5: Aircraft maintenance in situation 3.
- Test 6: Equipment supply in situation 3.

After test 3 and test 4 (normal—stress situation), conductors need to fill a questionnaire. In the questionnaire, they need to score a few items in these 4 small tests, including physical labor intensity, mental labor intensity, physical operation complexity, mental operation complexity and Cooper-Harper.

3.4 Experimental Progress

Preparations.

a. Place all the needed equipment in these two tasks according to the experiment instruction.
b. Set the camera in a proper place in order to record how conductors complete their tasks.
c. Use the alcohol cotton ball to clean the left side of all the main operators' chest and make them wear heart rate monitor belts. Make sure the heart rate monitor belts are closely attached to their skin. At the same time, we need to have them wear heart rate monitors on their wrist. We need to make sure that all heart rate monitors are matched with the sensor and all of them are in good conditions.

Experiment Processing Steps. All ten groups conduct six tests described in 3.3 respectively. In order to eliminate errors and keep experimenters are in the same physiological status before every test, we need to give enough time for all experimenters to rest after each test. During each test, we should record time and result, film the whole progress and monitor their heart rate.

When test 3 and test are over, conductors need to fill a questionnaire independently according requirements.

3.5 Data Processing

Confirm the Selection of Different Parameters in Different Progress of This Experiment. Selection of different parameter is as follows:

- Test 1 and test 2 are rule-based ones; experimenters are of average training level; experimenters are in low-stress situation; favorable man-machine interface.
- Test 3 and test 4 are rule-based ones; experimenters are of average training level; experimenters are in normal-stress situation; favorable man-machine interface.
- Test 5 and test 6 are rule-based ones; experimenters are of average training level; experimenters are in high-stress situation; favorable man-machine interface.

Real Measured Data Processing. The setting of limited conducting time for conductors: according to empirical value and expert evaluation.

The setting of normal conducting time: the average conducting time after expert evaluation.

Actual error rate: If experimenters can not complete tasks in required time, they fail, which also means they make an error. The number of failed test to the total number of tests ratio is the actual error rate.

Questionnaire Processing. Combine all the scores in different parts of the questionnaire according to Entropy Method and use MATLAB to solve. Use Entropy Method to access the weight in every evaluation index (physical labor intensity, mental labor intensity, physical operation complexity, mental operation complexity) of different tests. Finally, we use weighted summation of all these indexes to get the scores of different groups in different tests.

Use the Method of Cooper-Harper to get the average score in different tests which we can regard as a standard to determine the importance of different tests and access the weight in different tests, and then use weighted summation of them all to get the final score of the whole progress.

4 Results and Analysis

4.1 Results of Heart Rate

In each group, a main operator was selected and his heart rate was measured during the operation process. Calculate the average value of ten people's heart rate with time and make out the graph of heart rate changes with time.

Curves represent the changes of heart rate with time in different stress situation. Straight line represents the average value of heart rate in the whole process. According to Fig. 1, it was found as follows: (1) In three different stress situation, the variation trend of heart rate is similar, which means the increase and the decrease of heart rate is consistent in different stress situation. (2) At the start, the heart rates in three stress situation are nearly the same. That indicates original state of operator is alike and only the different stress situation causes influence on heart rate during the operation process. (3) The range of heart rate in the high stress situation is higher than that in the normal stress situation. And the range of heart rate in the low stress situation is the lowest. This consequence also can be found through the average value of heart rate in the whole process. It is easily found that there is a good correspondence between the heart rate and stress situation.

Therefore, result of heart rate testifies the rationality of three different stress situations from the objective facts. Base on this, we can select the parameter of HCR model.

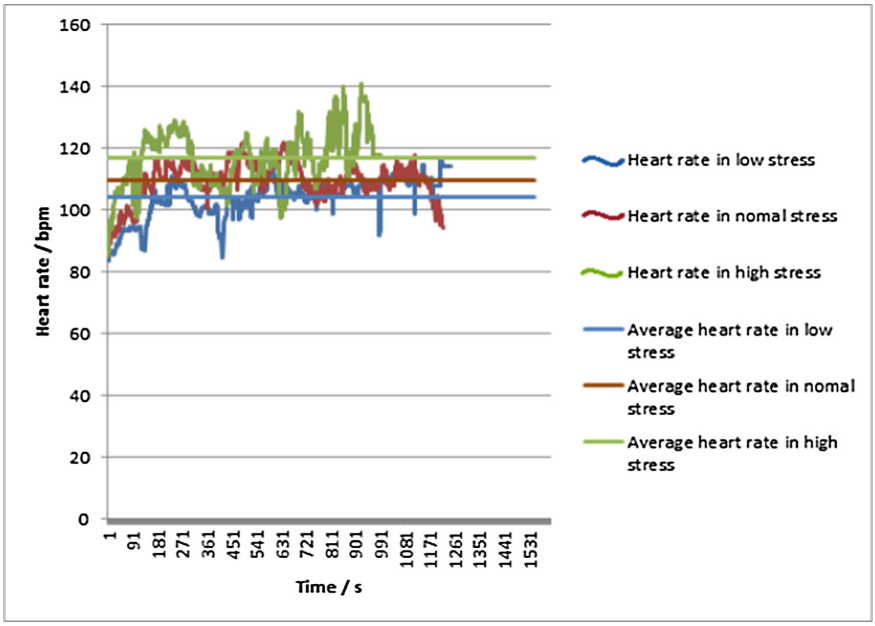

Fig. 1 Changes of heart rate with time

4.2 Results of HCR Model

According to Table 1, actual error rate is very consistent with the error rate calculated from HCR model. The relative error (2.92, 2.10, 3.83, 7.38, 1.04, 6.70 %) among six groups are all below 8 %, which agrees with condition of parameter validity (threshold is 10 %). Meanwhile, it could be found that magnitude of absolute error (10^{-2}) is very small, which indicates the difference between the actual error rate and error rate calculated from HCR model is small.

Paired sample t-test of actual error rate and error rate calculated from HCR model is showed in Table 2.

$$t = \frac{\bar{d}}{s_{\bar{d}}} = \frac{\sum_{i=1}^{6} d_i}{\sqrt{\frac{\sum_{i=1}^{6} d_i^2 - \frac{(\sum_{i=1}^{6} d_i)^2}{6}}{6 \times (6-1)}}} = -1.0951 \tag{6}$$

$$t_{5,0.05(two-sided)} = 2.5076 \tag{7}$$

Table 1 Error rate calculated from HCR model and actuality

Stress situation	Mission	t allowed time/s	Tn general operation time/s	Error rate calculated from HCR model	Actual error rate	Absolute error	Relative error
Low stress	Aircraft maintenance	420	322	0.4854	0.5	−0.0146	2.92 %
	Equipment supply	720	645	0.6126	0.6	0.0126	2.10 %
Normal stress	Aircraft maintenance	390	333	0.3847	0.4	−0.0153	3.83 %
	Equipment supply	420	440	0.5369	0.5	0.0369	7.38 %
High stress	Aircraft maintenance	210	209	0.7073	0.7	0.0073	1.04 %
	Equipment supply	400	326	0.5335	0.5	0.0335	6.70 %

Table 2 The significant test (paired sample t test)

Actual error rate (P_1)	Error rate calculated from HCR model (P_2)	$d = P_1 - P_2$	d^2
0.5	0.4854	0.0146	2.1316×10^{-4}
0.6	0.6126	−0.0126	1.5876×10^{-4}
0.4	0.3847	0.0153	2.3409×10^{-4}
0.5	0.5369	−0.0369	1.3616×10^{-3}
0.7	0.7073	−0.0073	5.3290×10^{-5}
0.5	0.5335	−0.0335	1.1222×10^{-3}

$$|t| < t_{5,0.05(two-sided)} \tag{8}$$

Thus, there is no significant difference between the actual error rate and error rate calculated from HCR model.

To sum up, it could be found that human operation error rate based on HCR model accords well with actual error rate. HCR model could be used to evaluate the rationality of cooperative task operation process.

4.3 Entropy Method

Divide the aircraft maintenance process into 7 task units and number each one from 1 to 7. In each task unit, we use the Entropy method to calculate and obtain the weight of four evaluation indexes, which is showed in Table 3.

Table 3 Entropy method processing of aircraft maintenance

Aircraft maintenance process	Weight of physical labor intensity	Weight of mental labor intensity	Weight of physical operation complexity	Weight of mental operation complexity	Final score of each task unit	Weight of each task unit
Task unit1	0.19	0.23	0.27	0.31	1.4	0.14
Task unit2	0.19	0.23	0.27	0.31	2.2	0.14
Task unti3	0.19	0.23	0.27	0.31	1.9	0.14
Task unit4	0.19	0.23	0.27	0.31	2.8	0.15
Task unit5	0.19	0.23	0.27	0.31	3.5	0.14
Task unit6	0.19	0.23	0.27	0.31	3.2	0.15
Task unti7	0.19	0.23	0.27	0.31	1.2	0.14

In each task unit, we could use weighted summation among the different score by expert and then calculate the average score as the final score of task unit.

Use the sum of mental labor intensity and mental operation complexity weight in each task unit as the standard to evaluate the importance of each unit. Then calculate the weight of each different task unit. Next, we use weighted summation among the final score of each task unit to obtain the final score of the aircraft maintenance process. Table 3 also shows the calculation process above.

The final score of the aircraft maintenance process is 2.3.

In the same way, Table 4 shows the consequence of equipment supply process.

The final score of the equipment supply process is 3.9.

4.4 Cooper-Harper Method

Table 5 shows scores of Cooper-harper and entropy method in seven task units of the aircraft maintenance process and the weight of each different task unit.

Table 4 Entropy method processing of equipment supply

Equipment supply process	Weight of physical labor intensity	Weight of mental labor intensity	Weight of physical operation complexity	Weight of mental operation complexity	Final score of each task unit	Weight of each task unit
Task unit1	0.19	0.23	0.27	0.31	4.8	0.20
Task unit2	0.19	0.23	0.27	0.31	4.0	0.20
Task unit3	0.19	0.23	0.27	0.31	3.5	0.20
Task unit4	0.19	0.23	0.27	0.31	3.8	0.20
Task unit5	0.19	0.23	0.27	0.31	3.2	0.20

Table 5 Score and weight of each task unit of aircraft maintenance process in C-h method

Aircraft maintenance process	Score of Cooper-haper	Score of entropy method	Weight of each task unit
Task unit1	1.2	1.4	0.08
Task unit2	2.5	2.2	0.14
Task unit3	2.0	1.9	0.12
Task unit4	2.9	2.8	0.17
Task unit5	3.1	3.5	0.22
Task unit6	3.6	3.2	0.20
Task unit7	1.2	1.2	0.07

Table 6 Score and weight of each task unit of equipment supply process in C-h method

Equipment supply process	Score of Cooper-haper	Score of entropy method	Weight of each task unit
Task unit1	5.2	4.8	0.25
Task unit2	5.1	4.0	0.21
Task unit3	4.0	3.5	0.18
Task unit4	4.7	3.8	0.19
Task unit5	3.2	3.2	0.17

Use weighted summation of Cooper-harper scores of 7 task units to get the final score of the whole progress. The final Cooper-harper score of aircraft maintenance process is 2.6.

In the same way, Table 6 shows scores of Cooper-harper and entropy method in 5 task units of the equipment supply process and the weight of each different task unit.

The final Cooper-harper score of equipment supply process is 4.5.

4.5 Comparison Between Subjective Evaluation Score with the Actual Situation

This article argues that: the higher score of labor intensity and complexity from the gray entropy method, the more complex mission is, and the longer the time required for completion is. The higher score of operation difficulty by the method Cooper-harper, the more difficult the operation is, the longer the time required for completion is.

The average time required for aircraft maintenance process is 333 s, and the average time required for equipment supply process is 440 s. It could be found that by using entropy method, the score of equipment supply process (3.9) is higher than

that of aircraft maintenance (2.3), which indicates the equipment supply process is more complex and needs more time to be completed. And this accords well with the fact that time for equipment supply (440 s) is longer than time for aircraft maintenance (333 s). Similarly, the Cooper-harper score of equipment supply process (4.5) is higher than that of aircraft maintenance (2.6), which means the operation of equipment supply is more difficult and needs more time to be finished. And this is suitable for the fact that time for equipment supply (440 s) is longer than time for aircraft maintenance (333 s).

In summary, it could be found that the entropy method and Cooper-harper method are two suitable methods to evaluate operation process which can be applied to evaluate the ship's workflow.

5 Discussion

(1) Generally speaking, different psychological stress states would cause different physiological reactions. Several physiological activities would appear when the stress increases: the excitability of central nervous system would increase; more aerobic blood would be pumped in order to maintain muscle movement; the level of blood sugar would elevate. Heart rate index was chosen because of its feasibility of measurement in this paper. The result shows that the value of heart rate has good corresponding to different stress states, which confirms the rationality of three different stresses in the experiment objectively.
(2) The high relative error(7.38 %–6.70 %)occurred because of the smaller base of measurement error(from 1 to 10). However, they are also lower than the allowed range (10 %).
(3) Human error rate model, grey entropy weight method and cooper-harper method have been widely used in practice. This paper verifies the coincidence between the result of typical tasks in carrier ground and the actual situation through these methods, which further indicates that it is reasonable to evaluate the process of synergetic-work in the carrier form different aspects using these methods. It could help evaluate the work flow in the carrier and predict kinds of complicated situations in the future.

6 Conclusion

(1) Human operation error rate based on HCR model accords well with actual error rate, which could be used in human error evaluation on ship.
(2) Score of labor intensity and complexity by the entropy method and score of operation difficulty by the Cooper-harper method could be quantitative indexes from subjective evaluation.

(3) Three methods evaluate the cooperative task operation process from different aspects, which consider the reliability and safety of human-machine system, the rationality of the function assignment, and the difficulty of operation respectively. Therefore, they are applicable to serve as quantitative evaluation method of cooperative task on the ship, which could be useful for the design and assessment of the process on the ship.

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Relating Musculoskeletal and Disability Conditions of Occupation-Induced Musculoskeletal Disorders to Non-occupational Congenital Disabilities

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Abstract Previous research indicates congenital disabilities may have similar physical outcomes to circumstantial disabilities encountered by occupational workers. This study attempted a preliminary mapping of musculoskeletal conditions of rice farmers to cerebral palsy (CP) patients. The farmers and CP patients were examined for lower extremity (LE) malalignment, perceived pain, and origin of structural damage. In agreement with farmers, CP participants exhibited foot pronation and knee valgus and perceived more hip and knee pain. In partial agreement with farmers, CP participant's pain origins included knee and ankle joints, and hamstring and gastrocnemius muscles, but not quadriceps muscle. The comparison showed that occupational and congenital disorder populations can be

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associated in terms of knee valgus prevalence, pain perception, and musculoskeletal impairments. Therefore, knee impairments and disorders should be emphasized for developing dual-use assistive technology to prevent further risk of LE injury for both farmers in work and CP populations in daily living tasks.

Keywords Circumstantial disability · Congenital disability · Musculoskeletal conditions · Structure malalignment · Pain

1 Introduction

Previous research has found that congenital disabilities may have similar physical and cognitive outcomes to circumstantial disabilities encountered by workers in occupational tasks [1, 2]. The nature of certain work environments can result in healthy workers exhibiting performance comparable to disabled populations. Many assistive technology (AT) designs for persons with disabilities have been applied to healthy workers who function in extreme environments. For example, Newell et al. [3] described the development of a multimodal workstation for computer task performance by persons with severe cognitive impairment along with assessment of use of the station by non-disabled users operating under high workload and safety-critical situations, such as air traffic controllers. Conversely, interventions designed to prevent worker disadvantage in extreme conditions may have utility for non-occupational disabled populations. Therefore, the study of physical conditions of occupation-induced musculoskeletal disorders (MSDs) could provide insight for interventions for congenital disabilities and support novel dual-use AT design.

Our previous research revealed a need for ergonomic interventions and ATs for Thai rice farmers [4, 5]. A MSD prevalence of 10.3–73.3 % was observed among Thai rice farmers [6]. We examined symptoms and causes of musculoskeletal and disability conditions of the lower extremities (LE) in 300 rice farmers (131 male and 169 female with age 45.13 ± 11.5) from Khon Kaen, Thailand. The participants had an average of 25.53 ± 11.5 years of experience with no less than 1 year of work in rice farming activities among all participants. Results showed a high prevalence of foot pronation (20.9 %) and knee valgus (18.5 %) [7]. Analysis of risk factors indicated that number of years of farming experience was associated with these specific malalignments (odds ratio = 1.04−1.06) [8]. Within the

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cultivation process, ergonomic screening results indicated that planting activity posed the highest risk for injury due to awkward posture, excessive force, and repetitive motion associated with this activity [9]. Related to this, farmers also perceived the greatest hip and knee pain (score of 6.1/10 and 3.6/10, respectively) during the planting activity [10]. Therefore, the planting process was selected as a target rice cultivation task for further analysis along with non-occupational congenital disabilities as bases for AT design. Physical examination of functional and diagnostic tests indicated that the origins of pain were from impairments of the knee joint (54.61 %) and lower extremity muscles [hamstring (36.2 %), quadriceps (30.4 %), and gastrocnemius (26.3 %)] [11].

In the present study, we attempted a preliminarily mapping of such occupation-related conditions to congenital disabilities, specifically musculoskeletal conditions of cerebral palsy (CP) patients. A CP population was selected due to CP orthopedic problems usually being overlooked or over-treated with surgery or heavy and uncomfortable bracing. Less invasive orthoses, similar to those used for treating work-related MSDs, may promote ease of daily living tasks. Moreover, several researchers have observed that many previous studies in disability engineering have been conducted with healthy populations under cognitive or motor restrictions. That is, disabilities are "simulated" to provide some insight for AT design and the validity of results relative to actual applications is questionable. Therefore, the study of relating musculoskeletal conditions of farmers to disabilities of the CP population, and development of AT for dual-population use, is expected to also yield substantial contributions for the CP scientific community. This study focused on the LE, as both farmers and CP patients most commonly report pain in these body parts. Figure 1 illustrates an example of rice farmer posture during the planting process as compared with the posture of a CP patient in standing. A rough similarity in leg position can be observed.

(a) (b)

Fig. 1 Example of posture comparison between: **a** farmer in planting activity; and **b** CP patient in standing

2 Methodology

2.1 Participants

Four CP patients (1 male and 3 female with age 15.5 ± 2.4 years) with spastic diplegia were recruited from the Srisangvalya Khon Kaen School for children with special needs. Access to CP patients through hospitals, clinics or educational facilities is extremely limited in both Thailand and the U.S. We were able to access a limited sample through contacts at the Khon Kaen University School of Medicine. Spastic diplegia was selected since this form of CP exhibits significant and constant tightness and stiffness in LE muscles. All CP patients who participated in this study had no surgeries on their spine and LE within 12 months prior to enrollment in the study. Participants also had LE pain that was related to foot mechanics.

2.2 Examination of LE Malalignments

The LE malalignment examination was conducted with CP participants to compare structural abnormalities with rice farmers. Anatomical alignment characteristics were measured for each participant, including pelvic angle, femoral antetorsion, quadriceps (Q) angle, tibiofemoral angle, genu recurvatum, tibial torsion, rearfoot angle, and medial longitudinal arch angle. All measurements were repeated three times by a single examiner with excellent test-retest reliability on all LE measures (ICC range of 0.89–0.98). The same examiner also performed the LE alignment examinations of rice farmers in our previous study. Participants were asked to be clothed in shorts that exposed LE parts for testing. For all standing measurements, participants were asked to stand barefoot with feet positioned at biacromial width and toes pointing forward. The procedure of the LE alignment measurements and classifications followed guidelines from the literature, similar to those used in our previous study [7]. Descriptive statistics were used to summarize all participant alignment characteristics.

2.3 Analysis of LE Pain Perception

Investigation of LE pain, as perceived by CP patients, was conducted for comparison with LE pain previously rated by rice farmers. The rice farmers were asked to fill out the Thai version of the Standardized Nordic Questionnaire (SNQ; [12]) for LE discomfort assessment before and after each stage of a complete cultivation cycle. Pain rating scales ranged from 0 to 10 points, where 0 represents no pain and 10 was intolerable pain. However, the self-report SNQ was not appropriate for use with CP patients due to participant inability to comprehend questions and perform

quantitative judgments [13]. Therefore, investigators interviewed CP participants and asked for verbal assessment of the level of LE pain they perceived during daily living activities. The investigators translated participant expressions of pain into rating numbers based on guidelines from the Borg CR10 Scale [14].

2.4 Examination of Structural Origin of LE Pain

Physical examinations were conducted to identify the origin of symptoms and affected structures of CP patients for comparison with rice farmer physical exam results. The structural origins of LE pain were identified for each of the 4 CP participants. The examinations of farmers were previously conducted after the target planting process. Examinations were two-stage including: functional screening and diagnostic testing. The procedure of the LE physical examination followed guidelines from the literature [15–19]. The screening examinations included: small knee bend (SKB); single dominant leg SKB; lunge; hop lunge and step-down [15]. A positive screening result was indicated if limited motion occurred or LE pain was perceived in comparison to the contralateral side. The diagnostic portion of the exam was conducted to detect the pathology for the intra-articular LE joint and was performed using a passive physiological movement [16]. LE muscle injury was also measured by a palpation test using pressure pain threshold resistance, an isometric contraction test and muscle length test [17, 18]. A positive result for at least one of the three examinations indicated LE muscle impairment. Neural tissue impairments were also assessed by prone knee bending, Straight Leg Raise (SLR) or slump test [18, 19]. A positive result for one of these three examinations indicated a neural tissue impairment.

All examinations were conducted by a single examiner, who is an expert physical therapist with 10 years of clinical experience in assessing MSDs and achieved very high test-retest reliability in all testing (ICC ≥ 0.9). This examiner also performed the LE diagnostic tests on rice farmers in our previous study. Descriptive statistics were used to analyze characteristics of the LE musculoskeletal impairment variables.

3 Results

3.1 Comparison of LE Malalignments

The average of three LE alignment measurements was used for analysis purposes. Table 1 presents the prevalence of LE malalignments for both rice farmers and CP participants, as observed in our previous and present studies. The findings indicated that foot and knee malalignments are common among Thai rice farmers as well as

Table 1 Prevalence of lower extremity malalignment

Characteristics	Malalignment (%)	
	Rice farmers	CP patients
Anterior pelvic tilt	10.96	0
Excessive femoral antetorsion	6.85	75
Knee valgus	18.49	100
Knee varus	3.43	0
Knee hyperextension	5.82	0
External tibial torsion	11.64	75
Foot pronation	20.89	100

CP patients. The prevalence of LE malalignments of rice farmers was greatest for foot pronation (20.89 %), followed by knee valgus (18.49 %). In line with results of the farmer investigation, all CP participants also exhibited foot pronation and knee valgus. No posterior pelvic tilt or supinated foot conditions were observed in either population.

3.2 Comparison of LE Pain Perception

Mean and standard deviation of perceived pain ratings for each LE body part for CP participants and rice farmers (induced by the planting task performance) are in Table 2. Pain rating results indicated farmers perceived the greatest pain at the hips and knees. During planting activities, farmer work posture is typically a combination of squatting, bending forward, and rotation of the trunk for several hours per work shift. Similarly, CP patients also perceived more pain in the hips and knees during daily living activities.

3.3 Comparison of Structural Origin of LE Pain

The prevalence of LE impairment-related pain characteristics of rice farmers and CP patients are in Table 3. Physical examinations, including functional and diagnostic tests, indicated that the origins of pain in farmers were due to impairments of

Table 2 Perceived pain ratings of LE body parts for rice farmers (resulting from planting task performance) and CP patients

Body part	Perceived pain ratings (mean ± SD; 0–10 score range)	
	Rice farmers	CP patients
Hip	6.08 ± 3.98	6.00 ± 1.83
Knee	3.55 ± 3.08	6.00 ± 1.83
Ankle/foot	0.52 ± 1.66	3.25 ± 3.95

Table 3 Prevalence of LE impairment-related pain characteristics of rice farmers and CP patients

Origin of pain	Musculoskeletal impairment (%)	
	Rice farmers	CP patients
Joint		
• Hip	22.18	0
• Knee	54.61	100
• Ankle and foot	5.12	100
Muscle		
• Hamstring	36.18	100
• Quadriceps	30.38	0
• Gastrocnemius	26.28	100
Neural tissue	26.62	0

the knee joints (54.61 %) and LE muscles [hamstring (36.18 %), quadriceps (30.38 %), and gastrocnemius (26.28 %)]. Partially conforming with farmer examination results, CP participant physical exams indicated origins of pain included impairments of the knee and ankle joints. The structural origin of pain for CP participants was also the hamstring and gastrocnemius muscles, but not the quadriceps muscle. Taken together, our results showed similar origins of pain for both populations.

4 Discussion and Conclusion

This research attempted to relate pain and work-related disabilities of the LE in rice farmers to the disability characteristics of a non-occupational population, specifically CP patients, as a basis for supporting dual-use AT designs for patients in daily living activities as well as farmers in work tasks. The musculoskeletal and disability conditions of the two populations were mapped to each other in terms of symptoms (malalignment and pain perception) and causes (origin of structural damage).

The comparison of farmers and CP participants showed that both populations are related in terms of knee valgus prevalence, knee pain perception, and knee musculoskeletal impairments. Therefore, knee impairments and MSDs should be emphasized in the development of any dual-use AT designs in order to prevent further risk of LE injury for both farmer and CP populations. The overall research findings are illustrated in Fig. 2.

In general, there is a need for disability engineering research to develop efficient and effective methods for characterizing disabling physical conditions of non-occupational populations due to genetic or disease factors as well as those of occupational populations due to work environment conditions and/or injury. This research can be used as a basis for designing dual-use AT for CP patients with loss of muscle control due to neurological dysfunction and in farmers due to work environment conditions.

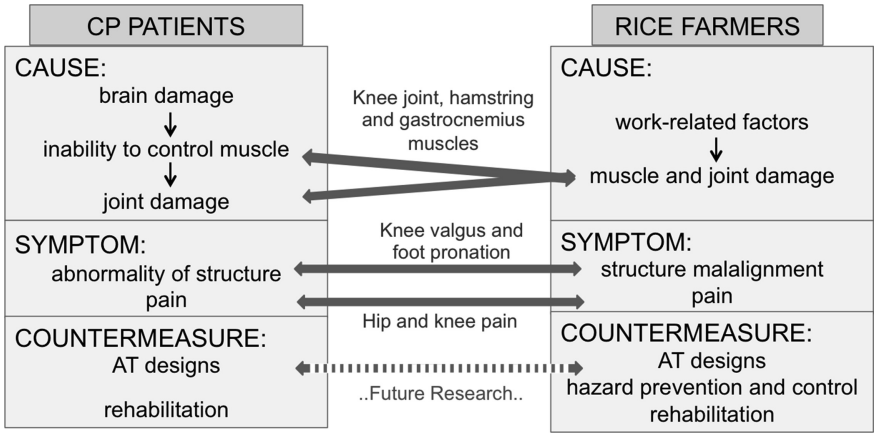

Fig. 2 Overall findings in the study

This research provided a preliminarily mapping of occupation-related MSDs to congenital disabilities of CP patients. In our previous study, we examined a substantial number of rice farmers to ensure reliability of our results. In the present work, we studied a limited number of CP patients due to access issues. Despite this limitation, we were able to make comparisons of physiological conditions among the two populations. Another limitation of the study included different assessment methodology used for rice farmers and CP participants (SNQ vs. Borg CR10). Due to inability to comprehend questions of CP participants, investigators had to interpret and translate participant expressions of pain into rating numbers of Borg CR10 scale. This might lead to an inaccuracy in the pain perception results of CP patients. Moreover, although we avoided using Likert self-report questionnaire, the interview questions still involved judgments of degree, which may be problematic for CP patients. Finlay and Lyons [13] recommended using screening questions regarding concrete events which frequency is known in pretest sessions. Our future study will include the pretest sessions, developed in collaboration with CP patient caretakers, to ensure the correction of such judgments.

Follow-on research is expected to include more CP participants to support inferential statistical analyses on results from the rice farmers and CP patients. Furthermore, we plan to pursue: dual-population AT design; rapid prototyping of low-cost highly usable AT (e.g., foot and knee orthotics); performance assessment using ergonomic measurement methods; and design validation using high-fidelity lab mock-ups of farm and daily living tasks as well as actual field tests.

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The Relationship Between Working Conditions and Ergonomic/Musculoskeletal Disorders in a Manufacturing Facility

Dennis R. Jones

Abstract My research investigates the relationship between working conditions and musculoskeletal disorders in an assembly facility. I believe that the physical and psychosocial aspects of work have a significant influence on the individual worker's health and well-being. The work organization at which I evaluated the employee's health and well-being was at a large manufacturing assembly facility. This research is based upon the Balance Theory Model of Smith and Carayon-Sainfort [1, 2]. The overall aim of this research is to improve the long term health and well-being of worker's in a manufacturing assembly facility. The overall purpose of this research is to try to identify the stressful working condition and attempt to control it. By trying to control the various musculoskeletal disorders in the work environment, you should also attempt to reduce or eliminate the level of stress, and to try to reduce or eliminate the level of strain.

Keywords Human factors · Ergonomics · Musculoskeletal disorders · Psychosocial · Balance theory model · Applied field research · Manufacturing · Assembly · Production processes

1 Introduction

In the year 2014; 1.157 million people report taking time off work to recover from musculoskeletal pain due to overexertion or repetitive motion [3]. Workman's compensation costs due to musculoskeletal pain or discomfort exceed $20 billion annually. In reality in order to estimate the actual costs related to musculoskeletal pain and discomfort, you must also estimate the indirect costs. Therefore workman's compensation costs due to musculoskeletal pain or discomfort are estimated at over $50 billion annually [4].

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I have done research on the relationship between working conditions and musculoskeletal disorders in an assembly facility. I believe that the physical and psychosocial aspects of work have a significant influence on the individual worker's health and well-being. The work organization at which I evaluated the employee's health and well-being was at a large manufacturing assembly facility. This research is based upon the Balance Theory Model of Smith and Carayon-Sainfort [1, 2]. This model specifies that the working conditions and other factors outside of work, can create a stress on the individual. This stress can have physiological and psychological consequences. If the stress exceeds the individual's capacity, the stress can produce a negative effect on the individual which could result in a strain. This is a bad fit between the individual resources and the work demands. If the stressful exposure continues for a prolonged time period, then this can result in serious musculoskeletal disorders.

The Balance Theory Model of Smith and Carayon-Sainfort [1, 2] is as follows (Fig. 1):

The Balance Theory Model is a system view concept for the various elements of work. The Balance Theory Model shows the stress that working conditions can exert on the individual. These five elements of the Balance Theory Model all interact to define how work is to be performed. The individual is in the center of the Balance Theory Model. The individual has physical attributes and characteristics, previous experiences and knowledge, individual attitude and personality, and learned behaviors from which to draw from in order to cope with the working condition stress. The elements of task, technology, organization, and environment all influence the job content of work, the physical effort required of the individual, and the level of stress placed upon the individual [1].

The overall purpose of my research is to try to identify the stressful working condition and attempt to control them. Therefore the purpose of an intervention is to try to control the various musculoskeletal disorders in the work environment. By trying to control the various musculoskeletal disorders in the work environment, you should also attempt to reduce or eliminate the level of stress, and to try to

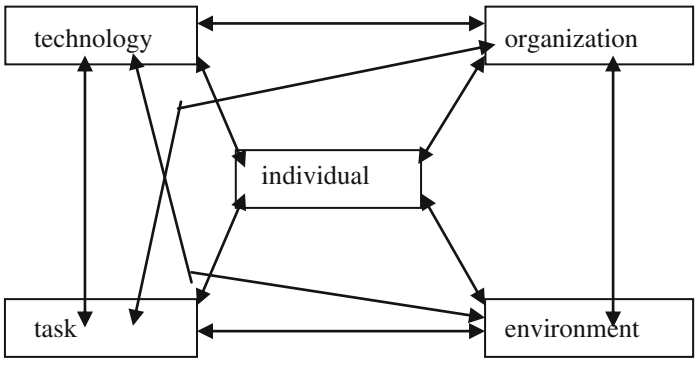

Fig. 1 The balance theory model of Smith and Carayon-Sainfort [1, 2]

reduce or eliminate the level of strain. There are a wide variety of things that can be attempted in the work environment in order to try to reduce or eliminate the existence of musculoskeletal disorders. These include engineering redesign, work method changes, administrative control, worker training, work hardening, and management organizational work rules to reduce exposures [5].

2 The Research Questions

Based on my objective to do research on the relationship over time between working conditions and musculoskeletal disorders in a manufacturing assembly facility, the following research hypotheses were explored:

H1: Self reports of physical aspects of work influence worker's musculoskeletal pain or discomfort. It is anticipated that the relationship will be stable over time.

H2: Self reports of psychosocial aspects of work influence worker's musculoskeletal pain or discomfort. It is anticipated that the relationship will be stable over time.

3 The Significance of the Research

The overall aim of this research is to improve the long term health and well-being of worker's in a manufacturing assembly facility. The overall purpose of this research is to try to identify the stressful working condition and attempt to control it.

One of the contributions of this research is to determine the relationship between working conditions and musculoskeletal disorders in a manufacturing assembly facility. Generally the literature on this topic tends to be more heavily concentrated on the office worker, or service provider type of worker. Therefore the area of workers in a manufacturing assembly facility needs further investigation. Generally, the combination of both physical and psychosocial aspects of work influencing worker's musculoskeletal pain or discomfort, also needs further investigation.

A second contribution is to improve the research techniques and methodology which has been utilized in some previous scientific studies which attempted to control musculoskeletal disorders. Specifically the scientific evidence on interventions to control musculoskeletal disorders has some shortcomings. The lack of sound research methods and the lack of sound research designs are a significant shortcoming in some of the existing literature. This position is supported by the National Academy of Sciences paper of Smith et al. [5]. Their paper investigated and reviewed the research on interventions to control musculoskeletal disorders.

A third contribution is that the results of this research can assist industrial engineers in designing the jobs of workers in a manufacturing assembly facility. The incorporation of both physical and psychosocial aspects on worker job design should reduce the worker's musculoskeletal disorders, and therefore improve the long term health and well-being of workers in a manufacturing assembly facility.

4 Literature Review—Summary

In summary, the National Research Council [6] concluded that there is theoretical evidence and some empirical evidence that links psychosocial factors and musculoskeletal discomfort. Stress appears to be a mediating variable that contributes to the development of musculoskeletal disorders. There also exists some theoretical evidence and some empirical evidence that links biomechanical factors and musculoskeletal discomfort.

In conclusion, more research studies need to be done in order to provide an answer to the existence of the link between biomechanical factors and psychosocial factors, and musculoskeletal disorders. Substantial research literature needs to be developed before a definitive answer could be given; yet the link seems very plausible.

5 Methodology—Study Design

The study was performed by using a multiple paged questionnaire to survey the three different assembly methods at the manufacturing assembly facility. Data was collected several times over a period of time; therefore a longitudinal study was conducted. These three different assembly methods were exhibited and displayed by three distinct individual manufacturing assembly lines. One of these manufacturing assembly lines consisted of the employee subjects of interest (i.e. the study group) which was called the study group. The other two assembly lines served as the control groups for the study group; these two areas were called the control group 1 and the control group 2.

The study group employee's assembly method consisted of utilizing an overhead powered conveyor system in order to assemble the product.

The control group 1 employee's assembly method consisted of utilizing automatic guided vehicles (AGVs) in order to assemble the product.

The control group 2 employee's assembly method consisted of utilizing a gravity roller conveyor (i.e. a manual push line) in order to assemble the product.

6 Data Collection

Data was collected from the three manufacturing assembly line area employee groups by utilizing a multiple page questionnaire survey. The multiple page questionnaire surveys were designed in order to obtain the information of desired pertaining to the research questions asked. The multiple page questionnaire surveys were given to both the study group and the control groups.

The multiple page questionnaire survey which was given to the study group and control groups was organized as follows:

A. Job Information (8 questions),
B. Characteristics of Work Environment (41 questions),
C. Quality of work Life (5 questions),
D. Health Information (23 questions),
E. Ergonomics and Physical Environment (28 questions),
F. Performance (11 questions),
G. Demographics (3 questions),
H. Implementation (3–5 questions)—this section was only given to the study group.

The multiple page questionnaire surveys for the study group and control groups were slightly different. The study group was asked additional questions in order to obtain information regarding their initial response to the new assembly method and the new assembly method implementation. Obviously the control group assembly methods had already existed for several years and therefore implementation questions pertaining to them were inappropriate and unnecessary; since we are only interested in the implementation of the study group assembly method.

7 Multivariate Analysis of Variance—MANOVA

I concluded from the results from the multivariate analysis of variance (MANOVA) that musculoskeletal discomfort is primarily influenced by psychosocial factors (such as anxiety, and uncertainty), and physical demands. As when psychosocial factors (such as anxiety, and uncertainty), and physical demands increased; musculoskeletal discomfort also increased. It could be implied that musculoskeletal discomfort and psychosocial factors (such as anxiety, and uncertainty), and physical demands are linearly related.

Therefore, when the physical demands are increased, the stress on the individual is increased, and the ergonomic musculoskeletal discomfort is also increased.

Also, when the anxiety and uncertainty are increased, the stress on the individual is increased, and the psychosocial factor discomfort (i.e. negative psychosocial factors) is also increased.

So, an increase in physical demands, results in increased ergonomic musculoskeletal discomfort. And, an increase in anxiety and uncertainty, also results in increased negative psychosocial factors.

8 Results and Discussion

8.1 Hypothesis 1—Results

H1: Self reports of physical aspects of work influence worker's musculoskeletal pain or discomfort. It is anticipated that the relationship will be stable over time.

Hypothesis 1 is supported.

8.2 Hypothesis 2—Results

H2: Self reports of psychosocial aspects of work influence worker's musculoskeletal pain or discomfort. It is anticipated that the relationship will be stable over time.

Hypothesis 2 is supported.

8.3 Discussion

The control groups appear to be stable over time in terms of musculoskeletal discomfort, neck/shoulder/back discomfort, hand/arm discomfort, and leg discomfort. The control group 2 (i.e. the manual push line) consistently exhibits higher self reports of musculoskeletal discomfort, neck/shoulder/back discomfort, hand/arm discomfort, and leg discomfort than the control group 1 (i.e. the AGV line), over the several rounds of data collection. This is to be expected since the human factors, ergonomics, and working conditions of the control group 2 is significantly worse than the control group 1.

The study group (i.e. the overhead powered line) exhibited lower self reports of musculoskeletal discomfort, neck/shoulder/back discomfort, hand/arm discomfort, and leg discomfort than the control groups. This is to be expected since the human factors, ergonomics, and working conditions of the study group was significantly better than the control groups.

The control groups appear to be stable over time in terms of the physical aspects of work. The control group 2 consistently exhibits higher self reports of physical demands, repetitive motions, and loading on individual than the control group 1, over the several rounds of data collection. This is to be expected since the human

factors, ergonomics, and working conditions on the control group 2 is significantly worse than the control group 1.

The study group exhibited lower self reports of physical demands, and repetitive motions than the control groups. This is to be expected since the human factors, ergonomics, and working conditions of the study group was significantly better than the control groups.

The control groups appear to be stable over time in some of the psychosocial aspects of work. The control group 2 exhibited lower self reports of task control, job control, resource control, and decision control than the control group 1, over the several rounds of data collection. This is to be expected since the human factors, ergonomics, and working conditions of the control group 2 is significantly worse than the control group 1.

The study group appears to be stable over time in some of the psychosocial aspects of work. The study group exhibited greater self reports of task control, job control, resource control, and decision control than the control groups. This is to be expected since the human factors, ergonomics, working conditions, and employee empowerment of the study group was significantly better than the control groups.

9 Summary/Conclusion

In summary, there is theoretical evidence and some empirical evidence that links psychosocial factors and musculoskeletal discomfort. Stress appears to be a mediating variable that contributes to the development of musculoskeletal disorders.

There also exists some theoretical evidence and some empirical evidence that links biomechanical factors and musculoskeletal discomfort.

In conclusion, more research studies need to be done in order to provide an answer to the existence of the link between biomechanical factors and psychosocial factors, and musculoskeletal disorders. Substantial research literature needs to be developed before a definitive answer can be given; yet the link seems very plausible.

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Musculoskeletal Disorders Among Rice Keeper Basketwork Workers

Orawan Buranruk, Wichai Eungpinithpong, Rungthip Puntumetakul and Kulwarang Wongwilairat

Abstract Musculoskeletal Disorders (MSDs) are obvious problems in occupations that can result in poor functional activity. A survey of the Thai national statistical office indicated the percentage of informal employment was as high as 62.6 % of the total employed persons in Thailand. Considered by the work regions, the informal employment mostly worked in the northeast of Thailand. In Khon Kaen province, rice keeper basketwork (RKB) is the major supplement of career. Most tasks in RKB are performed with prolonged sitting on the floor and using repetitive movements of upper extremity for long periods, were likely to increase the MSDs. Thus, this study aimed to investigate the MSDs and the association between MSDs and baseline demographics, work characteristics among RKB in basketwork group. Data were collected through the use of the Standard Nordic Questionnaire (SNQ) in Thai version. The results showed that the top three of MSDs in twelve months period were shoulder pain, upper back pain, wrist and hand pain and the last seven days was found slightly less in the same following areas were shoulder pain, upper back pain, wrist and hand pain. Therefore, this study can be used as guide in planning for prevent MSDs.

Keywords Basketwork · Musculoskeletal disorders · Task analysis

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1 Introduction

Musculoskeletal disorders (MSDs) are injuries and disorders of the soft tissues such as muscles, tendons, ligaments, joints, cartilage and nervous system [1] that can result in pain with or without movement, swelling, tenderness, reduced range of motion and/or stiffness, and tingling and/or numbness in nerve-related injuries or disorders [2]. Musculoskeletal pain is common in the working population [3], that is one of the main occupational problems among health care workers [4] and a significant cause of morbidity [5]. Several factors, such as excessive repetition, awkward postures [2, 6, 7], physical workload or force [6, 8] and static work [1, 9] are associated with MSDs. European workers commonly report MSDs as work-related health problems [10] and a major source of disability and lost work time [11]. The United States estimated that about 40 % of all upper extremity MSDs in the total US employed population were attributable to occupational exposures, representing over 500,000 people affected per year of work-related musculoskeletal disorders [12]. In Thailand, the problems in the work environment, the most problem was working condition include body of work that is not healthy for a long time, causing inflammation and malfunction of various organs in the body 48.2 % [13]. The health effects of computer use among Thai Commercial Bank Workers in Khon Kaen province found that the repetitive movement strain of the wrist and hands and used computers were found to increase risks of MSDs [14]. The study of ergonomic analysis of rice field plowing found that the repetitive motion and extreme posture were considered the main underlying factors in the MSDs [15]. Furthermore, the characteristics of the basket workers such as prolonged sitting on the floor, using hand, fingers, wrist and shoulder repetitive movements in most of time, was likely to increase the MSDs [16]. Previous studies have not assessed ergonomic risk and the association between MSDs and ergonomic risk among rice keeper basketwork (RKB) workers. Thus, this study is set up to investigate the MSDs, level and ergonomic risk all steps of RKB procedure and the association between MSDs and baseline demographics, and work characteristics among RKB workers to reduce work-related musculoskeletal disorders.

2 Methodology

This study is cross-sectional study design in Yang Khum subdistrict, Nong Rua district, Khon Kaen province, Thailand. All procedures of the study are in accordance with the standards of the Khon Kaen university ethics committee for human research. Subjects of this study are RKB workers by purposive sampling method from 3 villages. They met the following criteria were included (1) experience in RKB for at least three months (2) RKB procedure at least three steps and (3) subjects provided written informed consent. Subjects were excluded if the subjects had (1) upper and lower limb deformity (2) limit range of motion of upper and lower

limb by joint stiffness, muscle shortening or muscle contracture (3) neurological signs of upper and lower limb and (4) serious diseases (such as cancer diseases, heart diseases and kidney disease. The eligible subjects received interviewed and assessed their baseline demographics, work characteristics, musculoskeletal disorders and ergonomic risk. The baseline demographics and work characteristics using a questionnaire developed by the researcher based on a literature review, (1) baseline demographics such as age, gender, body weight, body stature, exercise, and underlying (2) work characteristics such as number of working hours a day, weekly working time, and additional occupations. The MSDs were evaluated by the Standardized Nordic Questionnaire Thai version. Statistics and data analysis was performed with SPSS program (version 19). Descriptive statistics were used to summarize baseline data (demographics data, work characteristics), level and ergonomic risks of the study population were presented as frequency, percentages, mean ± standard deviation. The analytical statistics were used to summarize prevalence of MSDs were presented as frequency, percentages and the 95 % confidence intervals. Multiple logistic regression were used to assess associations between factor variables and reported MSDs were presented as odds ratios (OR) and 95 % confidence intervals. p values below 0.05 were considered statistically significant.

3 Results

The study sample were comprised all 74 RKB worker. The results showed the distribution of MSDs on various parts of the body of the subjects. The top three of the most distribution of MSDs in the last seven days were shoulder pain (85.14 %, 95 % CI: 79.68–89.34), upper back pain (81.08 %, 95 % CI: 74.20–84.02), wrist and hand pain (64.86 %, 95 % CI: 58.37–69.60) and the last twelve months were shoulder pain (90.54 %, 95 % CI: 84.37–95.74), upper back pain (87.84 %, 95 % CI: 81.02–91.55), wrist and hand pain (72.97 %, 95 % CI: 66.26–78.33) respectively. The associations between top three of the most distribution of MSDs in the last seven days period were shoulder pain, upper back pain and wrist and hand pain and baseline demographics and work characteristics. Shoulder pain: The main statistically significant risk factor was daily working time more than 8 h (OR: 5.67, 95 % CI: 1.41–5.94, p-value: 0.032) and experience in RKB more than or equal to 40 years (OR: 1.41, 95 % CI: 1.07–2.30, p-value: 0.003) (Table 1). Upper back pain: The main statistically significant risk factor was daily working time more than 8 h (OR: 7.28, 95 % CI: 1.22–11.23, p-value: 0.044) and no breaks during working (OR: 1.63, 95 % CI: 1.33–8.01, p-value: 0.002) (Table 2). Wrist and hand pain: The main statistically significant risk factor was daily working time more than 8 h (OR: 1.29, 95 % CI: 1.13–1.89, p-value: 0.024) and experience in RKB more than or equal to 40 years (OR: 4.18, 95 % CI: 1.03–13.93, p-value: 0.049) (Table 3).

Table 1 The associations between shoulder pain and baseline demographics, and work characteristics (n = 74)

Independent variables	Shoulder pain		OR (95 % CI)	p-value
	Yes n (%)	No n (%)		
Demographics characteristics				
Age (years)				
≥50	52 (70.27)	9 (12.16)	1.14 (0.06–10.01)	0.647
<50	11 (14.86)	2 (02.70)	0.37 (0.17–8.10)	1.000
Education				
Elementary school	61 (84.72)	11 (15.28)	1.18 (0.07–1.30)	0.230
High school	2 (100.00)			
Underlying disease				
Yes	22 (84.62)	4 (15.38)	2.33 (0.99–5.48)	0.502
No	41 (85.42)	7 (14.58)		
Regularly exercise				
No exercise	61 (87.14)	9 (12.86)	1.15 (0.05–1.27)	0.025
3 times/week	2 (50.00)	2 (50.00)		
Body mass index (BMI kg/m^2)				
Obesity (≥ 25)	24 (85.71)	4 (14.29)	3.54 (0.32–9.13)	0.596
Overweight	16 (94.12)	1 (5.88)	0.92 (0.80–1.07)	1.000
Normal (18.5–22.9)	24 (82.76)	5 (17.24)		
Work characteristics				
Daily working time (hours)				
>8	55 (85.94)	9 (14.06)	5.67 (1.41–5.94)	0.032*
≤8	8 (80.00)	2 (20.00)		
Experience in rice keeper basketwork (years)				
≥40	38 (82.61)	8 (17.39)	1.41 (1.07–2.30)	0.003*
<40	25 (89.29)	3 (10.71)		
Hand dominance				
Right	57 (85.07)	10 (14.93)	1.25 (0.06–1.49)	0.165
Left	6 (85.71)	1 (14.29)		
Rest breaks during work				
No	42 (85.71)	7 (14.29)	1.00 (0.17–5.87)	0.071
Yes	21 (84.00)	4 (16.00)		
Environment problem				
Yes	24 (85.71)	4 (14.29)	5.00 (0.49–10.87)	0.285
No	42 (85.71)	4 (08.70)		

* Statistical significance (p-value < 0.05)

Table 2 The associations between upper back pain and baseline demographics, and work characteristics (n = 74)

Independent variables	Upper back pain		OR (95 % CI)	p-value
	Yes n (%)	No n (%)		
Demographics characteristics				
Age (years)				
≥50	50 (67.57)	11 (14.86)	0.31 (0.26–2.75)	0.300
<50	10 (13.51)	3 (04.05)	1.25 (0.07–2.17)	0.203
Education				
Elementary school	59 (81.94)	13 (18.06)	1.22 (0.09–1.36)	1.000
High school	2 (100.00)			
Underlying disease				
Yes	21 (80.77)	5 (19.23)	3.50 (0.08–11.29)	0.325
No	40 (83.33)	8 (16.67)		
Regularly exercise				
No Exercise	57 (81.43)	13 (18.57)	5.00 (0.63–13.39)	0.154
3 times/week	3 (75.00)	1 (25.00)		
Body mass index (BMI kg/m^2)				
Obesity (≥ 25)	23 (82.14)	5 (17.86)	0.19 (0.01–1.99)	0.376
Overweight	13 (76.47)	4 (23.53)	0.54 (0.36–8.27)	1.000
Normal (18.5–22.9)	25 (86.21)	4 (13.79)		
Work characteristics				
Daily working time (hours)				
>8	54 (84.38)	10 (15.62)	7.28 (1.22–11.23)	0.044*
≤8	5 (50.00)	5 (50.00)		
Experience in rice keeper basketwork (years)				
≥40	39 (84.78)	7 (15.22)	4.46 (0.76–16.09)	0.107
<40	25 (89.29)	3 (10.71)		
Hand dominance				
Right	54 (80.60)	13 (19.40)	1.78 (0.30–10.41)	0.614
Left	7 (100.00)			
Rest breaks during work				
No	41 (83.67)	8 (16.33)	1.63 (1.33–8.01)	0.002*
Yes	19 (76.00)	6 (24.00)		
Environment problem				
Yes	22 (78.57)	6 (21.43)	1.44 (0.23–8.84)	1.000
No	38 (82.61)	8 (17.39)		

* Statistical significance (p-value < 0.05)

Table 3 The associations between wrist and hand pain and baseline demographics, and work characteristics (n = 74)

Independent variables	Wrist and hand pain		OR (95 % CI)	p-value
	Yes n (%)	No n (%)		
Demographics characteristics				
Age (years)				
≥ 50	43 (58.11)	18 (24.32)	1.64 (0.15–10.47)	1.000
<50	7 (09.46)	6 (08.11)	3.75 (0.27–9.39)	0.559
Education				
Elementary school	47 (65.28)	25 (34.72)	1.54 (0.30–1.83)	1.000
High school	2 (100.00)			
Underlying disease				
Yes	21 (80.77)	5 (19.23)	0.73 (0.56–0.96)	0.278
No	29 (60.42)	9 (39.58)		
Regularly exercise				
No Exercise	44 (62.86)	26 (37.14)	0.54 (0.05–5.54)	1.000
3 times/week	3 (75.00)	1 (25.00)		
Body mass index (BMI kg/m^2)				
Obesity (≥ 25)	14 (50.00)	14 (50.00)	0.16 (0.07–0.82)	0.526
Overweight	0 (58.82)	7 (41.18)	1.50 (0.10–12.67)	1.000
Normal (18.5–22.9)	24 (82.76)	5 (17.24)		
Work characteristics				
Daily working time (hours)				
>8	40 (62.50)	24 (37.50)	1.29 (1.13–1.89)	0.024*
≤8	10 (100.00)			
Experience in rice keeper basketwork (years)				
≥40	34 (73.91)	12 (26.09)	4.18 (1.03–13.93)	0.049*
<40	16 (57.14)	12 (42.86)		
Hand dominance				
Right	46 (68.66)	21 (31.14)	1.75 (0.35–8.62)	0.669
Left	4 (57.14)	3 (42.86)		
Rest breaks during work				
No	31 (63.27)	18 (36.73)	1.43 (0.40–5.10)	0.744
Yes	18 (72.00)	7 (28.00)		
Environment problem				
Yes	15 (53.57)	13 (46.43)	1.80 (0.39–8.18)	0.704
No	39 (84.78)	7 (15.22)		

* Statistical significance (p-value < 0.05)

4 Discussion

This study found that the distribution of MSDs in the last seven days and twelve months, the most common were shoulder pain, followed by upper back pain and wrist and hand pain. The top three of the most distribution of MSDs in the last twelve months were shoulder pain (90.54 %), upper back pain (87.84 %), and wrist and hand pain (72.97 %), and the last seven days were shoulder pain (85.14 %), upper back pain (81.08 %), and wrist and hand pain (64.86 %). This due to the work characteristics of workers including prolonged sitting on the floor without back support and using upper extremity repetitive movements for a long time. These findings are consistent with those of Punnett and Wegman [6] and Da Costa and Vieira [7] that awkward postures, excessive repetition and physical workload or force [8] are associated with MSDs. The distribution of MSDs in the last twelve months has a higher distribution than in the last seven days, probably because the last twelve months, workers have been employed primarily in conjunction with farming which is associated with the use of the shoulder such as farming, sowing and plowing, etc. When they do not work in the farm, they will take woven, so the MSDs increased. Previous studies on MSDs in women bamboo basket workers in Madurai city of India in the last month found distribution to be highest for the low back pain 99 %, upper arm 98 %, and shoulder pain 93 % [17]. In Thailand, the similarities characteristics of job in "Rom Suk" broom weaving workers in Khon Kaen province found distribution of musculoskeletal and upper limb disorders was 83.7 % [18] and distribution of musculoskeletal pain in the textile occupation in Khon Kaen province in twelve months were shoulder pain 49.8 %, low back pain 46.6 %, and neck pain 42.6 % [19]. The findings from current study on the similarities characteristics of job are in agreement with the trends of these distribution rates. High risks of MSDs were observed for similarities characteristics of job in the same areas of the body as reported by the previous studies.

In the association of shoulder pain, upper back pain and wrist and hand pain with baseline demographics did not find risk factors all variables. The shoulder pain, upper back pain and wrist and hand pain was found associated with the work characteristics. The most significant associations were daily working time more than 8 h. These findings are consistent with those of Parimalam et al. [17] that the bamboo basket workers continuously work for more than 2 h/day were found to increase risks of shoulders and back pain, and Chaiear et al. [14] found that the repetitive movement strain of the wrist and hands and used computers at least 5 h/day. Furthermore, the study of dentists in Vietnam founds working more than 8 h/day associated with MSDs [20]. The associated factors of shoulder pain and wrist and hand pain were experience in RKB more than or equal to 40 years. This finding was also consistent to the study of Shuval and Donchin [21] the workers working at the Hi-Tech company for more than 2 years were found to increase risks of shoulders pain and the workers working more than 4 years were found to increase risks of wrist and hand pain. The associated between experience in RKB and MSDs that occur because of the cumulative trauma disorders (CTD) resulting

from months or years [22]. The associated factors of upper back pain were no breaks during working. In a similar study, the bamboo basket workers continuously work without any break or change of posture is a risk factor for back pain [17] and the study of dentists in Vietnam working more than 60 min without a break, and only sitting while working were significantly associated with MSDs [20].

5 Conclusion

This study suggests that RKB is an occupational risk for MSDs especially for shoulder pain, upper back pain and wrist and hand pain. The most associating factors of MSDs were daily working time more than 8 h, followed by experience in RKB more than or equal to 40 years and no breaks during working. Knowledge from this study can be used as guidelines for create the intervention model for prevention and appropriate behavioral change to reduce work-related musculoskeletal disorders among RKB workers. For the workers who did not make baskets to make a career, the findings were found the risks of working in each step. It would help to know the method of risk prevention resulting in MSDs before making a career of basketry.

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HTA-Based Tracking of Pilot Actions in the Cockpit

Sebastien Mamessier and Karen M. Feigh

Abstract This work presents a computational goal-oriented task model based on Hierarchical Task Analysis (HTA) able to support accurate tracking of pilot actions and current goals in a controlled environment. Formal semantics are proposed to capture the expressiveness of pen and paper HTA using a computational approach based on open petri nets. Finally, a case study involving professional airline pilots is conducted to demonstrate the resulting tracking system with realistic data.

Keywords Human factors · Task analysis · Human-automation interaction

1 Introduction

1.1 Motivation

Hierarchical Task Analysis (HTA) has been used extensively to support Human Factors (HF) and Human Automation Interaction (HAI) experts' practice. It is mostly used as a goal-oriented task model to analyze operators' behavior when interacting with complex socio-technical systems. HTA models can then serve as a starting point for more specialized analysis methods such as Systematic Human Error Reduction and Prediction Approach (SHERPA) or Critical Path Analysis (CPA).

Vicente summarizes the different possible interpretations of a HTA model as either descriptive or normative [1]. A descriptive HTA attempts to capture realistic

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workers' goal-oriented behavior whereas a normative HTA tries to capture the current system's operational work requirements independently of the operators being observed to identify potential bottlenecks. In both cases, an HTA model is capable of representing a realistic goal-oriented work model, containing more accurate HAI-related information than procedural manuals or classical system representations. We therefore believe that HTA models can be used for other purposes such as live tracking of airline pilots' actions. However, HTA suffers of the absence of formal semantics to be comprehensible beyond Human Factors practitioners.

This work presents a simplified HTA-based, goal-oriented task computational model able to precisely track pilot actions, active goals and subgoals in a controlled environment for descriptive and normative purposes. Possible applications of such an approach are concerned with early user-centered design, training tools and human machine collaboration in the cockpit.

1.2 Approach

The approach described in this paper can be decomposed in three steps. The first part attempts to capture the expressiveness of pen and paper HTA with a computational model. Secondly, this work adapts a petri net tracking algorithm that projects actions to the underlying HTA model. Finally, a case study involving seven professional airline pilots performing an approach in a controlled environment demonstrates the HTA computational model and the tracking system with realistic data.

The tracking algorithm relies on the semantic alignment between HTA plans and petri nets and previous work on petri net state estimation. It takes into account live flight telemetry data, detection of pilot actions along with a reference HTA model. The overall architecture is precisely described to demonstrate the generic and reproducible nature of the approach.

2 HTA Semantics

Hierarchical task analysis has been used in several different fashions since it was first introduced by Annett et al. [2]. It is difficult to find consistent semantics in the available literature to formalize the different concepts involved in a HTA model. Shepherd [3] and Stanton [4] clarified HTA terminology and summarized notation conventions including precise definitions of *tasks*, *goals*, *plans*, *redescription* and *decomposition*, hence providing a great foundation for this work. Building on such previous efforts, this section synthesizes a computational-friendly terminology while attempting to respect the original intent and expressiveness of HTA analysis as well as overcoming some of its practical shortcomings.

2.1 Hierarchy Modeling

Task Redescription. The structure of a HTA represents a hierarchical relationship between tasks. Semantics of the parent—children links are usually not formally described which can lead to confusion.

Lower levels usually carry a finer description of the work of operators/automation and tend to be more implementation and interface-specific. For instance, higher levels of an Airliner Approach HTA (i.e. the final phase of a flight prior to landing) will be practically the same regardless of the airline and aircraft manufacturer whereas lower levels contain procedural and equipment related specifics.

As explained by Annett in [5], *redescription* of a task stands for detailing out the possible routes to reach the task's goal in terms of a list of subtasks whose accurate description of the execution flow is contained in the task's plan. The number of *redescription* levels therefore depends on many factors such as the purpose of the analysis and degree of prior knowledge about the system. A single HTA might also show a horizontal heterogeneous degree of *redescription*, i.e. containing tasks that are more detailed than others.

Goal Decomposition. Decomposition specifies a task goal with a greater resolution in the system state space. This step is very useful when going from a paper-based approach where goal specification can stay qualitative (ex: Land the aircraft) to a computational implementation which requires an exact, often mathematically decomposable goal/completion condition (ex: AC on the runway, with a given energy level).

Formal Semantics. An HTA model is composed of hierarchically organized tasks, in formal terms, an element m of the space of all HTA models A is a 3-tuple (h, T, P) where h, the HTA hierarchy is a *labeled ordered rooted tree*, $T = \{T_i\}_{i=1,\dots,n}$ the list of tasks whose elements are bound to the tree vertices. Task semantics are further developed in Sect. 2.2. $P = \{P_i\}_{i=1,\dots,n}$ is the list of plans, and each P_i is an open petri net, for which details are provided in Sect. 2.3.

2.2 Task Modeling

Common HTA practice uses the terms: *operations*, *tasks* and *goals* to describe items of the HTA, *goals* being primarily used to describe members of the upper levels and *task* for lower levels. The lowest hierarchical level often consists of *operations* which stand for more or less atomic tasks, the exact level of terminating detail is purpose specific. *Operations* typically represent tasks that describe physical actions such as *Press Approach button*. To simplify the terminology, we consider every element of a HTA to be a task with the following definition:

A task T_i is a contextual, agent-agnostic piece of work, characterized by a human-readable description and a machine-readable goal description.

Contextual means that a task only carries a meaning as part of a task hierarchy, operator agnosticism specifies that a *task* does not carry information about the type, nature or identity of the agent responsible for its completion. A *subgoal* is a special type of task whose completion can be fully specified by a target region in the system state space. An *operation* is a special type of task that cannot be redescribed. Redescription of an *operation* would lead to a *task* with agent-specific attributes which is in contradiction with this definition of a *task*.

As such, *task* specifies its goal but no instructions for its realization. However, the hierarchical structure of the HTA can be used to *redescribe* a *task* T_i in a list of subtasks organized through a *plan* P_i.

2.3 Plans Modeling

Graphical representations of HTA often minimize the importance of plans. Moreover, HTA *plans* are often omitted by novice Human Factors practitioners as if they were obvious or trivial. However, HTA plans are a significant part of the expert knowledge captured in a HTA model.

Paper-based HTA show arbitrarily complex and compound *plans* using the expressiveness of the English (or other) language. The absence of clear restrictions on plans is a great challenge for any formalization attempt of HTA models. However, commonly used plans largely fall into one of a handful of archetypes [4], see Table 1.

Plans describe processes using references to tasks (1, 2, 3, 4) and conditions (X) as shown in Fig. 1. We propose to base the formal semantic description of plans on *petri nets* as they are well studied and their core semantics are consistently defined [6]. Moreover, *petri nets* seem to be expressive enough to carry HTA plans knowledge and flexible enough to attach a customized execution/tracking model. The specific flavor of such petri nets is usually referred to as *open petri nets* as we allow interactions between the net and an external simulation environment. Open petri nets have been formally described by Baldan et al. [7] and shown to inherit mathematical properties from regular petri nets such as decidability of reachability.

Table 1 HTA plan archetypes

Type	Aliases	Example
Linear plan	Sequential	Do 1 then 2 then 3 then 4
Any order plan	Non-linear	Do 1, 2, 3,4 in any order
Parallel plan	Simultaneous, concurrent	Do 1, 2, 3, 4 at the same time
Conditional plan	Branching, choice	If X do 1 else 2
Cyclical plan	Repetitious	Repeat 1 until X
Compound	composed, complex	Do 1 then 2, 3 in any order, repeat until X

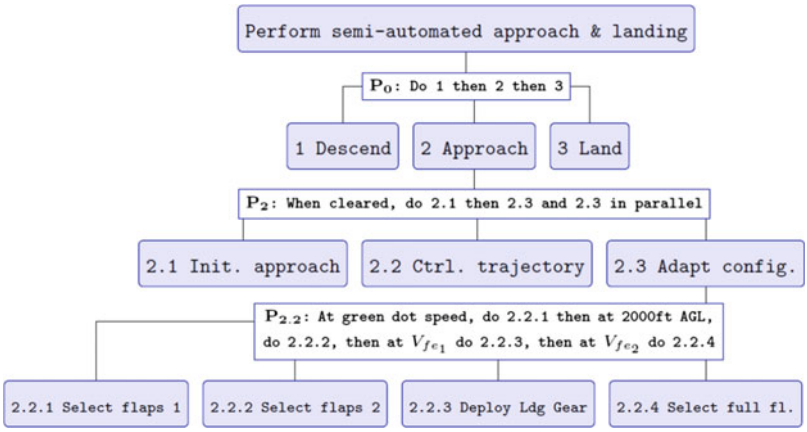


Fig. 1 Example of HTA model with redescription of tasks approach and adapt configuration and associated plans

Potential applications of petri nets mathematical properties are further discussed in Sect. 5.

A petri net—and therefore a plan—is represented by a 4-tuple

$$P_i = (S, T, Pre, Post) \tag{1}$$

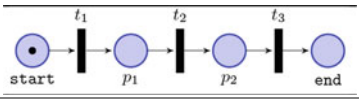
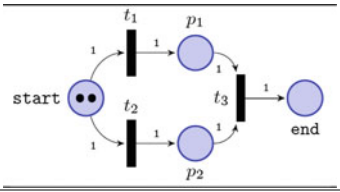
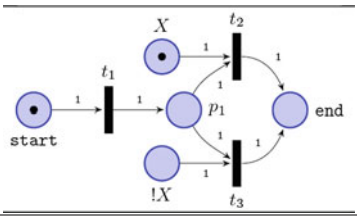
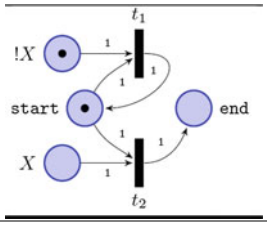
where S is the set of places, T_i the set of transitions, Pre: $P \times S \rightarrow \mathbb{N}$ the set of arcs with multiplicity connecting places to transitions, Pre: $P \times S \rightarrow \mathbb{N}$ the set of arcs with multiplicity connecting transitions to places. A place—graphically represented by a circle—can contain a certain number of *tokens*. The distribution of tokens across places—also called the *marking* of the net—represents the current state of the net. Circulation of tokens through the graph/plan is ruled by the arcs connecting places to transitions and their multiplicity. In the contact of task analysis, transitions represent subtasks and places can be interpreted as preconditions. More details about the execution of the petri net in the context of HTA-based tracking can be found in Sect. 3.

HTA plan semantics can be aligned to *petri nets* in the form of a translation table shown in Table 2. Using these mappings, one should be able to formalize arbitrarily complex HTA plans previously expressed using the traditional pen and paper based HTA terminology.

2.4 Condition Modeling

Both *task* and *plan* semantics rely on so-called *conditions* as a machine-interpretable proxy respectively for the tasks' goal states and plans'

Table 2 Translation table between HTA plans and corresponding petri nets building blocks

Type	Aliases	Example
Linear	Do 1 then 2 then 3	
Parallel	Do 1,2 at the same time then 3	
Conditional	Do 1 then if X do 2 else 3	
Repeat	Do 1 until X then do 2	

Input arc multiplicities correspond to the number of tokens required to fire a transition (start a task T_i), output arc multiplicities indicate the number of tokens produced by the completion of a transition/task. Places labeled p_i represent the post-completion state of task T_i

branching/decision triggers. This formal representation of such condition is out of the scope of this work, and for the purpose of this study conditions were simply implemented as Boolean javascript functions acting on the system state space.

3 HTA-Based Tracking

Tracking a human operator involved in technical operations can take different forms depending on the purpose of such tracking and the assumptions made regarding human behavior. Nevertheless, most tracking methods involve both a model of the phenomenon being tracked and measurements fed into this model. Moreover, Rasmussen's skill, rules, knowledge (SRK) theory of human activity can provide a basic categorization of potential tracking approaches [8].

At the *skill* level, previous work has modeled and attempted to track pilots' actions such as manual flight or driving using parametrized filters and estimators inspired from controls theory. The goal of such an approach could be to provide adaptive controllers to optimize performance of the human-machine system as a whole. Others have used Kalman filters to model pilots' short term memory in the context of loss of control or spatial disorientation [9, 10].

At the *rules* level, tracking can be defined as identifying the current tasks and goals operators are engaged in. The objective is to be able to analyze, detect errors and potentially provide contextually relevant support. A robust tracking at this level is essential to gain an understanding of operators' behavior and is therefore an important prerequisite to safe and efficient human-machine collaboration. Here we propose using computational HTAs to this aim.

This section focuses on the *rules* level as we believe it concentrates many of the Human Automation Interaction (HAI) related problems reported in recent aviation accidents [11]. Also safety assessment of new concepts of operations such as single-pilot operations are likely to rely on effective human systems interaction at this level of granularity.

3.1 HTA Model Dynamics

We define the state of a dynamical HTA model as a mapping from the set of tasks $T = \{T_i\}_{i=1,\ldots,n}$ onto the Boolean domain. It represents the active tasks at a multilevel granularity. As each HTA task is also embedded within a plan described by a petri net, the state of the HTA model if also fully identifiable by the corresponding set of nested petri net markings $M = \{M_i\}_{i=1,\ldots,n}$. Defined as such, HTA dynamics inherit from petri nets the characterization of a discrete event dynamical system (DEDS), with a variable time step defined by intervals between asynchronous events $e_k, k \in \mathbb{N}$. The time schedule of observable events is noted $t_k, k \in \mathbb{N}$. The marking of plan P_i at time t_k is noted $M_i^k = M_i(t_k)$. The dynamics can therefore be summarized:

$$M_i^{k+1} = f_{P_i}(M_i^k, e_{k+1}) \tag{2}$$

where f_{P_i} integrates events according to open petri nets dynamics of plan P_i. In our case, this includes spontaneous token generation in places bound to environment simulation variables and token update caused by asynchronous subtask completion. The Javascript library pnets[1] was developed by the author and used to run petri net

[1] https://github.com/smamessier/pnets.

based HTA models and connect them to a flight simulation environment or any asynchronous remote call.

3.2 HTA State Estimation

A tracking algorithm, also called *estimator* consists of a set of rules to decide of the best next state estimate given the current estimate, a model of the dynamics and potentially inaccurate/incomplete observations. Previous work on Petri net state estimation is mostly focused on fault diagnosis and process control but can also serve the purpose of marking estimation. Giua et al. [12] proposed an algorithm to calculate the minimal explanation firing vector for a given observed transition in the presence of potentially *silent*, i.e. unobservable and/or indistinguishable transitions. Cabasino and Giua [13] extended it to enumerate consistent petri nets markings from a sequence of interleaved observable and unobservable transitions. This algorithm was adapted to fit the computational HTA framework presented in this article. The objective is to calculate the set of consistent states and the set of consistent sequences of unobserved transitions/tasks that can respectively result from and account for observations. In the case of asynchronous petri nets, each observation corresponds to a single event, i.e. a single transition/task T_i. This method also handles the problem of indistinguishable tasks (for instance the same action could occur in two separate branches of the HTA).

3.3 Evaluation Metrics

Two metrics are of interesting when evaluating a computational HTA with respect to tracking: tracking *perplexity* and *surprise*. A good HTA-based tracking session will show low levels of surprise and perplexity when fed with real data. However, one might want to put more emphasis on either one or the other depending of the purpose of the analysis.

Tracking Perplexity. We define the task tracking perplexity p as the average number of active and non-started subtasks in a task's plan throughout completion of the task. Low perplexity will allow a support system to provide highly relevant support and efficiently collaborate with a human operator. High perplexity can be caused by a high degree of task parallelization of a procedure or by a very permissive HTA model.

Surprise. Surprise is defined as the cumulated number of observed tasks (firing of the corresponding transition) that were not activated in the petri net at the time of observation, i.e. not enabled by the estimated state. HTA models leading to low-surprise tracking are either very descriptive of the data or simply very general.

4 Case Study

To illustrate the capabilities of the computational HTA proposed here, a case study was conducted. Seven pilots were tasked to perform an Instrumental Landing Systems (ILS) approach using a preprogrammed flight plan of the RISUN7 approach at Clermont Ferrand airport (LFLC). The experiment was conducted in a Virtual Reality (VR) environment, previously described in [14], thus providing recording of telemetry, pilot actions, head and finger tracking data. The simulated automated flight systems were similar to those of an Airbus A320, five pilots had experience flying Airbus machines and the two others were more familiar with Boeing cockpits. Recorded telemetry and user input data covers—for each pilot—around 15 min of flight from a waypoint halfway through the descent until the

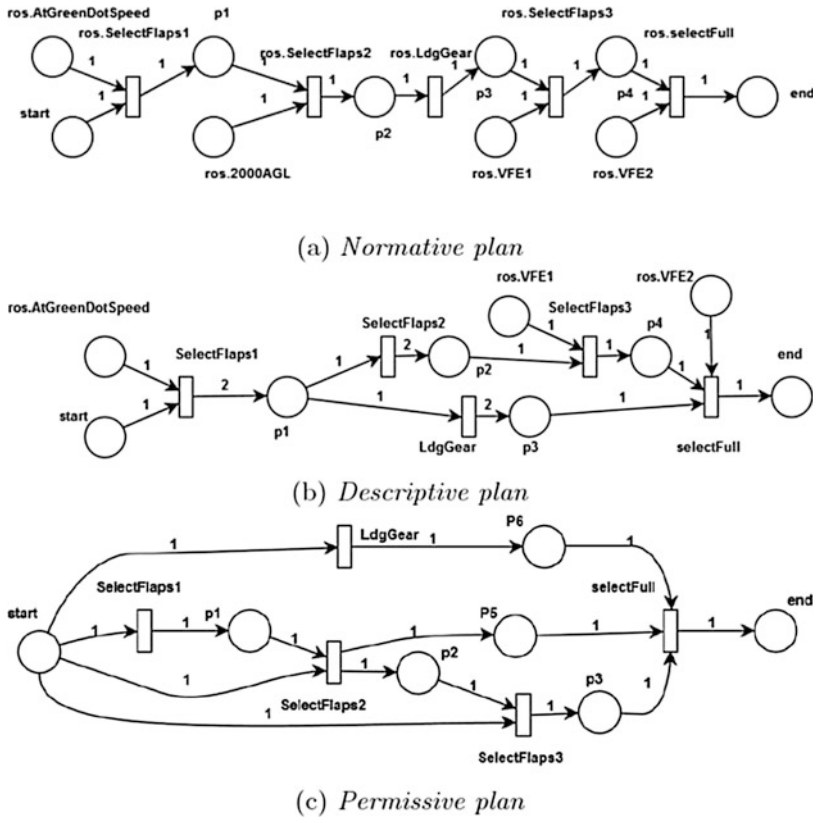


Fig. 2 HTA plans for task adapt aircraft configuration during final approach. Places prefixed with ros indicate nodes interacting with the flight simulation environment. The *normative* plan strictly implements a generic Airbus A320 final approach procedure regarding flaps and landing gear. The *descriptive* approach relaxes the 2000AGL precondition and introduces some degree of parallelization. Finally, the *permissive* plan removes all assumptions regarding subtask order

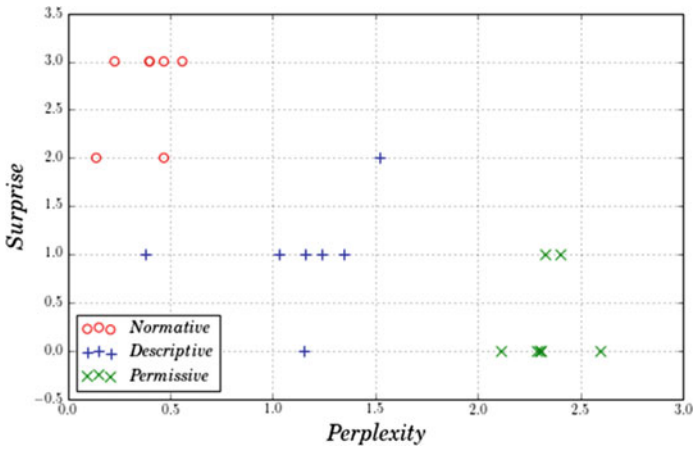


Fig. 3 Tracking performance for the task adapt aircraft configuration in the perplexity x surprise plan plotted for the seven pilots of the case study

actual landing at LFLC. We propose three versions of the plan for the HTA task Adapt aircraft configuration, respectively called *normative*, *descriptive* and *permissive*. The *normative* plan exactly reflects a final approach procedure whereas the *permissive* plan does not assume knowledge about the order of subtask execution. Finally the *descriptive* plan provides a tradeoff, trying to capture best the observed practice as shown in Fig. 2.

We plotted the performance of the tracking of task *Adapt aircraft configuration* in the perplexity x surprise plan for the seven pilots using subsequently the *normative*, *descriptive* and *permissive* plan. As expected, the perplexity is high for the permissive plan and low for the normative. The opposite conclusion holds regarding the occurrence of surprises. Finally, the descriptive plan consistently provides a tracking model balanced across both metrics. The three HTA models—sampled from the high-dimensional spectrum of potential HTA models—provide a good coverage of the perplexity x surprise space and thus open the way to the definition of tailored cost functions and HTA-model learning/optimization (Fig. 3).

5 Applications and Future Work

This type of approach can be used to accurately track trainees' actions during initial simulator flight training and propose online guidance and scenario adaptation. Moreover, a robust HTA model can be highly valuable as a knowledge base for expert agent models engaged in fast simulations, potential integration to Work Models that Computes (WMC) is under investigation [15].

In the case study, three HTA models were compared. Future work will propose a learning method automatically optimizing the *descriptive* model against relevant metrics.

In parallel to improving the robustness of such HTA models, it is also planned to investigate relevant cost functions and decision rules to tune the tracking algorithm depending on the application. Moreover, formal analysis using petri nets mathematical properties will be considered.

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DFS ConceptDesk—An Approach to an Intuitive UX for Air Traffic Control

Thomas Hofmann, Jörg Bergner and Robert Schnuell

Abstract In this ergonomic, experimental case study, the design and implementation of an experimental workplace for air traffic controllers (ATC) is described. It discusses how such a project in the development of new forms of interaction for highly complex and safety-critical HMI workspaces makes sense.

Keywords High-risk work · Shared workspace · Air traffic control · Physical interaction

1 Introduction

The workload of air traffic controllers on the coordination of air traffic is enormous. With increasing air traffic the mental workload will rise in future. Today an air traffic controller has a variety of HMI to interact with. This situation requires a high level of cognitive effort, which makes it difficult to focus on the primary activity of air traffic control.

Therefore, the DFS CONCEPT DESK was designed. This integrated prototype system of hardware and software includes numerous technical display and interaction systems in a homogeneous workplace concept.

The final system consists of two displays (>85″), of which the horizontal display is equipped as a multi-touch display. The entire system is operated via touch input, physical artifacts (avatars)—and hardware keyboard for numerical input.

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The system integrates all content into a homogeneous visualization and interaction methodologies previously presented separate HMI. With the help of this system a lot of different workspaces and different interaction methodologies for the future interaction between air traffic controllers and the air traffic can be evaluated.

1.1 Project Approach

Due to different previous project it was known that the interaction of ATC does not work optimally with the existing technology. The decisions of ATC based on a complex information situation. In the Tower of an hub airport there are up to 11 different hmi systems, the external view and the acoustic information of his colleagues influencing the decision of the ATC (Fig. 1).

The aim of the project was to reduce the variety of information massively with the aim of reducing the cognitive workload of the ATC. The studies focused primarily on the number of technical information (and their heterogeneous data representation) to unify and interacting with these.

Within the project, an experimental workspace should be constructed to:

- Representing consistent interaction principles
- Interpret information for the ATC
- Allow intuitive interaction

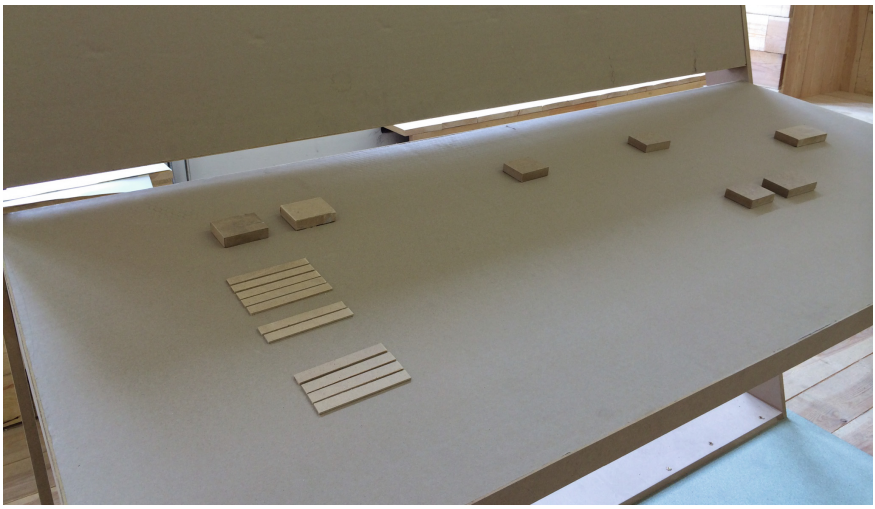

Fig. 1 First cardboard mockup for initial user experience questionnaires and look and feel testings

2 Concept

As part of interdisciplinary workshops different application scenarios were discussed to develop a plausible basis for the development of hardware and software.

The following aspects should be considered the workplace:

- large-scale representations
- flexible task division
- work for 1 and 2 persons
- customization of the GUI

The workplace should be built as a stand-up workplace to achieve the highest possible flexibility for experimentation. The CONCEPT DESK was made up of two areas of work (vertical screen with 83″, horizontal interaction area with 85″). The horizontal workspace should be tilted slightly to the user to increase the readability and facilitate interaction (Fig. 2).

Fig. 2 Second prototype: interactive user experience and look and feel testing's

3 Results

3.1 Design

The CONCEPT DESK was deliberately designed very simple. The focus was on keeping the work area as large as possible. Due to the use of rear projection for the horizontal surface of the table could be designed very delicate. In the vertical two flat screens were used. These screens were covered with a glass pane, which gives the impression of a large screen (Fig. 3).

The GUI of the CONCEPT DESK was drafted only prototypically. The aim was to give users a basic impression of a future interaction. So only fundamental interaction principles were outlined (touch, multitouch) and implemented—the design should not give the impression of a final product. The goal was to involve the user within the design of future HMI systems (Fig. 4).

3.2 Technology

The aim of the project was to give users a realistic impression of future forms of interaction. Thus a fully functional multi-touch environment was developed. There are three different kinds of interactions possible, which are based on infrared detection and Bluetooth communication that were implemented to the CONCEPTDESK.

Interaction with Fingers. On the one hand it is possible to interact with fingers, which is the most natural type of interaction. The user can interact with the GUI with one finger. But the user is even able to use multi-touch features like gestures. Submenus can be opened via those gestures, which have the positive aspect of a better-ordered interface without to much menu buttons for every kind of interactions (Fig. 5).

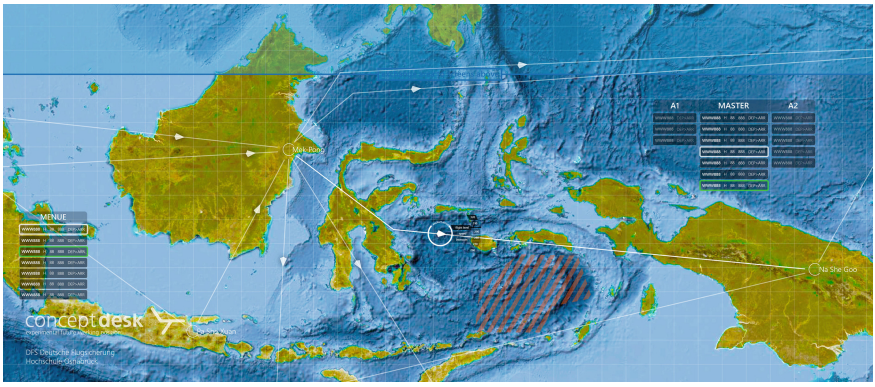

Fig. 3 Example screenshot of the GUI (daylight visualisation)

Fig. 4 Final design of the CONCEPT DESK (computer simulation)

Interaction via an Interactive Stylus. The second interaction parameter is the ability to control the interface via an interactive stylus. The system is able to recognize the position of the stylus on the touch surface of the concept desk as well as the current button stats of the stylus simultaneously. With those functions the user is able to interact with the more high-risk parts of his job. For example transmit new flight levels. The input via fingers is more natural but the most people can effect more precise interactions with a stylus.

The stylus includes a two-step authentication as well. So high-risk interactions will only be executed when the stylus interacts with the surface and an authentication button is pressed on the stylus at the same time. With this feature the user do not have the ability to create false interactions anymore (Fig. 6).

Interaction by Physical Components. The third interaction is based on the interaction with physical components. The desk is able to detect objects, which are placed on its surface. There are two different kinds of application possibilities with this feature. On the one hand the interface is able to detect any object, which is placed on its surface (an can avoid an overlapping of physical objects and digital content). On the other hand the system can handle the so-called ‘avatars’. An avatar is an actively marked object, which can interact with the system and displays a new way of interaction between the user and the desk.

By interaction with ‘avatars’ the user is able to interact with the desk via physical objects which are based in our three dimensional world. The system binds information, functions or menus on those avatars (Fig. 7).

Fig. 5 Example of the working touch interaction (drag and drop of the changing of flight routes)

Fig. 6 Calibration process of the stylus

Fig. 7 Calibration process of the stylus

In this high-risk field of work it is very important that the system will give the user the related information in a almost natural way. So it makes it easier for the user to keep track of all relevant information on the surface. With the ability to bind information not only on a 2D surface but also on real physical objects it makes those information tangle for the users mind. An example of the usage of avatars are 'flight strips'. Currently many ATC work with those paper strips everyday. So it is more naturally for the user to interact in the future with physical avatars which has the shape and the function of those old strips with the possibilities of digital information than rather to transfer the strips into a digital 2D version via 'skeuomorphism'. Another example of the usage of those avatars is the ability to control viewports like the current weather or radar. If the user do not want to interact with those viewports he can easily shift the control avatars of this viewport to the top of the surface so the viewports will appear on the vertical screens.

4 Summary

After just a few weeks of use (workshops, presentations, discussions), the following findings were found:

- The DESK CONCEPT inspires users to develop interaction concepts for the future control of the air traffic
- The presentation of new forms of interaction in the ATC environment leads to an increase in acceptance of appropriate technology

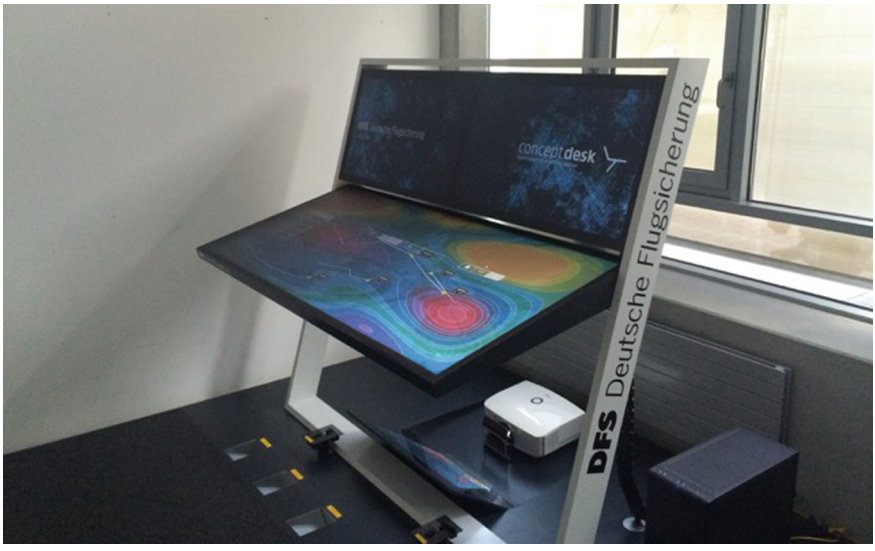

Fig. 8 Final CONCEPT DESK prototype

- Some previously rejected HMI concepts are defined as requirements for future research projects
- Some designed interaction details turn out to be useful in the context of ATC

5 Discussion

Within the project with the DFS numerous findings for future HMI solutions were obtained. So it turned out that it was actually possible to reduce the complexity of the existing interfaces massively. The ATC are open to new interaction concepts. Due to the existence of a prototypical workplace a very constructive and realistic discussion is possible (Fig. 8).

However, the project also shows that a final assessment of the viability of new HMI solutions in the context of such a complex context is not possible. In the following projects detailed investigations shall be made. Due to the special requirements in the ATC environment there is a need for extensive technical tests, simulations and UX evaluation. In a research project just started multi-touch and 'avatar'-based functionalities will be designed and evaluated to analyze very detailed requirements of ATC interaction characteristics.

The Pattern of Upper Arm and Back Movements for Automotive Assembly Operators: Exposure Variation Analysis of Acceleration Data

Mohsen Zare, Benard Mignot, Jean-claude Sagot and Yves Roquelaure

Abstract Upper limb and back injuries are common musculoskeletal disorders among automotive assembly operators which can reduce operators' ability and increase industries costs. Characterizing and quantifying movements and postures of the upper limb and back can discriminate the workload between assembly tasks in the real settings. Characterizing and developing a pattern of movements help to understand the function of body parts and to investigate the reasons of injuries. The aim of this study was, therefore, to characterize upper arm and back movements in the automotive assembly tasks, using accelerometer data and Exposure Variation Analysis. One workstation of a truck assembly plant including various assembly tasks was selected for data collection. Two experienced operators who assembled Selective catalytic reduction (SCR) tank on trucks during the 11 min cycle time were included as participants of the study. Acceleration data were registered by the triaxial accelerometers placed simultaneously on the right/left upper arms and lower back of the participants. Video-recordings of operators' activity were performed and synchronized with the acceleration data. The EVA method was used to plot movements of the upper arms and lower back. The pattern of movements for the arms and back was plotted for various assembly tasks such as tightening, material handling, and inserting (with force). The EVA showed the difference between assembly tasks in term of frequency and intensity which can be used to distinguish the tasks causing either upper limb disorders (such as rotator cuff syndrome) or low

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back pain. Furthermore, transition of accelerometer data in a way that provide meaningful and understandable information has been a challenge in the quantification of workload, and the EVA can illustrate and characterize a pattern of movements and postures during different tasks.

Keywords Physical movement · Upper arms · Characterizing · Exposure variation analysis · Assembly tasks

1 Introduction

Work-related musculoskeletal disorders (WR-MSDs), absenteeism, and poor product quality and productivity are the main challenges of the manufacturing industries which can be related to non-ergonomic situation and physical workload [1, 2]. WR-MSDs is a serious occupational disorders among the automobile assembly workers due to risk factors related to various tasks such as tightening, picking up, lifting, and material handlings. Repetitions, forceful exertion, awkward postures, and insufficient recovery times have been identified as frequent risk factors which mainly influence the shoulder, elbow, hand and low back [3, 4]. To establish an efficient WR-MSDs preventive program which assure less musculoskeletal disorders in the automotive industry, exposure to risk factors should be measured in various tasks and workstations. Furthermore, illustrating risk factors and possible variability within and between individuals/groups will provide precise input for decision makers to find solutions for improving work conditions. Current risk assessment approach used in the automotive industry in general reveal little evidence of exposure dose for awkward body/limb postures and movements, and they are unable to show variation. Previous studies showed that direct measurement methods such as accelerometer provide accurate data in capturing time and intensity of movements [5, 6]. Recent-developed devices such as accelerometer that are small, wireless and inexpensive enable ergonomists to measure operators' movements and activities in a field for long periods of time [7]. Although accelerometer can even measure the smallest movement of operators in a task, the main challenge is how to quantify and illustrate the frequency, magnitude and variation of exposure across time. A method is needed to compute and visualize the data measured by accelerometer in the understandable and meaningful way, particularly for the stakeholders in the automotive industries. Exposure variation analysis (EVA) has been used as a method to quantify variation of muscle activity measured by electromyography across time [8]. EVA provides an approach to analyze exposure (posture and movement) frequency, magnitude and variation during assembly tasks. Regarding the growing application of direct measurement method such as accelerometer for posture and movement measurements, the methods such as EVA is required to meaningfully analyze and illustrate the pattern of accelerometer recordings. The purpose of this study was to measure the movements and postures

of the operators in the assembly workstation by direct measurement method and to demonstrate the application of EVA to accelerometer data for providing a pattern of movement and posture across time.

2 Materials and Methods

One workstation of a truck assembly plant including several assembly tasks was selected for data collection. Each workstation had its own group of operators who worked in this area. The assemblers rotated between workstations every 2 h. The SCR tank had to be assembled on the truck chassis at the workstation under study ("mounting SCR Tank on chassis"). This workstation included the tasks such as manually lifting the reservoir tank (13 kg), connecting hoses and cables, tightening hose clamps and finishing cable routing on the top of the tank. Four operators rotationally performed these tasks; two of whom participated in our study. All subjects consented to participate in the investigation. The cycle time was 11 min, which consisted of the time for performing assigned tasks and recovery time. To measure the movements and postures of the upper arms and back, three sensors were fixed with double-sided adhesive to the body segments of each operator according to the pervious study [9, 10]. Two tri-axial accelerometers were placed in lateral side of the right/left arms in the middle of the humerus (the Y-axis was vertical). The line from the rounded head of the acromion to the lateral epicondyle was measured and divided into two for the placing of accelerometers on the humerus. Another accelerometer was placed with the vertical Y-axis at L3 on the lower back to assess back movement. Each accelerometer was recorded between +1 and −1 g. All of the sensors were connected (wireless) to a data logger attached to the operator's belt that recorded raw signals from the body segments while performing assembly tasks. The accelerometer provided three signals which represented the acceleration (g number, acceleration of earth gravity) at three orthogonal axes of the sensor, sampled at a frequency of 128 Hz. Accelerometer data processing was carried out in Matlab. The primary aim of the data processing was to obtain the flexion/extension and movements of the back and upper arm. Several processes such as calculation of angles and filtering of signals (to eliminate vibrations and micro-movements) were required to analyse accelerometer data. Measurement of angles based on a tri-axial accelerometer was performed according to the literature [9]. To convert Cartesian coordinates into spherical, the following equation was used:

$$\varphi = \tan^{-1}\left(\frac{y}{\sqrt{x^2 + z^2}}\right) \tag{1}$$

A low-pass Butterworth filter of 4th order with cut off frequency of 5 Hz [11] and [12] was used to distinguish periods of activity/rest of a body segment. The signals (φ) were numerically calculated between the angles of −90° and 90°. To classify these angles as a risk factor on the interval of 0°–180°, the values of φ were

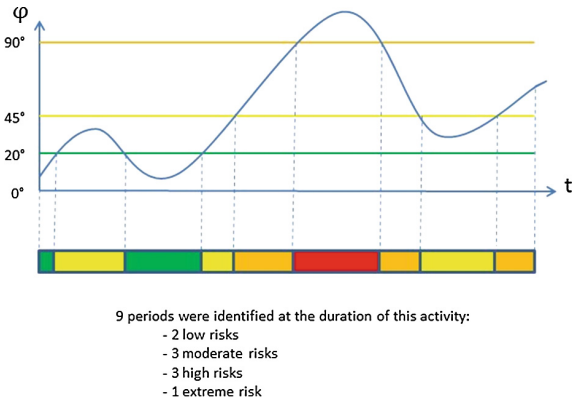


Fig. 1 Time interval over which the angle measured (φ) corresponds to a period of constant risk

added by 90°. The angles measured were classified in several categories according to predetermined thresholds:

- Angles from 0° to 20° were minimum risk (green), 20°–45° moderate risk (yellow), 45°–90° high risk (orange), and >90° extreme risk (red).

At this step, a time interval over which the angle measured (φ) corresponds to a period of constant risk (remaining within the same risk level) was calculated. All measures were calculated and classified based on the duration of time periods and different risk levels (Fig. 1). EVA method was used to illustrate movements and postures of the upper arm and back.

3 Results

Table 1 shows the frequency of time periods at different risk levels for the upper arm and back when two participants performed the same assembly tasks. The cycle time defined by the factory was 11 and 10 min (600 s) of registered data were selected for final analysis. Given sampling rate at 128 Hz, our analysis were performed on 76800 data that were captured during 10 min.

As shown in Table 1, more than 49 % of time periods the left/right upper arms for two participants were classified in the yellow zone (20°–45°). The same results were observed for the back, as 50 % of the time periods were classified in the yellow zone. The number of period shows the rhythm of movements at different risk levels. A high period number indicate that the angle (φ) of a body segment such as the right/left upper arm or back change rapidly between different threshold limit.

Both participants showed similar percentage of time period in the yellow zone, but the percentage of time period was different in the orange zone (45°–90°). The first participant was less exposure for the right arm (13 %) compared to the second participant (25.5 %), and similar results were observed for the back. However, the frequency of time period for the left arm in the orange zone was 23.1 % for the first participant more than the time periods observed (12.9 %) for the second participants (Table 1). For two participants, the number of periods

Table 1 The number of time periods at different risk levels for different body segments of two participants

Risk level	Right arm n (%)		Left arm n (%)		Back n (%)	
	Participant 1	Participant 2	Participant 1	Participant 2	Participant 1	Participant 2
Green (0°–20°)	364 (37 %)	184 (24.6 %)	144 (26.8 %)	249 (37.2 %)	113 (47 %)	90 (44.8 %)
Yellow (20°–45°)	489 (49.7 %)	368 (49.1 %)	268 (49.9 %)	334 (49.9 %)	120 (50 %)	100 (49.7 %)
Orange (45°–90°)	129 (13 %)	191 (25.5 %)	124 (23.1 %)	86 (12.9 %)	8(3 %)	11 (5.5 %)
Red (>90°)	3 (0.3 %)	6 (0.8 %)	1 (0.2 %)	0	0	0
Total	985	749	537	669	241	201

indicates differences on the execution of the task. The right arm has a higher activity for the participant 1 (985 vs. 749 time periods), but the left arm was more active for the participant 2 (669 vs. 537 periods).

None of the two participants presented exposure to extreme risk for the back. High risk exposure was also low. The back was less exposure to WR-MSDs risk factors during the tasks. As for the arms, participant 1 has a higher rate of angle changes between threshold level compared to participant 2 (241 vs. 201 periods). For each participant, the number of periods for the arms is approximately three times higher than for the back. This means that the rhythm of movements at different risk levels of the arm is higher than the back (variations are more frequent).

Table 2 provides exposure variation based on different time periods and risk levels for the first participant. The most exposures were classified in the time period 0–0.5 s and 0.5–2 s which show the fast movements in the short duration of time (less than 0.5 s). The similar results was observed for the right/left upper arm, but the number of fast movements (less than 0.5 s) for the back was less than the upper arm.

Figure 2a, b and c demonstrate Exposure Variation Analysis which is illustrated based on the data from Table 2. Participant 1 had less long periods (>2 s) than participant 2 (54 vs. 74) for the right arm, while reverse results were observed for the left arm (82 vs. 61). Exposure of the right arm to low risk (green) in the long periods (2–5 s and >5 s) was higher for the participant 1 (32 on 54 identified periods) compared to participant 2 (14 on 82 identified periods). However, the opposite results were observed for the left arm. Exposure of the left arm to moderate risk (yellow) in the long periods (2–5 s and >5 s) was higher for the participant 1 (48 on 74 identified periods) compared to participant 2 (29 on 61 identified periods).

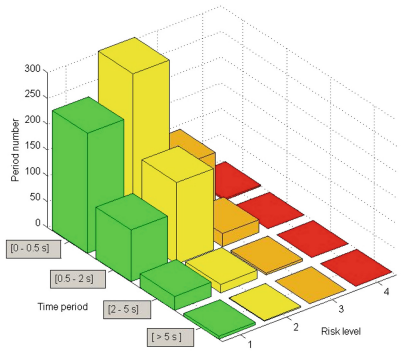
The pattern of movements and postures of the first participant is shown for the assembly tasks in a duration of 10 min. The illustrative column is classified in four class of time duration and risk level (Fig. 2).

Table 3 shows exposure variation based on different time periods and risk levels for the second participant. As similar as participant 1, most exposures were classified in the time period 0–0.5 s and 0.5–2 s which show the fast movements in the short duration of time (less than 0.5 s). The number of fast movements (less than 0.5 s) for the back was less than the upper arm (Table 3).

Table 2 Exposure variation based on duration of time and risk level for the first participant

Risk level	Right arm				Left arm				Back			
Time period	Green*	Yellow	Orange	Red	Green	Yellow	Orange	Red	Green	Yellow	Orange	Red
0–0.5 s	232	313	100	3	92	112	61	1	26	54	4	0
0.5–2 s	100	158	25	0	38	108	51	0	38	48	4	0
2–5 s	27	16	4	0	11	35	10	0	25	18	0	0
>5 s	5	2	0	0	3	13	2	0	24	0	0	0

* Green 0°–20°, yellow 20°–45°, orange 45°–90°, and red >90°



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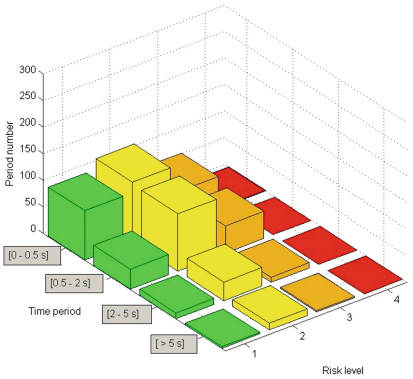

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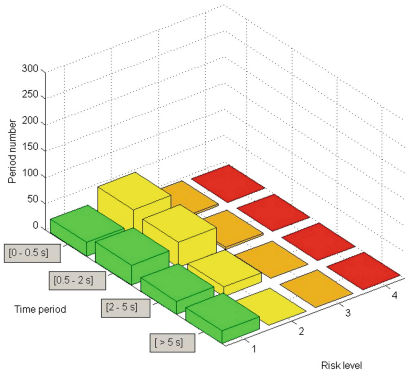

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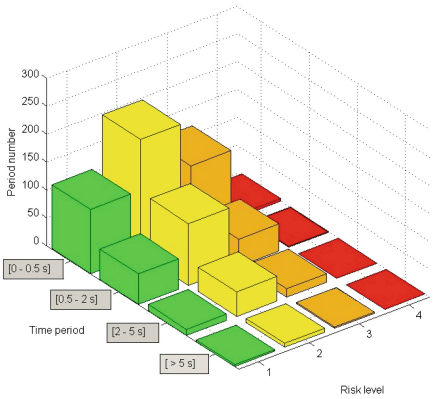
Fig. 2 Exposure variation analysis based on time duration (0–0.5 s, 0.5–2 s, 2–5 s, and >5) and risk level (*green* 0°–20°, *yellow* 20°–45°, *orange* 45°–90°, and *red* >90°) during 10 min of performing assembly tasks for participant 1 for the right arm (**a**), left arm (**b**), and back (**c**)

Figure 3a, b and c demonstrate Exposure Variation Analysis which is illustrated based on the data from Table 3. The pattern of movements and postures of the second participant is shown for the same assembly tasks as participant 1 in a duration of 10 min (Fig. 3).

Table 3 Exposure variation based on duration of time and risk level for the second participant

Risk level	Right arm			Left arm					Back			
Time period	Green	Yellow	Orange	Red	Green	Yellow	Orange	Red	Green	Yellow	Orange	Red
0–0.5 s	115	206	125	5	150	173	60	0	33	72	6	0
0.5–2 s	55	111	49	1	71	132	22	0	16	27	5	0
2–5 s	11	44	15	0	18	22	4	0	12	1	0	0
>5 s	3	7	2	0	10	7	0	0	29	0	0	0

* Green 0°–20°, yellow 20°–45°, orange 45°–90°, and red >90°



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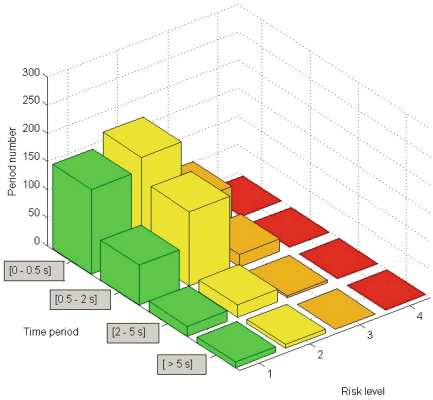

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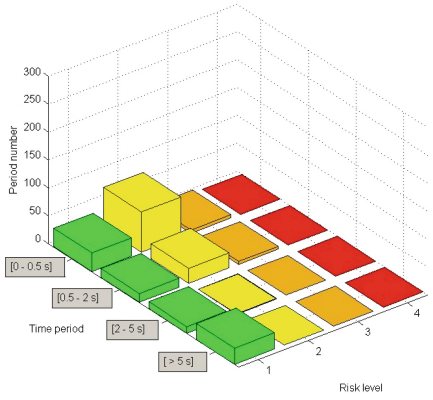

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Fig. 3 Exposure variation analysis based on time duration (0–0.5 s, 0.5–2 s, 2–5 s, and >5) and risk level (*green* 0°–20°, *yellow* 20°–45°, *orange* 45°–90°, and *red* >90°) during 11 min of performing assembly tasks for participant 2 for the right arm (**a**), left arm (**b**), and back (**c**)

The most proportion of period number for the back in the low risk (green) category was observed in the long period (>5 s) for participant 2 (29 on 90 identified periods), while this proportion was lower for the first participant (24 on 113 identified periods).

4 Conclusion

Accelerometer data provide precise information to assess movements and postures of the operators and can be considered as a valuable tool for better understanding the reasons of musculoskeletal disorders in the assembly tasks. However, the main challenge is to provide data in a way that would be understandable and meaningful. The EVA method is proposed in the previous literature to demonstrate the pattern of either muscle activity (measured by electromyography) or physical activity (measured by accelerometer) for various jobs [7]. The EVA was used in this study as an illustrative tool to demonstrate the pattern of movements and postures for the upper arm and back. The results explain the application of the EVA for two participants of an automotive assembly workstation. Movements and postures for the upper arm and back are classified based on risk level and the duration of time period. The pattern of movements in a series of assembly tasks revealed a classification in the short duration of time (less than 0.5 s), particularly for the upper arms. The comparison between subjects showed the different pattern of exposure, as velocity and repetition of movements were different.

Small number of participants and measurements (2 participants and 3 sensors) in this study makes it difficult to show the real workload at this workstation. However the EVA is a useful method for capturing the pattern of movements and postures based on accelerometer data which illustrate exposure, repetition and even velocity. Reducing a large number of data collected by accelerometer into meaningful and analyzable information, the EVA method can be proposed to use largely in the manufacturing industry to visualize the pattern of movements and postures for the various body segments. It is suggested to investigate data of more workstations and participants for future study. Furthermore, it should be considered the other body segments in the analysis.

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Repetitive Working in Slaughterhouses: The Esthesiometry Use of the Hand as a Proposal for Assessing Levels of RSI Compression Syndromes of the Upper Limbs

Pedro Reis, Antônio Moro, Diogo Reis and Eliane Ramos

Abstract This is a descriptive, exploratory and cross-sectional study aimed at determining the predictive value of esthesiometry for diagnosing compressive neuropathies of the upper limbs in freezer warehouse workers. Participated in the study 300 workers aged from 20 to 50 years who work for more than 12 months in poultry slaughterhouses, whose work activities are characterized by repetitive movements and prevalence of biomechanical requirements. Data collection used esthesiometry resources to determine the sensitivity of the hand of workers; the use of a dynamometer to verify and assess the handgrip strength, and the use of a questionnaire to record socio-demographic characteristics of participants. As statistical criterion for analysis, descriptive statistics and the ROC curve (Receiver Operating Characteristic) were selected in order to identify the best cutoff point handgrip strength value and the result of hand esthesiometry to indicate the presence of RSI in the upper limbs. The results indicated that the handgrip strength is efficient in diagnosing RSI by compression syndromes in 77.67 % of cases for the right side of the body and in 71 % of cases for the left side of the body. Thus, considering the analysis by statistical method by applying the ROC curve, the esthesiometry procedure used as predictive diagnosis was characterized as the best criterion for the early identification of RSI by compression syndromes in the upper limbs. Thus, esthesiometry seems to be an easy-to-apply quantitative tool able to identify changes in sensitivity even before the onset of RSI, providing more

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accurate objective results when compared to the handgrip strength, both for its diagnosis and follow-up, which can be used in slaughterhouses safely and effectively.

Keywords Esthesiometry · Slaughterhouses · Repetitive strain injury (RSI)

1 Introduction

Assessing the sensitivity of the median nerve is important in preventing neuropathy, since early diagnosis can prevent further median nerve compression—CNM [5]. In the distal regions of the peripheral nerves, are the sensory receptors for heat, cold, pressure, touch and pain which are interpreted in the cerebral cortex in order to elicit the adequate motor responses to stimuli. Consequently, when the nerve conduction is affected, there will be an inadequate response to the stimulus [8, 10, 12, 14, 18, 21].

Therefore, muscle functional capacity depends solely on the integrity of a neural pathway. Thus, when the neural pathway is compromised begins muscle atrophy, decreasing volume, loss of strength and sensitivity [1]. As a result, damage in the median nerve pathway can affect upper limbs (UL) function [21].

The human hand is a multifunctional organ, able to perform gross and fine movements. The upper extremities great sensory capacity is essential to carry out the activities of daily living (ADLs). However, it becomes ineffective in performing such tasks if the nerve conduction suffers an injury, impairing all of its functionality [13, 22].

The median nerve arises from the brachial plexus in the roots of C5 to T1, and its motor functionality depends on the upper limb adequate innervention [17]. Thus, the median nerve innervates the hands including portions of the first, second third and forth fingers and the palm [19].

According to Netter, the median nerve is the primary dermatome responsible for motor function of the hand, and when compressed in the carpal level, a common pathology arises in the workplace, affecting mainly females, called Carpal Tunnel Syndrome [19]. Along the median nerve pathway, compression can occur in several points, causing other conditions such as pronator teres syndrome and anterior interosseous syndrome.

The median nerve innervates the long palmar, flexor carpi radialis, flexor digitorum superficialis and deep flexor of the index and middle fingers, and pronator teres and quadratus [14]. Therefore, when the median nerve is affected, grip strength will be impaired [3, 11].

Results of handgrip strength in women in the dominant hand present average values between 27.5 [16] and 28.5 kgf [2]. According to Morrow, handgrip strength values less than 18 kgf in the left hand, and 22 kgf in the right, are considered "poor" values for women [2, 7]. Values less than 24 kgf may indicate handgrip deficit in females [17]. Therefore, grip strength, when properly evaluated, can be useful in assessing the functional capacity of the hand [20, 21, 24].

The difficult clinical characterization of median nerve compression CNM in its early stages, and the subjectivity of pain intensity, reinforces the need to develop a reliable method for diagnosis. Therefore the aim of this study was to analyze the effectiveness of esthesiometry and handgrip strength, in identifying and characterizing the CNM, in women performing repetitive movements in the slaughterhouse work setting.

2 Method

This is an exploratory descriptive research with a correlational approach. The sample consisted of 300 female workers, 20–50 of age (± 8.3 years), and predominantly right hand side dominant. The study included participants that were employed for more than 12 months, and performed repetitive tasks in the work station. Participation of the subjects in the study was voluntary, and informed consent was signed.

Exclusion criteria included pregnancy, traumatic neuropathy, leprosy, diabetes, neurological disorders and any surgical intervention in the UL within less than six months. Descriptive statistical analysis and ROC (Receiver Operating Characteristic) was performed, using SPSS version 15.0. Research approved by the Human Research and Ethics Committee, certificate number 2098, FR437763 by CEPSH/UFSC.

2.1 Grip Strength Assessment and Median Nerve Sensory Perception

The protocol for conducting handgrip strength evaluations was in accordance with the norm of the Brazilian Association of Hand Therapists and Upper Limb Rehabilitation. Hand grip strength was measured using the Jamar® dynamometer, set in the 2nd position [1, 6, 20, 23].

Due to the differences in age, the handgrip strength was analyzed following recommendations for females in the age range of 15–59 years old [17]. During the assessment the workers were positioned in sitting on an adjustable bench, with thighs supported on the seat and both feet touching the ground, ankles in neutral position, knees flexed at 90°, back supported, and hips at 90° of flexion (Fig. 1).

Regarding the handgrip strength assessment, during evaluation the subject maintained elbow in 90° of flexion, shoulder slightly abducted, forearm in neutral position, wrist in 0º–30º of extension and 0º–15º of ulnar deviation. The participants were verbally instructed to perform a grip with maximal effort. There were three attempts, and the higher value was recorded. The pause between repetitions was 60 s. All workers were assessed by the second hour after the start of each work

Fig. 1 Evaluation procedure for assessment of median nerve sensitivity utilizing esthesiometry (Semmes-Weinstein SORRI®) and handgrip strength assessment, utilizing the JAMAR® dynamometer

shift. The first shift "A" starting at 03 h:25 and "B" starting at 04 h:43; second shift "A" starting at 13 h:02 and second shift "B" at 14 h:45.

Esthesiometry was performed for sensory assessment (Fig. 1) with the use of Semmes-Weinstein SORRI® monofilaments. This instrument consists of nylon filaments, with heterogeneous thicknesses and same length dimensions. When applied on the skin causes a pressure measured in grams, 0.05 (thinner monofilament) and 4.0 g (thicker monofilament) [8, 15, 20, 26].

During the assessment the participant hands were supported; pressure on the skin was applied with the filament for 2 s, on the median nerve innervated area (Fig. 1), with an interval of 1.5 s between applications. The participant field-of-view was restricted during the procedure to avoid any visual input. Area with calluses, scar tissue and ulcers were avoided. The assessment started with the thinner filament (0.05 g) repeating the test three times consecutively. Once the participant was able to perceive the stimulus answering "yes", the filament number was recorded.

2.2 Assessment of Median Nerve Compression

In order to assess the MNC level an interview questionnaire was conducted. The questionnaire was prepared in accordance with the guidelines of the Technical Standard for assessment of disability, established by the Ministry of Social Welfare which establishes the stages of RSI/MSDs from 1 to 4 [5, 20, 26]. Stage 1 does not

present clinical signs and allows the worker complete recovery to return to work the next day. However, workers classified at this stage were considered healthy. Workers classified in the stages 2, 3 and 4 were considered, in this study, as having MNC. In order to better quantify the pain intensity, an adapted Borg scale (2000) was used, which ranges from 0 to 10. The pain level was classified as minimal pain (0–3), Moderate pain (4–6), Severe Pain (7–8) or unbearable Pain (9–10).

3 Results

3.1 MNC Stages

Regarding the median nerve compression level (CNM), 157 participants (52.33 %) were in the Stage 1, 68 (22.67 %) at Stage 2, 62 (20.67 %) at Stage 3, and 13 (4.33 %) Stage 4, totaling 143 participants (47.67 %) presenting with MNC. Individuals on stage 1 can recover with rest periods, which is not true for more advanced stages [4, 21].

Prevention of progression to advanced stages can prevent loss of strength, swelling, loss of numbness, pain, inability to perform ADLs, psychological disorders, depression, and continuous use of medication [20].

3.2 Handgrip Strength and Esthesiometry Values

The results showed 41.67 % of workers classified as having "poor" handgrip strength, which can be a contributing factor associated with compression syndromes of the upper limbs (Fig. 2). According to Magee [17], values lower than 21 kgf are considered "poor" for women. Handgrip strength can be a predictor of compression

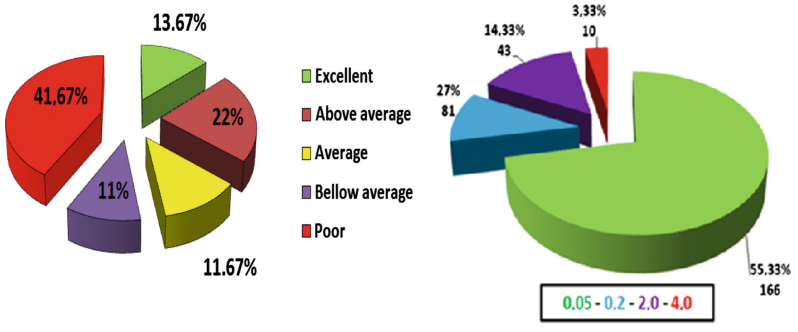

Fig. 2 Results of the assessment of the handgrip strength and esthesiometry for evaluation of median nerve impairment

syndromes of the upper limbs, since compression of the peripheral nerves of the UL contributes to loss of grip strength.

According to Fig. 2, the esthesiometry revealed median nerve adequate sensory perception at the right UL in 166 (55.33 %) individuals, and 134 (44.67 %) with sensory deficits, were 81 (27 %) presented level 2, with 0.2 g pressure, 43 (14.33 %) individuals at level 3 with 2.0 g pressure, and 10 (3.33 %) at level 4, with 4.0 g pressure presenting total sensory loss.

According to the results, 53 workers (17.66 %) were in the advanced stage of sensory loss and may present compression syndrome of the median nerve, which can be detrimental for all activities that require performing handgrip and flexion movements [14]. Nerve damage can contribute to motor and sensory disorders, mainly affecting strength and sensitivity [25].

The values of the area under the ROC curve and confidence intervals (95 %) are related to the criteria for the use of esthesiometry and preen are manual force as predictors of Carpal Tunnel Syndrome. According to Reis and Moro, isometric grip force of the fingers is an important clinical sign of upper limb function, when weak innervation of the median nerve decreases handgrip strength, compromising both flexion and extension [20].

Although the literature presents handgrip values that vary depending on age, biological individuality and sex, the lower strength values, regardless of age, for females range from 21 to 24 kgf [2, 16, 17, 21]. Therefore, grip strength values under 21 kgf should be investigated, due to the possible association with the presence of MNC.

3.3 Analysis of Handgrip Strength and Esthesiometry Values Through ROC Curve to Investigate the Presence of MNC

The values of the area under the ROC curve and the respective intervals and confidence (95 %) are related to the criteria for the use of esthesiometry and preen are manual force as predictors of carpal tunnel syndrome. In this sense, the Roc curve cutoff points indicate the best fit between the sensibility and specificity of use of the two tested evaluation protocols. It was used as a pattern Level 1 “N” of 157 healthy workers, and Levels 2, 3, 4, “N” of 143 workers diseased.

Regarding the handgrip values, the data showed the cutoff point with the best fit for the indication of the presence of MNC, with the condition being equal to or greater than four (≥4), with an area under the curve of 0.779 (95 % CI: 0.724; 0.833) demonstrating a reasonable diagnosis. This corresponds to values below the average, in which there were a total of 11 % of workers, and a total of 41.56 % with “poor” values. Therefore, 52.67 % of the workers would be identified as having MNC. However, 81.82 % of these workers were classified as having the condition

(sensitivity), and 73.89 % as healthy (specificity). The test appeared to be 77.67 % efficient in identifying the condition.

The cutoff point with the best fit for an indication of the presence of CNM through the esthesiometry was the value equal or greater than two (≥2) for both sides. The ROC curve showed an area of 0996 (95 % CI: 0.940, 0.990), which suggest reliability of the esthesiometry test. Among the workers 47.67 % (n = 143) presented MNC, and the esthesiometry indicated the presence of MNC in 44.67 % (n = 124). Accounting for the total number of participants the test identified 93.01 % of those with MNC, and among the considered healthy, all were correctly classified with 96.67 % efficiency.

4 Conclusion

The handgrip strength showed a relative likelihood for indication of CNM. However, esthesiometry showed greater efficacy in the diagnosis. Thus, as an affordable instrument and of easy application and acceptance by the participant, the esthesiometry of the peripheral nerves through the monofilaments presented consistent and reliable data, and can be used as a reliable tool to diagnose the presence of MNC in the slaughterhouses.

Therefore, through specific protocols, the site of compression can be identified, as well as the type of compression syndrome. The most common affecting females is the carpal tunnel and pronator teres syndrome. Another important factor is the identification of diseases due to neural compression in the slaughterhouse setting. The study showed the need for early screening of workers, to prevent the increase in incidence of these conditions. Currently most of Brazilian slaughterhouses do not perform preventive screenings.

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Work-Related Musculoskeletal Disorders Among the Hairdressers: A Pilot Study

João Cruz and Mónica Dias-Teixeira

Abstract The amount of data and research effort to indicate the MSDs among hairdressers has been limited. This study aims to describe the work-related musculoskeletal disorders among on-job hairdressers, by identifying the body regions associated with significant discomfort. The study was conducted with thirty professional hairdressers. Self-reporting work related questionnaire on MSDs to develop, were distributed in hairdressing of Setubal (Portugal). The results from the study show that all of hairdressers reported spine discomfort, followed by discomfort in the shoulders (83 %), hands and wrists (43 %) and lower limbs (30 %). The main causes of these symptoms is the standing posture throughout the workday, repetitive movements and the maintenance of high upper limbs during prolonged time. Within the limitations of the study, it reveals that there is no relationship between the increased level of discomfort with age or with working hours. More research is needed on musculoskeletal problems with hairdressers and beauticians with an emphasis on a larger sample.

Keywords Work-related musculoskeletal disorders (MSDs) · Ergonomics · Hairdressers

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1 Introduction

The musculoskeletal system is a complex entity, composed by muscles, tendons, the skeleton, cartilage, ligament, nerves and blood vessels. In addition to supporting the weight of the body, bones work together with muscles to maintain body position and to produce controlled, precise movements. Without the skeleton to pull against, contracting muscle fibers could not make us sit, stand, walk, or run [1]. Coordination, balance and muscle tone are all dependent on a stable posture—in all bodily situations [2]. Movements run constrained, awkward or poor cause muscle fatigue even when the work activity does not require high muscle forces. Also, the mechanical load on the spine and joints is higher in these postures [3, 4].

So, awkward postures, repetitive work, or handling heavy materials often are significant contributors to leading to musculoskeletal fatigue, pain or other kinds of disorders [5–7]. Work-related musculoskeletal disorders (MSDs) are mostly cumulative disorders.

They result from repeated exposure to high or low intensity loads, over a certain period of time (several months or years, in many cases). Because individuals often repeat actions or spend long periods of time carrying out work activities in awkward postures, or with intense mental stress throughout the work day, many MSDs are associated with labor.

The nomenclature MDSs was first used in the late 50s, to designate a set of diseases, syndromes and/or musculoskeletal symptoms that particularly affect the upper limbs, relating its emergence with the process work [8–10].

Upper limbs (the hand, wrist, elbow and shoulder), the neck and lower back are particularly vulnerable to MSDs.

MSDs are episodic—the pain often subsides or disappears, only to recur later. Many MSDs are transient, with symptoms disappearing with rest or change of activity. But some MSDs may become persistent or irreversible.

Higgs et al. [11] described the age influence on the frames of MSDs, remembering the importance of this factor in the pathogenesis of some degenerative musculoskeletal pathologies. The number of work-related MSD complaints increases with age [12]. At the age of 55–64 the number of self-reported symptoms is 1.7 times higher than at the age of 25–34 years [13].

In some studies there was no significant association between sex and outcome of MSD [14, 15].

However, the risk of male workers suffering from an MSD is 1.3 times higher than the risk of female workers: 35/100.000 compared to 27/100.000. In terms of references work-related MSD complaints, the risk is only slightly higher among male workers (1.07 times higher) [16].

Factors contributing to MSDs includes excessive use of force, repetitive work, working in awkward postures, vibration, working in cold environments, and prolonged sitting or standing. They are also affected by levels of stress, autonomy and support from colleagues, individual's prior medical history, physical capacity and

age, and social factors such as leisure activities. These factors may act uniquely or in combination [17].

MSDs are the work-related health problem with the highest impact on sickness absenteeism in Europe; 39 % of total sickness absence of 2 or more weeks is due to work-related MSD symptoms (in comparison, 19 % of total sickness absence is due to stress, depression and anxiety). MSDs are also the work-related health problem with the highest impact on permanent incapacity; 61 % of permanent incapacity is due to MSDs (compared to 10 % due to stress, depression and anxiety and 10 % due to cardiovascular disorders). Almost 24 % of workers who have suffered from a work-related MSD complaint in the past 12 months have a sick leave period between 1 and 13 days. 11 % have a sick leave period between 2 weeks and 1 month, and a little more than 20 % have a sick leave period of more than 1 month [18].

The first studies were described in "occupational cervicobrachial disorder" in cash register operators, driller's card and Japanese typists; in Australia, described "occupational overuse injury" in typists and workers of the assembly line; cases were subsequently referred to "cumulative trauma disorders" in workers exposed to cumulative trauma, including operators of video display terminals in the United States of America [9, 19].

Several groups of workers have been identified at risk of developing MSDs, including: telegraphers [20, 21], workers of the assembly line [22], sand core making workers [7], brick field workers [23, 24], machine register operators [25], typists, telephone operators and other administrative workers [21], Americans echocardiographists [26], workers in the fish-processing industry of Thailand [27], workers in arts and illustrations [28], Norwegian workers of food production and administrative services [29], cameraman's of American journalistic enterprises [30], workers of Sweden's electrical equipment industry [31], nurses [32], workers with mental disabilities (packaging cutlery, carpentry/joinery, stuffing, industrial laundry, ironing, gardening, and aid to patient transportation) [33], workers in construction [34], graduates in pathological anatomy, cytological and thanatological [35], physicians, surgeons and dentists [15, 36] and workers in the Cutting and Frames area [37]. Within this context are the hairdressers, versatile professionals who work in extremely irregular hours, and most often in uncomfortable positions. Therefore, it is necessary to alert and pay special attention to these professionals because their work involves numerous risk factors for health, mainly because they spend the entire workday in the standing position. Thus, considering that this group presents several risk factors for developing this syndrome due to the peculiarities of their work, as well as the small number of scientific publications on MSDs in professional hairdressers, there was an interest in investigating the relationship of the work of these professionals with the onset of diseases as a way to help expand scientific knowledge in this area and improve the quality of the working life of a professional hairdresser.

This study aims to determine the presence of symptoms of MSDs in professional hairdressers in Setubal District, as well as observing the most affected anatomical regions and trace the socio-demographic profile of study participants.

2 Methodology

Descriptive and cross-sectional study, verifies the conditions of the present moment estimating the prevalence of an event (musculoskeletal disorders) in a specific population (hairdressers).

2.1 Subject Selection

Thirty professional of hairdressers were invited to join this pilot in Setubal District using a hairdresser-oriented musculoskeletal questionnaire developed for this study. The predominant age was between the 20 and 64 years old; approximately 40 % of hairdressers are between 10–19 years, 30 % up to 9 years, 17 % were 20–29 years old, and 13 % had more than 30 years of experience. The mean working hours was 9 ± 2 h per day. All subjects are right handed.

2.2 Hairdresser's Oriented Musculoskeletal Questionnaire

A hairdresser-oriented musculoskeletal questionnaire was conducted. The questionnaire was divided into three sections: demographics, work history, and symptoms and injuries. To assess the presence of persistent musculoskeletal symptoms, the initial screening question was "have you experienced any recurring symptoms such as pain, aching or numbness". An affirmative response also generated a series of further questions to establish onset, quality, frequency, duration, and the intensity of the symptoms, and a history of injury to that particular body region. In this population, injuries were suspected of being a common cause of musculoskeletal symptomatology. Consequently, another set of questions was used to characterize injury to individual body regions.

The survey data were collected and analyzed using SPSS version 21. Because the sample size is small, non-parameter analyses, such as the Pearson χ^2 test was applied to these raw data. Analyses included descriptive statistics.

3 Results and Discussion

3.1 Reliability

Reliability participants were recruited from the same beauty salon and were asked to complete the questionnaire at two different times approximately 4 weeks apart. Intra-class correlation coefficient (ICC) kappa and sensitivity were used as measures of validity and/or reliability.

The reliability of the questionnaire was assessed with the test-retest method. The areas addressed included questions of work-related musculoskeletal symptoms, and of work conditions items. The results showed that for these sections of the musculoskeletal symptom and work history questionnaire the observed agreements ranged from 72.5 to 95.0 %, and the calculated kappa estimates ranged from 0.50 to 0.80. Injury to body regions and job specialty had the highest kappa values of K = 0.72. The hairdresser-oriented musculoskeletal questionnaire approach has represented a very high level of reliability on a five-point scale (Cronbach's alpha = 0.95). Therefore, the results collected, based on a step-by-step confirmation approach, are reliable.

3.2 Discomfort in Body Regions

All hairdressers reported spine discomfort, followed by shoulder (83 %), hand and wrist (43 %), these being the most used by these professionals at work, and lower limbs (30 %). This result validates a level of discomfort among body regions as being the same as in previous research by Wu et al. and Chuang. Moreover, 90 % reported a "moderate-to-strong" level of spine and shoulder discomfort. These dates were confirmed by other authors [38]. Therefore, among hairdressers, the spine and shoulder regions are the most likely to suffer bodily discomfort.

3.3 Symptoms and Risk Factors

The study investigates the symptoms of discomfort reported by the hairdressers. The results showed that 77 % of hairdressers reported arthritic pain in the cervical column and dorsal column (17 %). The results showed a prevalence of painful symptoms between 3–4 years in 30 % of hairdressers; and 5–6 years in 20 % of hairdressers. But most important is that 20 % of hairdressers feel pain for over 10 years. No association between the pain in the spine and years of service was found ($p = 0.57$; $\alpha = 0.05$). Therefore, working experience may not be a risk factor which results in discomfort of body regions. Significantly 47 % of hairdressers seek help from others to perform work tasks and 23 % modified their stance.

The etiology of pain focuses in the excess of working hours (97 %); stress (83 %) elevation above shoulder level objects (63 %); hand as wrists in intense effort (63 %); and working in posture torsion of the body constantly (53 %). Also no association between the pain symptoms and the age ($p = 0.23$; $\alpha = 0.05$) and number of customers per day ($p = 0.80$; $\alpha = 0.05$). Most hairdressers (77 %) perform their tasks standing, 17 % work sitting with rotation of the spine and 7 % sitting with the elevation of the upper limbs. 43 % of hairdressers indicate that they perform movements that are repeatable and unique and 30 % reported to be repetitive and dynamic movements. 60 % of hairdressers elevate objects above

shoulder level. Also no association between the anatomical areas affected by pain and to mode of execution tasks ($p = 0.88$; $\alpha = 0.05$), the classification of movements ($p = 0.85$; $\alpha = 0.05$) and the elevation of objects above shoulder level ($p = 0.70$; $\alpha = 0.05$).

Only in 13 % of hairdressers pains disappear when they are away from work tasks. Regarding the time of disappearance of pain, the data showed that 54 % of hairdressers report that the pain disappears within 3–5 h after the end of job, and 32 % within 6–9 h. The pain occurred in conditions of the job are manifested as a feeling of discomfort, localized or not, end of journey or during peak production, which sometimes improves, to rest or to decrease the rate of work [39].

4 Conclusions

The result indicates that most discomfort body regions were the cervical column and shoulder. The main cause of these symptoms are standing posture throughout the workday, repetitive movements and the maintenance of high upper limbs during prolonged time. Moreover, the study reveals that there is no relationship between the increased level of discomfort with age or with working hours.

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Part II
Physical Ergonomics in Design

Effect of a Functional Garment on Postural Control for Adolescents with Early Scoliosis: A Six-Month Wear Trial Study

Joanne Yip, Pak-Yiu Liu, Kit-Lun Yick, Mei-Chun Cheung, Chi-Yung Tse and Sun-Pui Ng

Abstract Postural alterations that are associated with the orientation of the head, shoulders, scapula, and pelvis in the three basic planes of the human anatomy are commonly found in adolescents with scoliosis. Yet there is a lack of functional garments in the market specifically designed for postural control to address early scoliosis in adolescents. The purpose of this study is to determine the effectiveness of a functional garment for girls aged 10–13 who have the early stages of scoliosis. The effects of this functional garment on postural changes are investigated in this study. Nine subjects have been recruited to take part in the study. A wear trial has been undertaken for 6 months to evaluate the effectiveness and practical use of the posture correction girdle by 3D motion capturing and 3D body scanning. After carrying out the 3D motion capturing, significant postural improvements are mainly found in the acromion and pelvis as observed from the frontal plane during standing, the back angle as observed from the sagittal plane during sitting, as well as control of the maximum range of anterior and lateral bending. After implementing the 3D body scanning, it is found that there is no significant change in the rotation angle in the

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horizontal plane due to a large standard deviation. The design of the functional garment is found to better control the acromion. The effectiveness of the girdle on postural changes could be affected by compliance, growth and curve type.

Keywords Posture · Scoliosis · Functional garment

1 Introduction

Posture describes the orientation of any body segment relative to the gravitational vector; that is, as an angular measure from the vertical [1]. Adolescent idiopathic scoliosis (AIS), which affects posture, is characterized by three-dimensional geometric deformations of the spine and rib cage that can lead to changes in the relationship between body segments [2]. Alterations in body posture are commonly found in AIS, including those associated with the orientation of the head, shoulders, scapula and pelvis in all three basic planes of the human anatomy [3]. The severity of postural imbalance and instability might be possible factors that are associated with the progression of spinal curves [4–6]. Hence, postural control, correction or training could be useful in controlling curve progression during the rapid growth period of adolescents with AIS.

In general, AIS patients are recommended to undergo different types of treatments which depend on their spinal situations and stage of scoliosis, e.g. (1) surgery for patients with a spinal curve that is greater than 41–50°, (2) bracing for patients with a spinal curve between 21 and 40°, and (3) observation with periodical spinal re-examination for patients with early scoliosis (spinal curve between 6 and 20°). However, researchers believe that other types of treatments or measures can be viable for adolescents with early scoliosis as opposed to only observation. "Posture reminders" from parents or provided through training devices for maintaining good posture are other options that are considered to be acceptable prophylaxis [7, 8]. The rationale of postural correction and control is to encourage patients to use their back muscles to keep the spine within its natural curvature. Consequently, the corresponding symptoms of imbalance in posture may be prevented with awareness and the patients may learn good postural habits that can be carried over throughout their entire lives [8–10].

Gur et al. [11] studied the effect of a spinal brace on postural control in patients with AIS in different sensory conditions and found that the brace improves postural stability. However, this kind of brace highly constrains body movement and may not be suitable for adolescents with early scoliosis. Our previous preliminary work shows that the posture of those with AIS could be immediately improved by wearing a tailor-made soft girdle [12, 13]. In the present study, a wear trial of 6 months has been undertaken to evaluate the effectiveness and practical use of this posture correction girdle as a form of postural control for AIS. The changes in posture are examined by 3D motion capturing and 3D body scanning.

2 Methods

2.1 Subjects

A screening program was carried out in Hong Kong during 2012 to 2014 with 8 schools and the target population was 10–13 year-old females. During the examination process, the subjects were invited to perform Adam's forward bending test and an OSI scoliometer was employed to measure the angle of trunk inclination (ATI) in the spine of the subjects while lying prone, in order to preliminarily assess their spinal conditions [9]. In total, out of the 497 participants who were screened, 109 were found to have an ATI ≥3 (21.9 %). The age and BMI distributions of the screened participants are summarized in Table 1. The participants were assigned to

Table 1 Age and BMI distributions of screened participants

Age	Group	Underweight		Normal weight		Overweight		Total	
10	N	15	23.4%	36	56.3%	13	20.3%	64	100%
		93.8%		80%		76.5%		82%	
	P	1	7.1%	9	64.3%	4	28.6%	14	100%
		6.2%		20%		23.5%		18%	
	Total	16	20.5%	45	57.7%	17	21.8%	78	100%
		100%		100%		100%		100%	
11	N	45	28.7%	86	54.8%	26	16.5%	157	100%
		69.2%		78.2%		76.5%		75.1%	
	P	20	38.5%	24	46.1%	8	15.4%	52	100%
		30.8%		21.8%		23.5%		24.9%	
	Total	65	31.1%	110	52.6%	34	16.3%	209	100%
		100%		100%		100%		100%	
12	N	36	24.3%	93	62.8%	19	12.9%	148	100%
		73.5%		80.2%		82.6%		78.7%	
	P	13	32.5%	23	57.5%	4	10%	40	100%
		26.5%		19.8%		17.4%		21.3%	
	Total	49	26.1%	116	61.7%	23	12.2%	188	100%
		100%		100%		100%		100%	
13	N	6	31.6%	9	47.4%	4	21%	19	100%
		85.7%		81.8%		100%		86.4%	
	P	1	33.3%	2	66.7%	0	0%	3	100%
		14.3%		18.2%		0%		13.6%	
	Total	7	31.8%	11	50%	4	18.2%	22	100%
		100%		100%		100%		100%	
All ages	N	115	29.6%	215	55.4%	58	15%	388	100%
		75.6%		79.3%		78.4%		78.1%	
	P	34	31.2%	59	54.1%	16	14.7%	109	100%
		23.4%		21.7%		21.6%		21.9%	
	Total	152	30.6%	271	54.5%	74	14.9%	497	100%
		100%		100%		100%		100%	

*Remarks:
N = Normal group (Participants with ATI 0-2°);
P = Possibly has scoliosis group (Participants with ATI ≥3°)

Remarks

N = Normal group (participants with ATI 0–2°)
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the normal subject group (N group) if they have an ATI 0–2° and to the group with the possibility of scoliosis (P group) if they have an ATI ≥3°.

Twelve participants from the P group accepted the invitation to undergo radiography for further evaluation. After the evaluation, a total of 9 participants with a Risser's sign ≤2, Cobb's angles of 6–20°, and without any previous surgical or orthotic treatment for AIS were recruited for the study. The study was approved by the Human Ethics Committee of the Hong Kong Polytechnic University. All subjects signed an informed consent form and along with their parents, were informed about the purpose of the study.

2.2 Wear Trial

A functional garment which consisted of a tight-fitting girdle, shoulder to top-hip in length, was used to help with facilitating support and control of the body from the shoulders to the top of the hips (as shown in Fig. 1). The application of supportive forces and a point-pressure support system with this girdle were considered to assist with maintaining a more balanced posture and reduce the amount of body bending during daily activities [10].

Each subject who participated in the 6-month wear trial was informed that the recommended girdling time for each day should be 8 h. They were provided with a 2 week adaptation period prior to the start of the wear trial, i.e. girdling time of 2 h in the first week and 4 h in the second week. It was also ensured that all of the subjects were correctly wearing the girdle before the commencement of the wear trial. A temperature logger (Thermocron) was inserted into each girdle for compliance monitoring and set to record data every 5 min.

2.3 Posture Analysis

In order to evaluate the effect of girdling and girdling time on the postural changes in the subjects, testing that comprised 3D body scanning and 3D motion capturing were carried out at the beginning (0 month), after 3 months and at the end (after 6 months) of the wear trial in two conditions, with the girdle and without the girdle, so as to obtain fair comparisons. The subjects were required to wear thin bra tops and tight shorts during the body scanning and motion-capturing processes, in order to obtain more accurate results. Moreover, the subjects were required to perform each task twice with and without wearing the girdle in all of the testing, and only the measurements taken after the task was performed for a second time were analyzed.

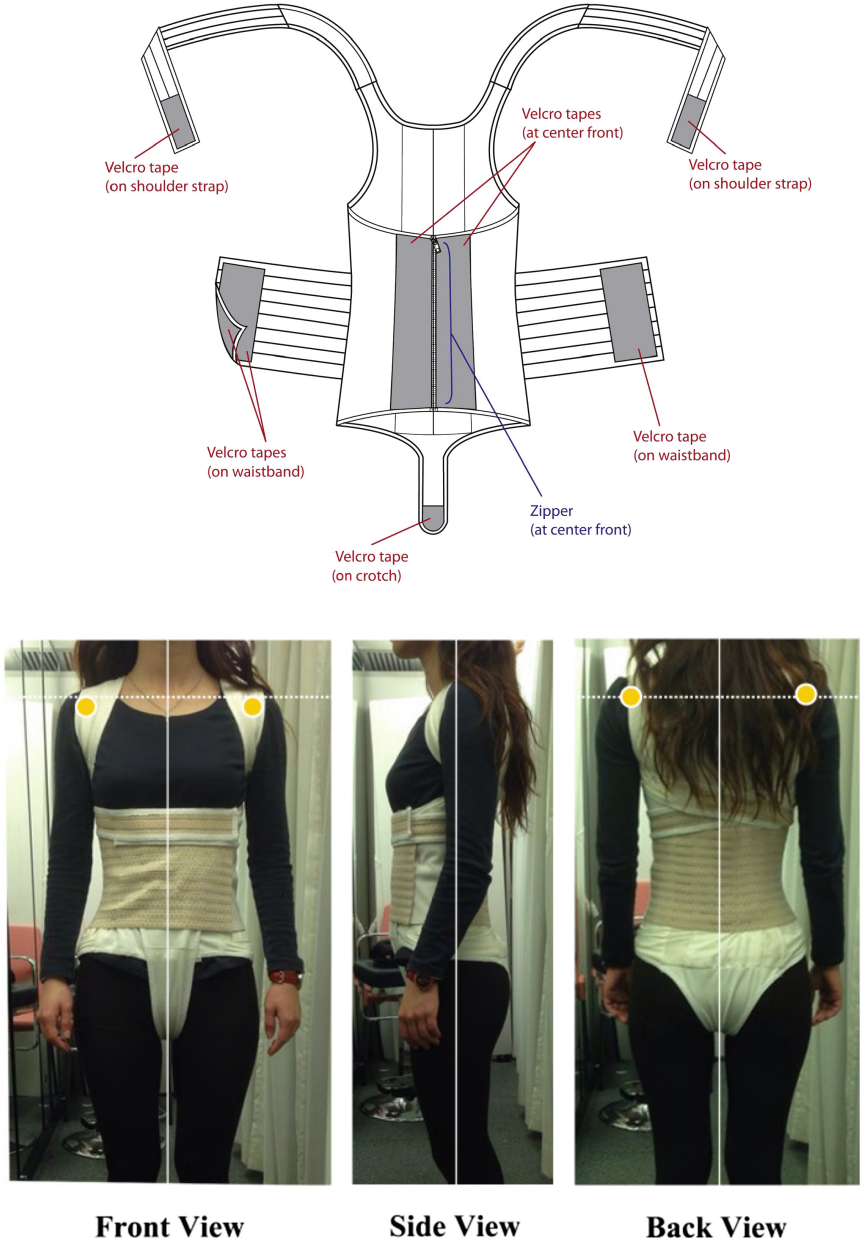

Fig. 1 Posture correction girdle on a subject

Three-dimensional body scanning was performed by using the Anthroscan system (Human Solutions) to evaluate the change in the rotation angle between the shoulders and pelvis in the horizontal plane during standing. During the scanning

process, the subject was to stand up straight with the shoulders back and feet apart in accordance with the footprint on the floor and parallel to the eye level with the floor. Markers were placed on both of the left and right sides of the acromion and pelvis, in order to mark the reference points for evaluation. The scanned data were exported after removing the noise and filling in the data gaps. Then, the data were processed by using MatLab 2013a. The data were aligned in accordance with the center of the body of the subjects, i.e. placement of their foot in the x, y and z-axes. The midlines of the body were marked at the shoulder and pelvis levels in the horizontal plane. After projecting the two lines on the same horizontal plane, the intersection angle was measured for comparison.

Three-dimensional motion capturing was performed by using the Vicon system, in order to obtain the data of a series of movements in the dynamic and static phases of postures with and without wearing the functional garment. The system contains a data-station, six wall-mounted video cameras with infrared sources, and a PC workstation. The infrared light-emitting diodes of each camera have a flash of 60 Hz and the system can obtain 3D co-ordinates from each marker through a 3D reconstruction method. Static and dynamic calibrations were implemented before the start of the experiment. As shown in Fig. 2, 15 reflective markers are placed onto specific landmarks on the body of the subject after palpation. The motions carried out in different scenarios, including standing, sitting, walking and bending, were captured, and then, 16 posture parameters were determined and analyzed [13].

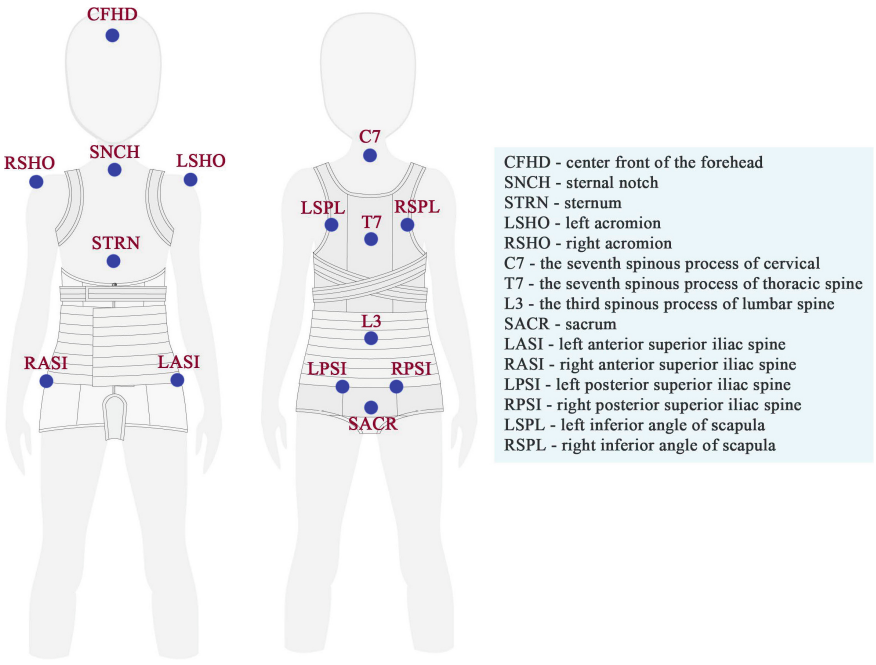

Fig. 2 Location of reflective markers used in 3D motion capturing

2.4 Statistical Analysis

In order to examine the possible effect of girdling on the postural changes of the subjects, IBM SPSS Statistic Version 20 was employed to analyze the data with 2-ways repeated measures ANOVA. The independent variables included girdling (with girdle and without girdle) and time (0, 3 and 6 months), while the dependent variables were the measurements obtained from the 3D body scanning and 3D motion capturing. The level of significance was set at $p = 0.05$.

3 Results

Nine female subjects with early scoliosis were recruited, but only 7 subjects (11.14 ± 0.90 years old, 146.86 ± 4.79 cm in height, 39.97 ± 12.03 kg in weight, BMI 18.36 ± 4.19, thoracic Cobb's angle 9.43 ± 6.11°, and lumbar Cobb's angle 10.57 ± 4.79°) completed the entire wear trial (6 months) and performed all of the evaluation tests. The average rate of compliance among the 7 subjects is 85.48 %.

3.1 Three-Dimension Body Scanning

Any improvements in the rotation problem at the level between the shoulders and pelvis as observed from the horizontal plane during standing might be indicated by a reduction of the rotation angle. The changes in the rotation angle in the horizontal plane during standing from 0 to 6 months are shown in Fig. 3.

According to the results of the 2-ways repeated measures ANOVA, with regard to the main effect, there are no statistically significant differences found in girdling with $F(1,6) = 3.591$, $p = 0.107$ and time with $F(2,5) = 2.963$, $p = 0.142$. With regard to the interaction effects, there is also no statistically significant difference found between girdling and time on postural change with $F(2,5) = 2.022$, $p = 0.227$. In other words, there is no statistically significant improvement of the rotation angle at the level between the shoulders and pelvis as observed from the horizontal plane during standing, which is induced by the effects of girdling and time.

3.2 Motion Capture (Vicon) Analysis

With regard to the angle measurements of the posture parameters, a more balanced posture in standing and walking, as well as better control of the range of bending,

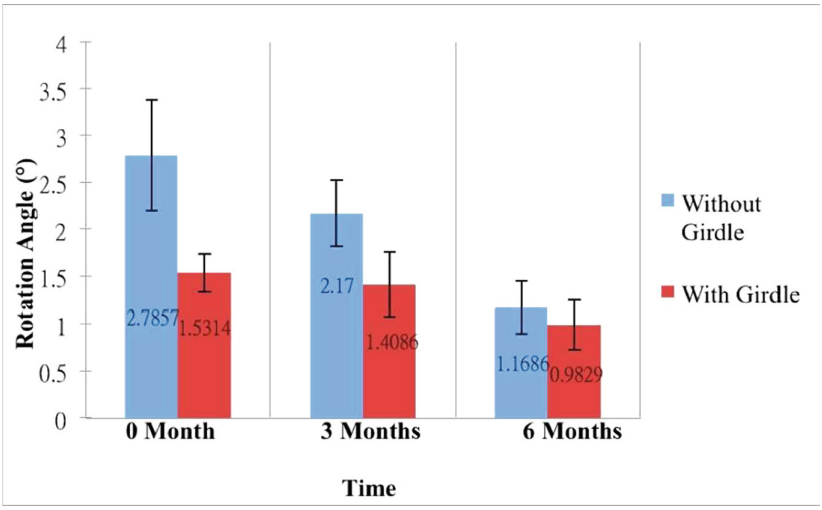

Fig. 3 Changes in rotation angle (°) in horizontal plane from 0 to 6 months

might be indicated by angle reductions, while a straighter back in sitting might be indicated by angle increases.

According to the results of the 2-ways repeated measures ANOVA (as shown in Table 2), there are statistically significant differences in the main effect of girdling on Posture Parameter 1 ($p < 0.05$), 4 ($p < 0.01$), and 9 ($p < 0.01$). The results indicated that girdling might possibly provide immediate improvement, including more even shoulders as observed from the frontal and horizontal planes during standing, as well as straighter upper back as observed from the sagittal plane during sitting. In addition, there are also statistically significant differences in the main effect of time on Posture Parameter 1 ($p < 0.01$), 9 ($p < 0.05$), and 11 ($p < 0.05$). A post hoc test (Bonferroni) was conducted to examine the pairwise comparison with time. The result showed that there are statistically significant differences between 0 and 6 months ($p < 0.05$) for Posture Parameter 1 as well as 0 and 6 months ($p < 0.05$) for Posture Parameter 11. However, no statistically significant difference was found for Posture Parameter 9. The results indicated that improvements with time might possibly be found with Posture Parameters 1 and 11, i.e. more even shoulders as observed from the frontal plane during standing and walking.

Moreover, according to Table 2, there are statistically significant differences of the interaction effects between girdling and time for Posture Parameter 1 ($p < 0.01$), 2 ($p < 0.05$), 10 ($p < 0.05$), 15 ($p < 0.05$), and 16 ($p = 0.01$). The interaction effects mean that the independent variables, i.e. girdling and time, have a complex influence on the dependent variable, i.e. postural change. The results indicate that the possible postural changes of Posture Parameters 1, 2, 10, 15 and 16, i.e. more evenness in the shoulders and pelvis as observed from the frontal plane during

Table 2 Descriptive statistics and results of 2-ways repeated measures ANOVA test for motion capturing

Descriptive statistics (n=7)						
Posture parameter	0 month (mean ±SD)		3 months (mean ±SD)		6 months (mean ±SD)	
	without girdle	with girdle	without girdle	with girdle	without girdle	with girdle
1)	3.386±1.440	1.706±0.691	2.117±1.007	1.373±0.862	1.564±0.805	1.292±0.872
2)	3.253±1.129	2.027±1.559	2.629±1.433	2.206±1.400	2.503±0.915	2.106±1.066
3)	2.376±1.332	1.477±0.467	2.091±0.061	1.999±0.750	1.978±0.575	1.833±0.581
4)	3.163±3.152	2.890±2.795	2.383±2.084	2.233±2.342	2.207±2.335	2.107±2.328
5)	4.457±3.142	4.487±3.119	4.091±2.433	4.121±3.584	3.617±3.356	3.490±3.710
6)	1.786±1.626	1.644±1.320	1.824±1.641	1.731±0.976	1.583±1.140	1.450±1.006
7)	2.563±2.074	3.209±2.498	2.514±1.704	2.544±1.914	2.536±1.628	2.437±1.817
8)	3.974±2.337	3.914±2.550	3.694±1.830	2.673±1.649	3.051±2.054	2.507±1.744
9)	151.567±6.553	153.117±6.464	153.734±5.986	154.223±5.266	155.818±5.262	156.899±5.671
10)	162.225±12.283	172.020±1.980	167.016±7.375	171.950±3.324	168.136±4.536	172.086±3.832
11)	10.343±1.852	8.863±1.848	9.776±2.504	9.653±3.253	8.746±2.004	7.890±2.564
12)	9.650±1.824	8.409±2.818	9.050±1.834	7.839±1.338	8.347±1.978	7.147±1.105
13)	22.493±7.340	18.774±4.793	19.156±4.589	17.339±5.279	18.381±4.699	17.246±4.102
14)	18.510±4.320	17.571±3.512	17.036±3.170	17.746±4.291	16.161±3.696	16.127±4.535
15)	84.717±28.133	75.057±18.860	80.547±24.846	73.524±21.130	80.589±25.208	74.866±23.430
16)	41.951±6.487	29.716±6.063	42.393±7.210	30.504±4.844	43.403±7.913	32.566±5.588

Results of 2-ways repeated measures ANOVA test					
Posture parameter^	Effect	F	Hypothesis df	Error df	Sig.*
1) Standing FP	Time	8.409	2	12	0.005*
- Acromion (°)	Girdling	6.083	1	6	0.049*
Markers: LSHD, RSHD	Time*Girdling	7.856	2	12	0.007 *
2) Standing FP	Time	3.032	2	12	0.086
- Pelvis (°)	Girdling	4.504	1	6	0.078
Markers: LASI, RASI	Time*Girdling	4.096	2	12	0.044*
3) Standing FP	Time	1.636	2	12	0.235
- Acromion/Pelvis (°)	Girdling	13.467	1	6	0.010*
Markers: LSHO, RSHO, LASI, RASI	Time*Girdling	0.220	2	12	0.805
9) Sitting SP	Time	4.270	2	12	0.040*
- Thoracic Angle (°)	Girdling	24.022	1	6	0.003*
Markers: C7, T7, L4, SACR	Time*Girdling	0.021	2	12	0.979
10) Sitting SP	Time	1.856	2	12	0.198
- Lumbar Angle (°)	Girdling	4.186	1	6	0.087
Markers: C7, T7, L4, SACR	Time*Girdling	5.111	2	12	0.025*
11) Walking FP	Time	4.449	2	12	0.036*
- Acromion (°)	Girdling	0.999	1	6	0.356
Markers: LSHD, RSHD	Time*Girdling	1.450	2	12	0.273
15) Bending FP	Time	0.445	2	12	0.651
- Maxi. Anterior Bending	Girdling	2.264	1	6	0.183
Markers: C7, SACR	Time*Girdling	6.021	2	12	0.015*
16) Bending HP	Time	0.456	2	12	0.645
- Maxi. Lateral Bending	Girdling	2.228	1	6	0.186
Markers: LSHO, RSHO, LASI, RASI	Time*Girdling	27.411	2	12	0.000*

Results of post-hoc test for the effect of time				
Posture parameter^	Item	Mean difference	Std. Error	Sig. (2-tailed)*
1) Standing FP	Pair 1: 0 vs. 3 months	0.744	0.252	0.076
- Acromion (°)	Pair 2: 3 vs. 6 months	-0.070	0.187	1.000
Markers: LSHD, RSHD	Pair 3: 0 vs. 6 months	0.674	0.149	0.012*
11) Walking FP	Pair 1: 0 vs. 3 months	1.194	0.511	0.175
- Acromion (°)	Pair 2: 3 vs. 6 months	-0.029	0.542	1.000
Markers: LSHD, RSHD	Pair 3: 0 vs. 6 months	1.165	0.266	0.014*

^FP: Frontal plane; HP: Horizontal plane; SP: Sagittal plane

*$p < 0.05$

The data are continuous data, but due to small sample size, may not be representative enough and cannot be normally distributed.

^*FP* Frontal planer, *HP* horizontal plane; *SP* sagittal plane

*$p < 0.05$

The data are continuous data, but due to small sample size, may not be representative enough and cannot be normally distributed

standing, a straighter lower back as observed from the sagittal plane during sitting, as well as acceptable constrained range of anterior and lateral bending, might have possibly been attributed to the effects of girdling and time.

4 Discussion

It has been documented that the ideal alignment in the vertical posture is related to the gravity line, which is a vertical line that passes through the center of gravity of the body [14, 15]. It has also been stated that good posture is a state of muscular and skeletal balance, which protects the body structure against injury or progressive deformity independent of whether the structure is working or resting [16].

In regard to the results of 3D motion capturing, significant improvements were mainly found on the acromion, especially in the frontal plane during standing. This result might be related to the design of the posture correction girdle in the present study and the bony structure of humans. In other words, the corrective forces from the adjustable shoulder straps can be directly exerted onto the bony points of the shoulders without the barrier of soft tissues. The postural improvements might also be attributed to posture training with the girdle, as it is believed that the back muscles of the subjects could be trained to keep the spine within a natural curvature, and thus prevent the corresponding imbalanced posture through awareness [8, 9, 17]. It has also been considered that children's bodies are "moldable", which means that their body postures could be improved and trained by using different methods [18]. In this study, the posture correction girdle acts as a training device, which reminds the subjects to maintain a better and more balanced posture during the girdling period.

In regard to the results of the 3D body scanning, the postural changes are obvious as seen in Fig. 3; however, the results are not statistically significant. The large standard deviation and small sample size might have led to this outcome. A large standard deviation indicates that the subjects have large individual differences. Since this is the case, a preliminary small statistical test was then carried out to determine whether if more homogenous subjects were recruited, the trend of the postural changes would be more obvious. In the preliminary test, 3 subjects with Cobb's angles (both the thoracic and lumbar curves) below 10° were assigned to Group 1, while 2 subjects with Cobb's angles (both thoracic and lumbar curves) more than 10° were assigned to Group 2, after referring to x-rays taken of the baseline. According to the results, the girdle is more likely to have a better effect on postural control for those in Group 1 (Cobb's angle below 10°), in which a significant across time effect was found $p = 0.008$. In Group 1, the mean of the measurements was reduced from 2.6733 (0 month) to 2.27 (3 months) and to 0.7867 (6 months) across time when the girdle was not worn, due to the higher homogeneity and smaller standard deviation of the measurements. Therefore, by using the result of this preliminary test as an indicator for subject recruitment, subjects with a smaller Cobb's angle, i.e. 5–10°, should be recruited for similar wear trials in future studies.

Finally, the compliance of the subjects might have affected the success of the girdling for improving posture and reducing the possibility of spinal curve progression, as patient involvement is one of the key factors that affect the success of treatment [19, 20]. With regard to the compliance of girdling in this study, Subjects 3 (100 %) and 4 (100 %) have the highest compliance, while Subjects 1 (62.5 %) and 6 (52.25 %) show the least compliance. These show that Subjects 3 and 4 wore

the girdle for nearly double the time of Subjects 1 and 6. They also show that the subjects who achieve improvement of posture are relatively more compliant in the wear trial of the present study.

5 Limitations and Future Studies

The effect of girdling and time on the changes in posture might be affected by a large standard deviation and small sample size. The standard deviation of the measurements decreases as homogeneity increases; therefore, subjects with a smaller Cobb's angle, i.e. 5–10°, should be recruited for similar wear trials in future studies. Also, some measurements show a trend of improvement, but not all demonstrate that the improvements are statistically significant. The specified length of time for the wear trial and small sample size might be possible factors that have affected the significance of the effects. Therefore, a longer wear trial period and a larger sample size are suggested for future related studies.

6 Conclusion

In this study, a posture correction girdle is found to contribute to postural changes in the subjects after a 6-month wear trial. Significant improvements are mainly found on the acromion as observed from the frontal and horizontal planes during standing, the back as observed from the sagittal plane during sitting, and there is an acceptable constrained range of anterior and lateral bending. Moreover, there is no statistically significant difference found in the results of the rotation angle in the horizontal plane after analysis is carried out with data from 3D body scanning due to the large standard deviation and small sample size. Compliance, growth and curve type might be factors that affect the effectiveness of this girdle on postural changes.

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Older Adults and Digital Technology: A Study of User Perception and Usage Behavior

Qingchuan Li and Yan Luximon

Abstract Nowadays, with aging society, there are an increasing number of older adults, who are current or potential users of digital technologies. However, how older adults perceive and use digital technologies does not receive sufficient research attentions. This study investigated older adults' user perception and usage behavior of digital technologies in Hong Kong. A semi-structured interview was designed to understand their feelings and experience of daily digital technology use. The results found that older adults presented positive attitudes to the digital technology use but less self-efficacy of their own capabilities of learning these technologies. The majority of participants reported difficulties when using and learning digital technologies, especially navigation problems. Additionally, there is a tendency of using mobile computing devices instead of computers among older adults. By considering older adults' special needs and limitations in future digital technology design, a better user experience could be assured.

Keywords Digital technology · Older adults · User perception · Usage behavior

1 Introduction

Nowadays, with aging society, there are an increasing number of older adults, who are current or potential users of digital technologies. However, the digital technology is still not widely adopted in the population of older adults compared with young people [1]. The study from Hong Kong Census and Statistics Department reported that more than 99.6 % of local residents aged at 10–34 years old had the

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computer knowledge, whereas only 30.1 % of older adults aged above 65 years old reported knowing how to use computers in 2015 [2]. This problem will probably be magnified while new technologies emerge with diverse interfaces and interaction styles evolving. The reasons may lie in many aspects. First, it is reported that older adults have fewer interests [3], and high level of anxiety when using technologies [4]. They also tend to show less confidence in their own knowledge, capabilities and skills of learning and using technologies [5]. Moreover, the aging process has started to bring significant changes to older adults' physical and mental abilities as early as mid-fifties [6], such as the visual perception, audition ability, movement control, and cognition. All of these declines may influence the way how older adults perceive and use the digital technologies. Therefore, it is essential to help the designers and practitioners to better understand the possible facilitators and barriers of learning and using technologies for older adults, especially when advanced technologies continue to emerge in their daily lives.

Research examining the relationships between the technology acceptance and attitudinal variables has proposed some important impact factors such as computer anxiety and self-efficacy [7–9]. In addition, individual's perception of technologies is reported to have some effects on user behavior, such as perceived usefulness and perceived ease of use [10]. The purpose of this study is to explore the user perception and usage behavior of digital technologies among older adults, and to investigate how their demographic factors, perception attributes, and usage behavior influence with each other. Specifically, older adults' perceptions of technology use and perception of their own self-efficacy in technology learning were investigated since these are major problems in technology acceptance. Older adults' usage behavior was analyzed by questions like how older adults adopt the technologies, and what problems they may encounter while using technologies. As there is a trend towards the use of mobile computing devices and touch-screen displays rather than computers and desktops, the digital technologies investigated in this study focused on both of the traditional computers and mobile computing devices with touch-screen displays, such as smart phones, tablets, and iPad.

2 Methods

The main method used in this study was a semi-structured interview, which was conducted in a local senior citizen center in Hong Kong. The semi-structured interview was chosen because it allows for planning interview questions and scheduling interview process in advance, and can be hosted in flexible locations based on older adults' daily activity place. Furthermore, as the older adults sometimes can't easily understand the questions, using interview also allows researchers to further explain to them in details. In this way, interviews can help older adults to better understand what we are attempting to ask. Considering of older adults' physical limitations, the whole section was controlled in 30 min for each participant.

2.1 Participants

Fifteen older adults participated in this study, including 5 males and 10 females. The participants were recruited from the local senior citizen center in Hong Kong. All participants reported being in good physical conditions and having the basic recognition capability of Chinese characters. In this study, the average age of participants is 77.9 ranged from 61 to 90 years old, with a standard deviation of 7.9 years old. Additionally, education backgrounds were also investigated. The majority of participants were at the education level below primary school (53.3 %), followed by those at the level of primary school (13.3 %), secondary school (20.0 %), and above the level of college and university (13.4 %).

2.2 Interview Design

Based on the literature review, this study is particularly interested in the following aspects of user perception: general attitude, perceived usefulness, self-efficacy to learn new digital technologies or applications. Participants' usage behaviors and using experience were detailed investigated, including different types of digital technologies they used, the average time they usually spent on, and their most frequently used functions and applications. Furthermore, participants were asked about their perceived ease of use and ease of learning about these digital technologies. Then they were required to rank the 11 possible difficulties and problems in terms of usability and learnability of digital technology use.

Three questions were designed to measure the old adults' user perception about digital technologies. Firstly, older adults' general attitudes were asked: *do you like the idea of using digital technology?* Then, a second question was used to investigate whether the digital technology could enhance their performance and bring convenience to their daily life. The questions were designed as: *do you think using the digital technology would bring some conveniences to your life?* Additionally, a third question was asked about their self-efficacy of learning new things: *do you feel confident to learn a new kind of digital technology or related application?* These three questions all used a format of 5 Likert scale to ask the participants to choose verbally. All related comments were recorded for further analysis.

For those who had the experience of using the digital technology, including computers, smart phones, tablets or iPad, smart watches and the other related technologies, three questions about their usage habits were asked. Participants were firstly asked to choose the most frequently used digital technology and indicate their using frequency. Then, participants were asked about their most frequently used functions or applications. Questions were like: *How often do you use digital technologies, including computer, smart phone, iPad or tablet, smart watch, or*

others? What is your most frequently used product? What are your most frequently used functions or applications? In addition, participants were also asked to evaluate the ease of use and ease of learning about these technologies. Particularly, 11 common difficulties and problems were summarized from the study of [11], including target design, graphics design, icon design, content and layout design, color design, and navigation problem. Participants were instructed to choose these possible difficulties based on their real experience, or indicate other relevant problems they encountered. In the end, to better learn how older adults gain supports from others and in which way they prefer to learn digital technologies, the question was asked: *When you learning a new digital technology or relevant application, in which way do you prefer to learn?*

3 Results

3.1 User Perception of Digital Technology

The majority of participants showed positive feelings to digital technologies (73.3 %). For example, 3 participants indicated that they appreciated the new things showing in their life, and they liked playing games using smart phones. However, there were still 3 participants reporting that they were bored with digital technologies because sometimes the technology was very complex and easily broken.

Regardless of whether the participants used digital technologies or not, 86.7 % of them showed positive attitudes towards the convenience that digital technologies could bring to them.

When the participants were instructed to verbally evaluate how confident they feel if they were asked to learn a new digital technology or application, most of them chose a positive answer (73.3 %). However, half of these participants actually showed little confidence considering of the whole interview. For instance, 2 of them demonstrated that they were too old to learn new things. 5 participants complained that they had bad memories and less patience to learn new technologies. 4 people reported that they had the confidence to learn new technology only when the technology was simple enough. Thus, based on the real situations, there were only about 33.3 % participants showing clear and strong confidence to learn new technologies.

For further analyzing, the spearman correlation analysis was used to examine the relationship between participants' demographic factors, perception attributes and usage behavior. As the results indicated, participants' perceived ease of use was positively correlated with participants' overall attitude ($p = 0.010$) and perceived usefulness of technologies ($p = 0.049$), as shown in Table 1.

Table 1 Correlation coefficient between perceived ease of use and perception attributes

	Attitude	Perceived usefulness	Self-efficacy
Correlation coefficient	0.735	0.604	0.595
p	0.010	0.049	0.054

3.2 Usage Behavior of Digital Technology

Totally, there were 11 participants having digital technology experience in this study. Among them, 4 participants (26.7 %) reported a low level of digital technology experience with 2–5 h per week. 6 participants (40 %) indicated a medium level of experience with an average time ranged from 0.5 to 3 h per day. Only one participant reported a high level of experience with 4 h per day. Additionally, many of the participants reported they used or owned at least two kinds of digital technologies. The majority of them indicated that they used the smart phones (81.8 %), followed by those who used the computers (63.6 %), and tablets or iPad (36.3 %). While they were asked their most frequently used digital technology, 5 participants chose smart phones (45.5 %), followed by 4 participants chose computers (36.3 %) and 4 participants chose tablets or iPad (36.3 %). The frequency of the most frequently used functions or applications reported by older adults is displayed in Fig. 1. As shown, besides the basic functions, the four most frequently chosen functions or applications were hobbies and entertainments (81.8 %), information, learning and education (54.5 %), health and wellness care (54.5 %), and social interaction (45.5 %). For older adults, supports from others are quite important for them to use and learn the digital technology. 11 older adults preferred to learn to use technologies with their children or husband, and only 2 older adults preferred to

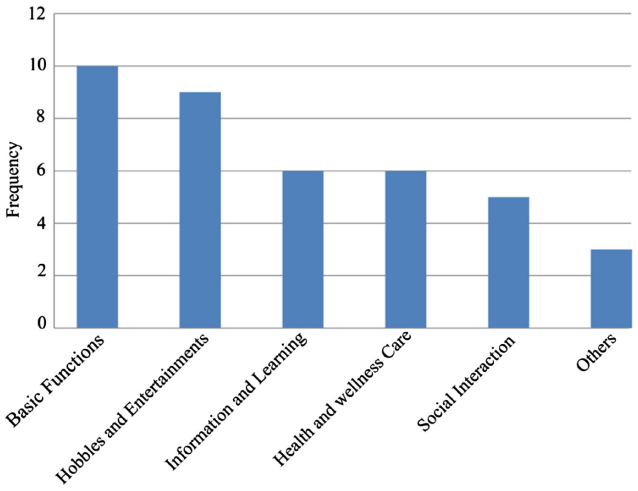

Fig. 1 Frequency of most frequently used functions among older adults (n = 11)

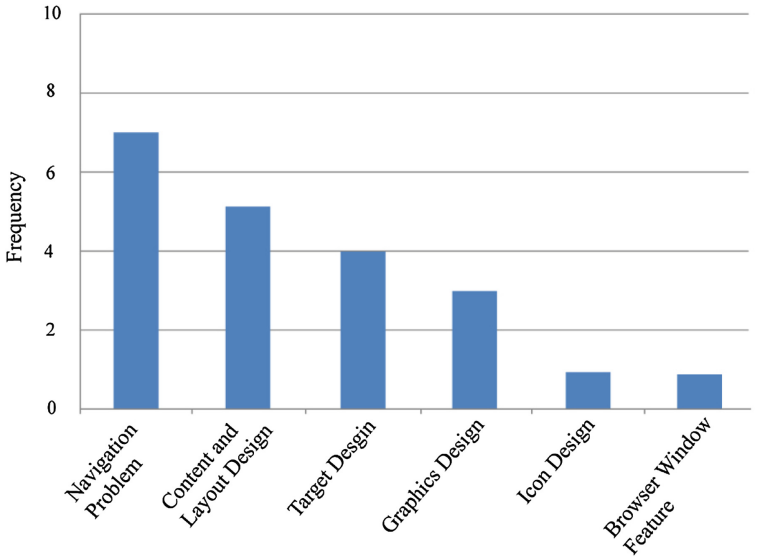

Fig. 2 Frequency of difficulties and problems related to digital technology using and learning (n = 11)

learn by themselves. Moreover, 9 older adults (60 %) indicated clear intention to learn more digital technologies in the future.

For those 11 participants who has digital technology experience, the general ratings of their perceived ease of use and ease of learning towards digital technologies were as follows: 8 participants found it difficult to use or learn the digital technologies (72.7 %); 2 participants found it not quite difficult to use or learn digital technologies and only 1 participant found it easy to use or learn digital technologies. When the participants were asked about their user experience or difficulties when using digital technologies, they tend to describe the digital technologies as complex, complicated and constantly changing. The frequency of difficulties and problems reported by older adults is demonstrated in Fig. 2. The common difficulties they encountered mainly focus on navigation problems, including the problems of pull down menus, navigating between different functions, and finding the way back to the previous interface. Additionally, the problems of content and layout design, and target design were also frequently reported by many participants.

4 Discussion

In this study, we explored the current situation of older adults' user perception and usage behavior of digital technologies in Hong Kong through a semi-structured interview.

Overall, the findings from this study indicated that the older adults' attitudes toward digital technology were quite positive, which are consistent with some other investigations which focused on desktops and computers [12, 13]. Not surprisingly, most of the older adults thought the digital technologies would bring conveniences to their daily lives. Nevertheless, regarding to older adults' perception of their own abilities to learn technologies, they showed a quite complicated attitude in this study. On the one hand, most of the participants firstly reported they were confident to learn new things. On the other hand, the majority of them reported negative attitudes to some extent during the whole interview process. The possible reason may lie on that older adults desire to contribute to the society [14] and tend to express their positive feelings of experience [15]. In this way, we suggest that using interview method is quite useful to dig out their real perspectives and feelings. By using different ways to ask each question and employing different approaches to comprehending each answer, the validity and trustworthiness of the research can be enhanced in the future study [16].

Contrary to some previous studies [10, 17], the findings from this research indicated that there is no correlation between demographic factors and perception attributes. That is to say, regardless of the age, gender and educational background, older adults generally hold positive attitudes to the digital technology and less confidence about their abilities and skills to learn or use these technologies. The differences may be caused by the wide use of digital technologies in older adults' daily lives in Hong Kong during recent years. An increasing number of older adults are convinced of the usefulness of digital technologies by their families and friends. In addition, the results from this study demonstrated that older adults' perceived ease of use was positively correlated with participants' overall attitude and perceived usefulness of digital technologies.

Surprisingly, the use of digital technologies is quite common among the older adults in Hong Kong. It is worth noting that, there is a tendency of using mobile computing devices and touch screen displays such as smart phones or iPad among these older adults, instead of desktops or computers. Especially, besides the basic functions, older adults showed the intention to use applications for hobbies and entertainment, information searching, and health-care related purposes. However, the majority of older adults in this study reported difficulties and problems to a different extent when using and learning digital technologies, which implies that current technologies are not successfully inclusive. The digital technology seems quite complicated, complex and changeable to them. Especially, the most frequently reported difficulties are related to the navigation problems. The possible reason is that older adults' usage of digital technology was still restricted in simply tasks which mainly required simple navigations. In addition, supports from others are quite important for older adults. Many participants prefer to learn new technologies with their children firstly and then practice by themselves. More importantly, the older adults showed some expectations for the future digital technologies design. For instance, some participants demonstrated that: "I wish the digital technology could be designed simpler and easier for us to use; otherwise, it is totally useless and meaningless for us".

5 Conclusion

This study investigated the older adults' user perception and usage behavior of digital technologies in Hong Kong, which will assist the designers and practitioners to better understand older adults' special needs and limitations while using digital technologies. These understandings can help with designing digital technologies to facilitate the diverse user capabilities for all potential users including older adults, in order to ensure users' ease of use and ease of learning, and a better user experience. The semi-structured interview in this study suggested that older adults tend to show positive attitudes towards technology use but less self-efficacy of their capabilities to learn technologies, which emphasizes the importance for researchers to continue focusing on this research area.

Overall, the majority of older adults perceived and experienced various difficulties when using technologies, which implies that current technologies are not successfully inclusive and the user experience should be improved. This finding also appeal the designers to consider older adults' unique capabilities and special needs when designing digital technologies, and make some allowances in design to facilitate their cognitive, visual and even emotional needs. For instance, the most frequently reported difficulties and problems from older adults were related to the navigation problems, which should be further emphasized in technology design. Further research is necessary to explore the relationships between different cognitive capabilities and usability problems. Also, research needs to be undertaken to investigate how to develop or design the digital technology based on older adults' unique cognitive and visual characteristics.

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Academic Professor Perception of the Future of Electronic Textbooks

Kimberly Anne Sheen and Yan Luximon

Abstract Electronic textbooks have slowly made their way into regular usage in classrooms, yet many electronic textbooks remain a digital representation of their physical counterparts and an understanding of how they should be organized or utilized is still lacking. In past research, questions to professors have not focused on how electronic textbooks are used in their course, how they believe students should use them, and what they believe is necessary in the future. Semi-structured interviews with design and engineering professors found that generally professors agreed with student ideas regarding future components. They did feel some additional components, such as tagging, would help facilitate student learning. This paper presents an understanding of different disciplines approaches and an understanding of electronic textbooks and what professors think should be included in the future. It also assists in highlighting any mismatch between student and professor perception of future electronic textbook components.

Keywords Electronic textbooks · Textbook design · Contrasting perceptions · Interviews · Future design

1 Introduction

Electronic textbooks are not new, but their prevalence in universities around the world is increasing. There are many perspectives to take into account when investigating electronic textbooks and their future. While publishers are creating electronic textbooks, it is the instructors and students who really should be dictating changes, as they are the end-user. While professor perception of electronic text-

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books has been identified in previous research, it has mainly been gathered during post experimental student usage in classrooms. Questions have not focused on how they believe current electronic textbooks fit in their courses, how they believe they should be used by students, and what they believe is necessary in the future for their students to meet their academic goals.

Electronic textbooks are commonly used by professors as one part of their larger teaching practices to support student learning [1]. Each professor's views on how they should be used differ, from an optional resource to required weekly readings. Professors tend to use textbooks as a tool to supplement the material they give during their lectures, which may cause the information given in class to have an obscure relation to what is read in the textbook [2]. Some professors even find what they teach is in disagreement with the text itself causing issues for the student and instructors [2]. Finding one textbook to support all the needs of specific classes is very difficult. And writing individual textbooks would not only be time consuming but would not be applicable to broader audiences because of differences in teaching philosophies. Although this type of custom publishing allows for flexibility because instructors can select their own segments of text, there is a lack of ability to fully take the ideas used during a course and seamlessly integrating it into the created text [3]. Some instructors prefer not to officially suggest textbooks as they believe that students will not complete the readings assigned and instead rely on their lectures, tutorials, and some electronic texts as references [4]. When assigning readings from electronic textbooks, professors are mixed in how they encourage students to interact with the textbooks. Some instructors ask students to use built in components, such as note taking capabilities, while other instructors do not encourage students to interact with electronic textbooks in any particular way [1]. Students have more positive reactions to components of electronic textbooks when instructors explicitly encourage the use of those components [5].

Overall, professors are reported to being happy with electronic textbooks in terms of products and technical capabilities, but are concerned with cost and student access to material, yet not as concerned about the digital rights management [6]. Although they are generally happy, technical issues stop some professors from encouraging use of electronic textbooks in their classrooms. There is a distinct fear that students will run into technical difficulties while using the electronic textbooks and it will negatively affect their reading [7]. Another consideration is the cost of faculty time in adopting a new textbook which makes some instructors wary as they need to adjust all of their instructional materials around the new textbook, but they are willing to take the time to do this if there was a clear educational value to the students [1].

Cost is an important aspect in relation to textbooks. Professors are aware that students who are burdened by heavy textbook costs may extend their time in university to try to combat the immediate costs and which eventually influences their academic success [8]. While faculty considers this issue, if the best choice of textbook for their class is an expensive physical textbook they will choose that textbook over a less expensive electronic or physical textbook [9]. While electronic textbooks can make online courses easier, they could be considered something

which can diminish the voice of the professor which may in turn negatively affect the university and professors' educational mission [6].

This paper will fill this gap in research by uncovering university professors' professional perceptions of electronic textbooks and their views of the necessary requirements of future electronic textbooks. Professors were selected from the Faculty of Engineering and the School of Design. By understanding how different disciplines approach and understand electronic textbooks and what they think should be included to create a textbook that meets their students' discipline specific needs will help to combat the one size fits all electronic textbooks that publishers are currently creating. The findings will also assist in highlighting any mismatch between the student and professor perception of electronic textbooks and their future.

2 Method

Design and engineering professors were chosen for comparison of views as these disciplines have many similar qualities while remaining distinct. In design, creativity in creating products is valued over working within the technological restrictions; whereas in engineering, practicality and working within the constraints to create a product is desired. Thus, design often focuses on a more aesthetic and a user focused approach to product creation, while engineering tends to be more practical and technical. Education in these particular disciplines aligns with these mentalities.

Short semi-structured interviews with engineering and design professors were conducted to gain an understanding of their views of electronic textbooks and the future of electronic textbooks. Each short session took less than 15 min and included six scripted questions and various follow-up questions based on necessity or clarification to explore the answers fully with flexibility [10]. The six questions asked were regarding their teaching experience, views on electronic textbooks in relation to personal teaching practices, beliefs on student engagement with electronic textbooks, views of the differences between physical and electronic textbooks, views on student responses regarding future electronic textbooks, and their professional beliefs on what should be included in future electronic textbooks.

3 Results

3.1 Participants

Four design professors and four engineering professors who teach undergraduate courses participated in the interviews. Design professors' experience teaching at a university level ranged from 4 to 22 years with a median of 15.5 years of experience.

Engineering professors had between 2 and 20 years of experience teaching at the university level with a median of 12 years' experience. The ethnicity of both the design and engineering professors were mixed, with the majority being Asian.

3.2 Professional Views on Electronic Textbooks

First professors were asked to discuss how and if electronic textbooks were used in their teaching practices. Design professors generally assigned electronic textbooks in their class assignments, mostly telling their students to access the electronic textbooks through the library website. They gave various reasons for their choice to use electronic textbooks such as the ability to give last minute readings to students, the ability to link directly from Blackboard, and an assurance that students will be able to access enough copies of the books. Design professors did acknowledge that electronic textbooks could not always fit their needs as an instructor or those of their students. Professors did discuss how textbooks for courses that require many images or which teach typography need a physical textbook due to quality concerns. In addition, it was reported that students often go to YouTube for tutorials over their textbooks for written information. Engineering professors had more of a mixed use of electronic textbooks within their teaching practices. Most engineering professors reported using both physical and electronic textbooks or not encouraging the use of one at all. Overall, all of the engineering professors believed that their students almost exclusively use electronic textbooks, as they believed they were easier to access, cheaper, and that students were more familiar with reading on monitors. The professors who did use electronic textbooks in their courses reported various reasons for their use, such as electronic textbooks made it easier to integrate information into their class presentations and that physical textbooks are becoming obsolete. Two professors, one from each discipline, reported that they rarely assign electronic textbooks in their teaching recently but still encouraged their students to use electronic textbooks as a referencing tool with very specific passages to read identified for the students.

Following that, professors were asked how they thought their students engaged with electronic textbooks. Design professors reported that they assumed their students were reading, but they were unaware of how their students were actually reading nor did they encourage a specific way of interaction. Some professors did not believed there was a difference in engagement while others believed that students were not reading as deeply as they should to succeed academically. Design professors also believed there were some unethical behavior occurring that may be associated with electronic textbooks, such as plagiarism and the downloading of pirated .pdf versions of electronic textbooks. Engineering professors believed that students did not like to read and would only read what they absolutely had to. Similarly to many design professors, engineering professors believe that the interaction did not change much between physical and electronic textbooks but raised the same concerns about students no longer reading deeply.

Professors were then asked what they believed were the differences between physical and electronic textbooks. Design professors believed there were benefits to electronic textbooks. They reported that electronic textbooks cost less, provided a minimal aesthetic, offered access that was more convenient, allowed for zooming and reading in the darkness, and allowed students to optimize their searching. While electronic textbooks afford these benefits, professors also reported that students had slippage between what they are referencing and what they did themselves. Design professors also reported that there were still some benefits to physical textbooks. By using physical libraries, students were able to find resources they would not previously have known about because of the structure of libraries. There was also a sense of urgency with a physical textbook that needed to be returned. While they saw those advantages, they believed that the advantages of physical textbooks are fading. Engineering professors generally believed that electronic textbooks were similar to their physical counterparts with some additional benefits. Professors reported that some electronic textbooks have beneficial components, such as video, better formatting, were more reader friendly, allowed for quicker searching, and allowed students to carry more books with them at one time.

3.3 View on Future Electronic Textbooks

After the previous views were elicited, professors were asked about their views regarding answers given by students about components they wished to be included in future electronic textbooks identified during a university wide survey [11] and later verified during small focus groups. Professors were first provided with the top five components their students desired in their future electronic textbooks (see Table 1). All the design professors felt that the students' views are understandable. While they felt some of these components were already available in some cases, they were not as convenient as they should be. Professors were especially open to the idea of videos, although one professor believed that the inclusion of videos might cover up learning disabilities or a lack of literacy. Engineering professors felt that the students' views on desirable components were understandable and in line with current student interactions. They felt that video integrates exceptionally well and enhances concept comprehension, but one professor thought that videos would be better used during lectures.

Table 1 The top five desired components by design and engineering students

Rank	Design students components	Engineering students components
1	Multimedia	Text
2	Bookmarks	Highlighting tool
3	Highlighting tools	Multimedia
4	Text	Bookmarks
5	Translation, dictionary, and encyclopedia	Translation, dictionary, and encyclopedia

Table 2 The top five undesired components by design and engineering students

Rank	Design students components	Engineering students components
1	Hide unimportant aspects of books	Hide unimportant aspects of books
2	Speech to text	Time management system
3	Time management system	Speech to text
4	Link to experts to answer questions	Text to speech
5	Text to speech	3D and manipulatable images

Professors were then provided with the top five components their students felt were undesirable for their discipline specific future electronic textbooks (see Table 2). Design professors mostly felt that the views of students made sense. One professor thought that the components were not vital but still found value in them. Another professor thought that some of the components considered undesirable were related to language issues and may be cultural. Overall, engineering professors thought that the student views were valid except for the case of 3D and manipulatable images which they thought had a place in engineering textbooks, especially those dealing with circuit boards and proteins, to assist in concept comprehension.

Following that, professors were asked what they wished to be included in future electronic textbooks. All design professors wished for their future electronic textbooks to include an advanced tagging system so that students and instructors could cross-reference with other materials to see more critical and diverse opinions. Design professors also wished for linking to other online media, direct links to materials from the reference sections, better access to encyclopedias, and more integrated touch menus. Engineering professors felt future electronic textbooks should not only include what the students felt, but they also felt that there should be links to experts for answers to student questions and so that authors could get direct feedback for edition changes. They also wished to see 3D and manipulatable images, supplemental materials such as PowerPoints for their use, and augmented virtual reality for better engage students in the material and assisting in making abstract concepts understandable in their future electronic textbooks. Professors thought that students should be able to mark on electronic textbooks in similar ways to how they mark physical textbooks, such as writing in the margins.

4 Discussion

How each instructor uses electronic textbooks in their courses change drastically [1], something that was reported by professors who took part in these interview sessions. Similar to previous studies, professors assume that students do not deeply read their textbooks and do not rely as heavily on them during course creation and instruction, leading students to feel that the text is irrelevant [3]. In fact, some professors believe that students do not read at all and will then not supply a

suggested textbook for the course [4]. Yet, one study showed that students do complete their reading but the vast majority does so only before the exam [12]. In fact, overall students read less than the instructors think is ideal for the student [1]. During interviews, professors reported uncertainty that students actually completed readings and most professors interviewed did not even encourage students to read or read a certain way when assigning electronic textbooks. This would seem to be detrimental to students' overall success as instructors who encouraged students to actively read and use some of the built in components found that their students use them more [1]. It should then be suggested that the professors, a vital end user of electronic textbooks, should be more active in encouraging students to use electronic textbooks to their full potential, not something that many instructors report doing. This encouragement will then have a positive effect on student success.

There are a few factors which faculty members have reported influence their decision to use electronic textbooks and which will influence their future adoption. One of which reported in interviews is the cost of textbooks, which has also been reported in the past [8]. Not all courses identify electronic textbooks which are appropriate for the needs. As design professors have reported, courses such as typography and image driven courses will still require physical textbooks. Previously, professors have also reported that they will choose a high cost physical copy of the textbook if it is more appropriate for their class [9]. In addition to generally lower costs, professors have also reported that electronic textbooks are more convenient for their students to access especially when they want to assign last minute readings. Almost all the professors interviewed discussed sending their students to the library's website for access to the electronic textbooks, although some were aware that students chose to download electronic textbooks illegally. While they reported this, they weren't very focused on it, which is in line with previous findings [6].

Overall, professors and students have similar beliefs about future discipline specific electronic textbooks. They stated that the components students desired will assist in concept comprehension, which may have been lost because of the change in reading techniques caused by the use of electronic textbooks. Professors did have some reservations regarding additional components added to electronic textbooks, such as multimedia, which may mask learning disabilities or limited literacy. Engineering professors did not always agree with students' views on undesirable components, especially 3D and manipulatable images. Past research has shown similar professor views on interactive figures, which they considered beneficial to learning, visualization, and student engagement in specific disciplines even after student enthusiasm for the component waned [5]. A professor interviewed also reported that edition revisions would be easier if future electronic textbooks included a way for students to send questions to authors. Similarly, it has been found that electronic textbooks also allow for easier reporting of incorrect material to the publishers [6]. The ease of finding out what information is troubling students or what information is incorrect that is afforded by electronic textbooks, would be valuable not only to students and faculty but also the industry as a whole. There are some other components that professors wished to be included in future electronic

textbooks, such as high level tagging features. They not only thought it would be beneficial to their research, but thought that their students would benefit from seeing different views, finding more information on assigned topics, and engaging more with the concepts combating surface reading. It is understandable that most students would not report this type of component as undergraduates are not working at as high level of critical research as professors. Without professor insight, components such as this would be lost.

5 Conclusion

Overall, professors tend to be open to electronic textbooks but are skeptical about student reading in general. They also agree with student perception of components necessary for future electronic textbooks, except in the case of 3D and manipulatable images. Since professors understand the rigors of research, they would like components such as tagging added to future electronic textbooks. Their insights on the requirements of student success may combat some of the issues with electronic textbooks, such as surface reading, because they will facilitate students' ability to understand complex concepts. By understanding how different disciplines approach and understand electronic textbooks and what they think should be included to create a textbook that meets their students' discipline specific needs will help to combat the one size fits all electronic textbooks that publishers tend to create. The findings also assist in highlighting any mismatch between student and professor perception of electronic textbooks and their future.

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Relationship Between Footwear Design Factors and Footwear Fitting and Comfort

Lanyin Jiang, Ameersing Luximon and Abida Younus

Abstract Footwear fitting and comfort is an important customer need which involves multiple factors. It includes both objective measurements and subjective perceptions, and can be influenced by shoe materials, weight and styles, foot shape, inside shoe climate, even colour and fashion. However, the influences of other design factors are still not clear. This research investigated the relationship between footwear design factors and footwear fitting and comfort. Two-level fractional factorial design analysis was used to evaluate the effects and find the vital factors. The results indicated that heel height has relatively significant influences on footwear comfort. High topline, low heel height, soft material, round toe, open toe, open heel and thin platform can provide better fitting and comfort.

Keywords Footwear · Fit · Comfort

1 Introduction

Footwear fitting and comfort is an important customer need that should be considered in shoe design and manufacturing [1]. It is a complex concept involving multiple aspects: Fitting requires the compatibility between the footwear and the foot shape and dimensions [2]; the foot can be supported appropriately without high pressure points [3]. Comfort includes subjective perceptions and can be influenced by various factors, such as shoe materials, weight and styles, foot shape, inside shoe climate, and also colour and fashion [1]. Due to the innovation of 3D modelling technologies, the measurement related to foot and footwear becomes more accurate, and relationships between shapes can be built in 3D system. Footwear fitting are

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improved through the development of these 3D models and digital shoe-lasts. However, the influences of other design factors are still not clear. Even if the shoes are made with the same shoe-last, the wearing feelings may still change for different designs.

This study aimed at exploring the relationship between footwear design factors and footwear fitting and comfort. The influences of each factor on fitting and comfort were investigated, and the interactions between the design factors were also analysed.

2 Methodology

2.1 Experiment Design

Design Factors. Seven footwear design factors were investigated in this study, including topline, heel height, material, toe type, toe design, heel design, platform height. In order to reduce the number of runs of testing all the combinations of factors, two-level fractional factorial design analysis was applied to the seven factors. Topline, heel height, material, toe type were the basic factors and the other three were interaction factors. The design characteristics are shown in Table 1.

There were two toe types and two heel heights. As a result, four types of shoe-last were needed in this experiment. The number of designs is $2^{7-3} = 16$. The levels of interaction factors were calculated from the corresponding basic factors in Table 2.

Design and Shoemaking. 16 sketches were drawn according to the levels of each design factor. Four shoe-lasts were generated from existing 3D shoe-last models and then manufactured. Except for the heel height and toe type, other designs were all the same. The sketches and shoe-lasts were then sent to shoe manufacturing factory to make the 16 pairs of shoes for experiment use. Table 3 show the shoe lasts that were used. 32 pairs of shoes were made in total, 2 pairs for each sketch for the convenience of the experiment.

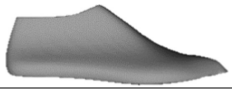
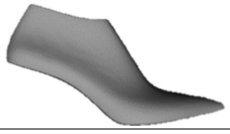
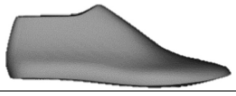
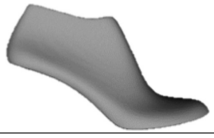
Table 1 Factors and levels

	Level	−1	1
A	Topline	Low	High
B	Heel	10 mm	70 mm
C	Material	Soft	Hard
D	Toe type	Pointed	Round
E	Toe design	Open	Closed
F	Heel design	Open	Closed
G	Platform height	0 mm	10 mm

Table 2 16 designs and their corresponding levels

No.	Basic factors				Interaction factors		
	A	B	C	D	E = A * B * C	F = B * C * D	G = A * C * D
1	−1	−1	−1	−1	−1	−1	−1
2	1	−1	−1	−1	1	−1	1
3	−1	1	−1	−1	1	1	−1
4	1	1	−1	−1	−1	1	1
5	−1	−1	1	−1	1	1	1
6	1	−1	1	−1	−1	1	−1
7	−1	1	1	−1	−1	−1	1
8	1	1	1	−1	1	−1	−1
9	−1	−1	−1	1	−1	1	1
10	1	−1	−1	1	1	1	−1
11	−1	1	−1	1	1	−1	1
12	1	1	−1	1	−1	−1	−1
13	−1	−1	1	1	1	−1	−1
14	1	−1	1	1	−1	−1	1
15	−1	1	1	1	−1	1	−1
16	1	1	1	1	1	1	1

Table 3 Shoe-lasts

Shoe-last 01: 10 mm, pointed toe		
Shoe-last 02: 70 mm, pointed toe		
Shoe-last 03: 10 mm, round toe		
Shoe-last 04: 70 mm, round toe)		

2.2 Fitting and Comfort Questionnaire

The questionnaire on overall and regional fitting and comfort was designed and adapted from previous studies [4]. The questionnaire mainly included three part: the overall fitting and comfort evaluation, the regional fitting evaluation, and marking the discomfort region on the graph. The evaluations used the rating from 1 to 5 to assess each item.

2.3 Participants

Forty Chinese females ranging from 18 to 54 with a mean age 26.5 participated in the experiment. They all wear European size 36 shoes in daily life and did not have serious foot injury in the last year. Their height ranged from 147 to 165 cm with a mean height 156.96 $\pm$ 4.55 cm, and weight ranged from 38 to 69 kg, mean weight 50.17 $\pm$ 7.36 kg. The average foot lengths and width were: Left foot mean length 22.64 $\pm$ 0.48 cm, mean width 71.23 $\pm$ 0.40 mm; Right foot mean length 22.47 $\pm$ 0.51 cm, mean width 71.15 $\pm$ 0.34 mm.

2.4 Experiment Procedure

Before the experiment started, the participant's foot length and width are measured using Brannock device to make sure her feet are size 36. The experiment would cease if the size did not satisfy the requirements. Then the participant signed the consent form and fill the personal information sheet. The participant tried on 16 pairs of shoes in random order and fill the fitting and comfort questionnaire according to her wearing and walking feelings. An information graph was provided to the participant in case that she could not understand the terms in the questionnaire. When the experiment finished, the participant received HK$50 payment and signed the receipt. The whole procedure took around 1 h. The data collected in the experiment were then input in Excel form and analysed using Minitab to investigate the relationships.

3 Results

3.1 Overall Fitting and Comfort

The average value of the ratings from all participants were used as the response for analysis. In the analysis of overall fitting and comfort on left and right foot, only

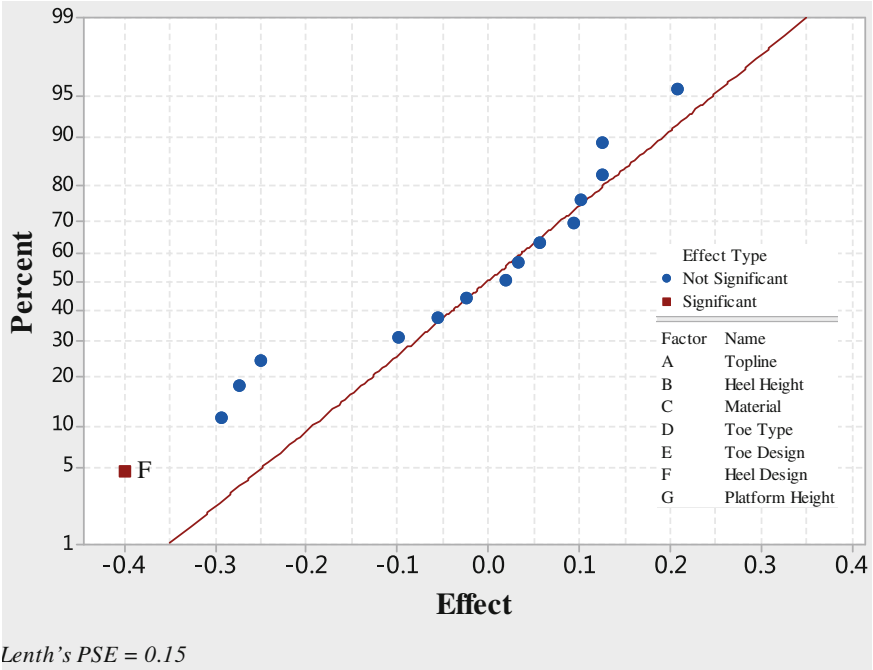


Fig. 1 Normal plots of the effects (response is average overall comfort of right foot, α = 0.05)

one significance was identified. As shown in Fig. 1, heel height has significant effect on overall comfort of right foot.

3.2 *Main Effects Plot*

The main effects plot of overall fit and comfort follow the similar pattern on both left and right foot. Better fit and comfort performance corresponds to high topline, low heel height (10 mm), soft material, round toe, open toe, open heel and thin platform (0 mm). Figures 2 and 3 show the response changes according to each factor assuming other factors are constant.

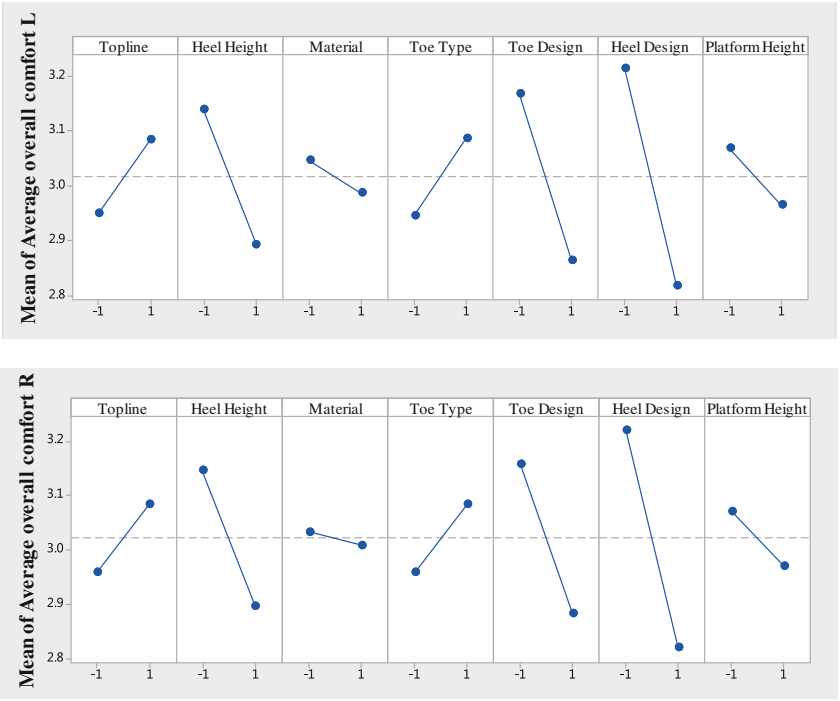


Fig. 2 Main effects plot for average overall comfort

3.3 Interaction Plot

For overall comfort, topline interacts with material, toe type, and toe design. As for overall fit, interactions mainly exist between topline and toe type, topline and toe design, and heel height and toe type.

4 Discussion

With a better understanding of the influences of design factors on footwear fitting and comfort, designers are able to improve their footwear design from the design stage, which can save cost and time for trials and errors in footwear manufacturing, and achieve a final product with good fitting and comfort satisfying customer needs. The results of this study investigated the effects of the seven factors on fitting and comfort, as well as interactions between them. However, the significance of these factors are still not prominent enough due to the limitation of the rating scale. The

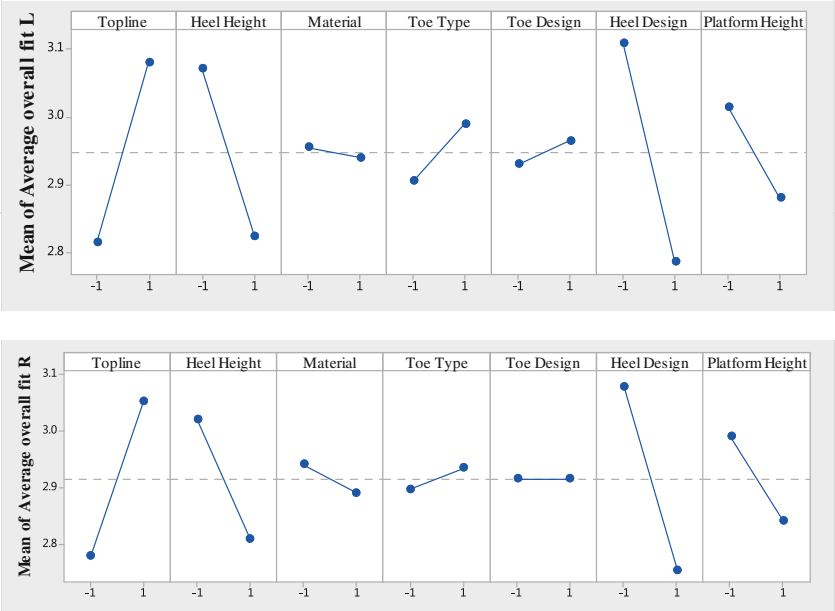


Fig. 3 Main effects plot for average overall fit

details of the interactions are also still waiting to be discovered. Specific analysis will be conducted on the data retrieved in this experiment to find concrete relations and conclusions.

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The Role of Footwear Fitting and Comfort in the Environmental Impact of Footwear

Ameersing Luximon and Lanyin Jiang

Abstract Sustainability has become a global concern in recent years. The traditional production and consumption patterns bring heavy environmental burdens. As the increasing of sustainability and environmental awareness, not only the governments launched regulations and policies to reduce the environmental impacts, consumers also have begun to show interests in eco-friendly products. The footwear industry plays a significant role in the impact of the contribution of apparel section. Various analyses have been conducted on this field aiming at optimizing the footwear life cycle management and design strategy to reduce the impact. As one of the most important properties of wearing products, fitting and comfort can influence consumers purchasing and usage, thus indirectly affects the environmental impact of footwear considering the whole product lifetime. This study focuses on the role of footwear fitting and comfort in the environmental impact of footwear, analysing the influence of fitting in different product life cycle stages.

Keywords Sustainability · Fit · Footwear

1 Introduction

1.1 Life Cycle Assessment

Life Cycle Assessment (LCA) is a common method used to analysis the environmental impacts through the entire life of a product. According to *ISO 14040.2 Draft: Life Cycle Assessment—Principles and Guidelines* [1], the definition of LCA is described as:

Life Cycle Assessment (LCA) is a technique for assessing the potential environmental aspects and potential aspects associated with a product (or service), by:

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- Compiling an inventory of relevant inputs and outputs,
- Evaluating the potential environmental impacts associated with those inputs and outputs,
- Interpreting the results of the inventory and impact phases in relation to the objectives of the study.

LCA takes consideration of all life cycle stages of a product, including raw material processing, manufacture, transportation and distribution, product usage, repair and maintenance, and end-of-life treatment.

The typical LCA consists of four main stages: goal and scope, life cycle inventory, life cycle impact assessment, and interpretation [1]. The goal and scope is a key step that identifies the purpose, sets the boundaries of the study, and determines the assumptions and methods that will be used. Then in the life cycle inventory stage, the raw materials and energy input and environmental output are summarized. The life cycle impact assessment analysis the environmental impacts according to the information collected in the inventory stage, and the interpretation stage gives out possible improvements reducing impacts at each product life cycle stages.

The life cycle inventory requires large database to calculate the environmental output. Lacking of appropriate data may lead to difficulties in conducting LCA and unreliable assessment results. As the application of LCA became wider during the last decades, many databases have been developed to support the inventory, including public national or regional databases, industry databases and consultants' databases. Usually LCA software tools provide databases to help build the inventory and convert to environmental impacts.

1.2 Environmental Impacts of Footwear

Sustainability has become a major concern in recent years. Footwear, as a part of necessary consumables in daily life, its production also involves sustainability and environment considerations. According to *World Footwear Yearbook: 2015 edition*, 24.3 billion pairs of shoes were produced in 2014 [2]. The huge production and consumption of footwear corresponds to significant social and environmental impact, which turns into great pressure to the industry. In order to improve their environmental performance, many companies started to evaluate their productions and publish reports of the impact of their products. Researches also have been conducted to analysis the footwear industry to propose possible solutions to reduce the impact.

In 1998, an LCA case study of leather shoe production (Milà et al. [3]) indicated the important contribution of leather production to the ecological impacts, including the agricultural part and tanning process. There were also important indirect impacts in manufacture stages caused mainly by electricity usage. Albers et al. [4] worked on the LCA of Simple Shoes; the results showed that material production and

manufacturing phase contribute to about 90 % of the environmental impacts of the whole shoe production, due to the raw material consumption and the involvement of machines and equipment. Other impacts are caused during transportation, packaging and end-of-life treatment. Van der Helm conducted a sustainability analysis in 2012 on Bata's footwear focus on 4 existing shoes of this company, including security shoes, pure PVC shoes, pure EVA shoes and leather shoes. The largest part (50–80 %) of Eco-costs and CO_2 equivalents contribution is in the material production phase, especially the production of PU, PVC and EVA [5]. In 2013, Cheah et al. [6] estimated the carbon footprint of a pair of running shoes along its whole life cycle. The total CO_2-equivalent is 14 ± 2.7 kg, while the materials processing stage (29 %) and manufacturing stage (68 %) make up the majority of the environmental impact. The transportation and end-of-life treatment phase contribute 2 and 3 % of the total impact, and the use stage only has 0.03 kg CO_2-equivalent, caused by the water consumption to wash the shoes.

1.3 Assessment of Environmental Impacts of a Product

Van Nes and Cramer [7] assessed the environmental impacts of a product considering its lifetime. The environmental impact during product usage phase $E_{usage} = e \times t$. e, t represents the impact of the (energy) consumption and the product usage time. The environmental impact of a product i over its lifecycle is described as: $E_{(i)} = E_{p(i)} + e_{(i)} \times t$. E_p represents the total impacts during the product production, distribution and disposal.

From this relationship, the total environmental impact continuously increases along the time and has a sudden increase when one product service life ends. The total impact of shorter lasting product is larger than the longer lasting product considering the same E_p and total usage time. According to the previous researches about LCA on footwear, the environmental impact during usage phase E_{usage} only takes a tiny part of the total impact. When applied with this relationship, E_p makes up the majority of the total environmental impact.

1.4 Service Life of Footwear

The service time of a product depends on the replacement decision made by the user. In Van Nes and Cramer's research, they also studied the influencing factors of people's motivation to replace a product. The factors are classified into three main categories: product characteristics, situational influences or external influences, and consumer characteristics. Product characteristics are the functions or other values that a product provides comparing to other products, such as wear and tear, comfort of use, design and quality. Situational influences or external influences refer to the factors outside the essential nature of the product, like the media influence and

market development. Consumer characteristics mean the individual differences on consuming behaviour and replacement decisions [7].

As one of the product characteristics, fitting and comfort can certainly influence the replacement decision, but at the same time, consumers also consider the design, style, quality, functions and other characteristics. This study aims at exploring the influence of fitting and comfort on the service life of footwear, and through the service life how the environmental impact changes with the fitting and comfort.

2 Methodology

A questionnaire was designed to understand the purchase, wearing and disposal habits on footwear. It consisted two parts. The first part was about personal information including gender, age, ethnicity, occupation, shoe size, and the consuming habits on footwear, the number and types of shoes owned and purchased each year, and the factors considered when purchasing shoes. The second part focused on the details of the shoes that were wore frequently and infrequently. Subjects were asked to select three pairs of shoes they often wear and three pairs they seldom wear, then answered the questions on shoe types, wearing frequency, wearing reason, activity, disposal reason and the estimated time they own them before disposal.

The questionnaire was build and distributed through online survey platform. Most of the questions were closed-ended questions.

3 Results

3.1 Participants

60 Chinese subjects between 14 and 48 years old (mean age 23.5) participated in this study, 10 males and 50 females, including 40 students, 29 employee/self-employed and 1 unemployed. Foot sizes ranged from European size 34 to 46, with a mean size 38.

3.2 Questionnaire

Part I. Figure 1 shows the answers of number of pairs of shoes owned, varying from 1 to 30. 11 people answer 10 pairs of shoes. As for the shoe type, the average results show that sports shoes are the most common type, with a number of 2.5 pairs, and sandals and flip-flops come to the second (2.28 pairs). Other choices

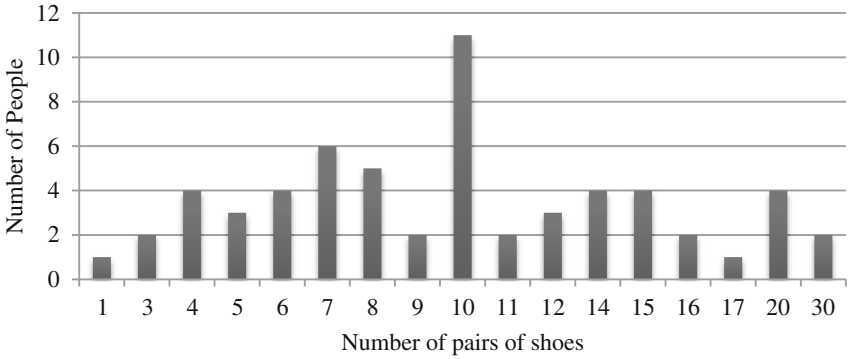

Fig. 1 How many pairs of shoes do you own?

include casual shoes (2.05 pairs), boots (1.77 pairs), dress shoes (1.33 pairs), and others (0.6 pairs). The number of shoes purchased annually follows the same tendency: Sports shoes average 1.2 pairs are the most, then casual shoes (1.03 pairs), boots (0.97 pairs), dress shoes (0.8 pairs), and others (0.33 pairs).

The question on the factors considered when purchasing shoes provides nine choices. Subjects were asked to select the most important three factors and rate their importance. The importance were then calculated according to the formula: Average Score = (Σfrequency × weight)/number of answers. The most important factor is counted as 3 and the third importance as 1. The results are displayed in Table 1. The most importance factor is fitting and comfort (7.14), then appearance (6.87) and price (4.39). Weight, brand and materials are least concerned with average score less than 1.

Part II. The six pairs of shoes were numbered according to the order in the questionnaire. The corresponding wearing frequencies are as follows (Table 2).

To give more clear comparisons according to wearing frequency, the figures and tables are arranged in the order of shoe 1, 2, 3, 6, 5, 4.

As the wearing frequency decreases, fewer people selected sport shoes as their answers, while the answers of dress shoes gradually increase. Dress shoes in shoe 1

Table 1 Which factors do you consider when purchasing shoes?

Factors	Average score
Fitting and comfort	7.14
Appearance	6.87
Price	4.39
Quality	3.00
Functions	1.14
Weight	0.88
Brand	0.49
Materials	0.12
Others	0

Table 2 Wearing frequencies

Shoes often worn	Shoes not often worn
Shoe 1: most often Shoe 2: relatively often Shoe 3: often	Shoe 4: least often Shoe 5: seldom Shoe 6: not often

are more than in shoe 2 mainly because of working dress requirements, which is shown in the following questions. There are no obvious tendency for other three shoe types, and the sudden increase answers of "Others" in shoe 6 is due to the question order: 10 out of 16 people wrote "no other shoes" or similar answers in the last section of the questionnaire, shoe 6 (not often).

For the most often worn shoes, 54.1 % subjects wore them almost every day, 16.4 % every other day, and 27.9 % a few days a week, while the least often shoes, 47.5 % subjects almost never wore them, 27.9 % wore them a few days a year and 16.4 % wore a few days a month.

Table 3 is the average estimated service life of each pair of shoes. The service life ranges from around 2 to 2.5 years. There are only five months' differences between the longest and shortest service life. However, considering the wearing frequency in Fig. 3, the actual wearing time of these shoes have large differences within similar length of service life. For shoe 1, people may wear them every day or every other day, and dispose them after two years because they are broken; but shoe 4 may only be worn a few days a year or almost never worn, and disposed due to new shoes purchased.

The Role of Fitting and Comfort. According to the previous researches, for footwear products, no matter which type of footwear, the majority of environmental impacts are already settled before product usage phase. Considering the total impacts of this kind of products along with time, the longer the shoes' service life is, the less the environmental impact they will cause. In order to extend the service life, reduce the impact in usage phase, of course the product durability needs to be taken into consideration, but for replacement decisions made before the product is worn out, other factors may also influence the total impacts.

Assume that the design/maximum Service Life is SL_0, and product usage frequency f, the impact during usage phase i. The actual service life ($SL < SL_0$), for one product with environmental impact I in a certain period of service time (T):

Table 3 Average service life

	Shoe 1	Shoe 2	Shoe 3	Shoe 6	Shoe 5	Shoe 4
Average service life (months)	23.17	23.10	24.87	23.52	24.83	28.30

$$SL = f \times T \tag{1}$$

Environmental impact effectiveness

$$E = \frac{I + i \times SL}{I + i \times SL_0} = \frac{I + i \times f \times T}{I + i \times SL_0} \tag{2}$$

Higher usage frequency results in higher environmental impact effectiveness of one product. Besides, if $T = 0$, which means that the product is never used, the environmental impact effectiveness of this product E also equals 0 since it never serves its own function but the impacts during material production and manufacturing stages were already made.

Among all the results retrieved from the questionnaire, fitting and comfort stands out in three aspects:

- Factors considered when purchasing shoes
- Wearing reason
- Disposal reason

Fitting and comfort comes to the first place as the most important factor people consider when they purchase shoes. Bad fitting and comfort may prevent consumers buying the shoes, which results in zero impact effectiveness of the footwear.

Good fitting and comfort are the major reason that people wear the shoes frequently, indicating that good fitting and comfort can improve the usage frequency (footwear wearing frequency). Thus the environmental impact effectiveness can be enhanced.

Although fitting and comfort takes a relatively small part in disposal reasons, since consumers will not purchase uncomfortable footwear at first, it may still be considered as a valid footwear replacement reason.

4 Discussion

As one of the essential product characteristics, the fitting and comfort has deep effect on consumer's purchasing of footwear and the wearing frequency, which will further influence the environmental impact of footwear in the lifetime. Results indicated that people tended to purchase and wear the shoes more often mainly due to the good fitting and comfort, and apart from the reason of worn out and poor appearance, people also disposed the shoes because of bad fitting and comfort.

The scope of this study was not large enough and did not cover age groups and occupation equally. The questionnaire can be optimised to a more concise format to improve the quality of answers. Future work will downsize the questionnaire, focusing on the relationship between fitting and comfort and the footwear service life with the help of LCA case studies, to investigate the specific influence of fitting and comfort on the overall environmental impact of footwear.

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Good Sleep Quality and Ways to Control Fatigue Risks in Aviation—An Empirical Study with Commercial Airline Pilots

Sebastian Siebericchs and Annette Kluge

Abstract As sleep is considered an important influencing factor on human fatigue, the correlation between sleep quality and fatigue was investigated. Secondly, the impact of the safety climate on the attitude towards reporting events was examined. One hundred and six German-speaking pilots participated in an online survey. The results showed a high correlation between a poor sleep quality and fatigue ($r = 0.67$) and a high correlation between fatigue and acute fatigue symptoms ($r = 0.68$). The subjective ratings of the safety climate within an organization correlated with the attitude to report human error related events ($r = 0.58$) and correlated with the attitude to report fatigue related events ($r = 0.33$). Further research should investigate the impact of mitigation measures on acute fatigue symptoms.

Keywords Fatigue · Aviation · Sleep quality · Safety climate · Reporting

1 Introduction

"Sleep is winning. My whole body argues dully that nothing, nothing life can attain is quite so desirable as sleep" [1]. This quote of Charles Lindberg's first transatlantic flight impressively demonstrates the vast impact of sleep loss onto the human body. While Lindberg had to fly his plane manually, since then aviation experienced many technological improvements such as different stages of automation. Nevertheless, the phenomenon fatigue still remains one of the major concerns in aviation. Since the working conditions present high challenges for the personnel involved, following accident statistics, pilot reports or operational flight studies, fatigue is even a growing concern in modern aviation [2]. Following the results of a survey from the European Cockpit Association (ECA) in 2012, 92 % of the German

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pilots experienced fatigue, 93 % stated that they made mistakes on flight deck due to fatigue, whereas only 23 % reported fatiguing events by using a fatigue report [3]. As Fatigue leads to mental, physiological and emotional performance impairments [2] and endangers flight safety, beginning in 2016 airlines need to prove organizational structures and valid mitigation measures (Fig. 1) to cope with the effects of fatigue evolving all stakeholders in order to show that they have realized fatigue as a specific hazard to flight operation.

Since sleep has been considered the most important influencing factor on fatigue [4], this work focused on the correlation between the assessment of subjective sleep quality and the level of individual experienced fatigue. In the context of aviation organizations the environment of individuals is determined by shift work, frequent time zone changes but also the safety climate within the organization [2]. Reports of crews concerning safety relevant incidents represent valid source of information for hazard identification. Even though the connection between safety climate and the attitude of employees to report safety related errors resulting from human errors became apparent in recent scientific works [5], in terms of fatigue it is unclear whether individuals feel the necessity to report events, which are explicitly fatigue related.

Fig. 1 A pilot taking a nap on flight deck

2 Sleep, Fatigue and Safety Climate—The State of the Art

2.1 Sleep, Circadian Rhythm and Fatigue

Sleep can be described as "the rest and recovery from the wear and tear of wakefulness" [6]. Sleep deprivation impairs human performance, increases the probably of mistakes and prolongs the time needed to fulfill tasks [7]. Especially in environments like aviation, where a general high-risk exposure is predominant, sleep loss induced mistakes can have significant effects on flight safety [8]. Sleep deprivation (PSD) results, if a human is deprived of a single stage of sleep; whereas total sleep deprivation (TSD) is a result of staying awake continuously [9]. If allowed sleeping after TSD the body will rapidly enter deep sleep stages to recover [10]. Following an International Civil Aviation Organization (ICAO) definition of sleep quality, a high sleep quality is characterized as a restorative value which is marked by several uninterrupted REM/non-REM cycles. Due to the working conditions in aviation industry, TSD as well as sleep inertia can be seen as major problems [7, 11]. To ensure a safe conduct of flight and reduce the risk of sleep inertia it is vitally important to ensure a high sleep quality before commencing duty and to comply with the regulations for controlled rest phases on flight deck [5, 11].

Human alertness varies in a highly predicable manner depending on the time of day. If this circadian rhythm is disturbed by shift work or time shift, performance impairments or disturbances of wakefulness may result [4]. Research about shift workers' performance proved performance degradations of up to 100 % in night shifts in comparison to daytime shifts [12]. Comparisons between shift work and blood alcohol levels show that during night work performance decrements equal to a blood alcohol level of 0.08 % may occur [13]. As the working environment of aviation personnel is characterized by shift work and frequent time zone changes and due to the fact that the adaptability of the circadian rhythm is limited by 60–90 min per day in a new time zone, flight crews in particular suffer from the so-called jet lag syndrome, which is characterized as "a general feeling of malaise with sleepiness, fatigue, insomnia, hunger, and digestive disturbances with constipation or diarrhea" [14].

Shift work, prolonged wakefulness, foreshortened sleep or events like travel across time zones may lead to insufficient sleep [10]. Insufficient sleep can be divided into disruptions of circadian rhythm being a result of changing time zones or shift work and on the other hand in chronic and acute sleep disruption [10]. A condition called circadian desynchrony comes up if normal sleep patterns and wakefulness are disrupted entirely [10]. Comparing acute sleep deprivation, resulting from single periods of extended wakefulness and sleep loss commonly seen in aviation, chronic sleep deprivation is the result of multiple nights with sleep less than 8 h [10]. A combination of acute and chronic sleep deprivation can lead to fatigue, which is a major concern for industries with working conditions that do not allow regularly high quality sleep, like aviation [10].

Fatigue can be seen as "a physiological state of reduced mental or physical performance capability, resulting from sleep loss or extended wakefulness, circadian phase, or workload (mental and/or physical activity) that can impair a crew member's alertness and ability to safely operate an aircraft or perform safety-related duties" [15]. In aviation fatigue has been identified as a highly relevant safety risk since decades [16] and contributes to 4 up to 7 % of all incidents in civil aviation; its psychological, physiological and emotional implication can influence safety and performance in aviation [2, 17]. The full bandwidth of implications of fatigue is often underestimated, although it is known for decades that sleep-deprived people think and move more slowly, encounter memory difficulties and tend to make more mistakes [8]. Fatigue can be subdivided into physical, mental and emotional symptoms and impairs cognitive, motoric and communicative abilities and varies between individuals [2]. In aviation the effects of fatigue have an impact on different important areas of aviators work: A study conducted with 67 experienced long-haul pilots showed that persons suffering from fatigue tend to increase the total number of mistakes significantly while working on flight deck [18]. Individuals suffering from fatigue also tend to a risky shift [19] and are highly impaired in situational awareness [9], which are also both vital aspects for aviators work. Fatigue also leads to an impairment of communication and social interaction [20]. Both aspects are crucially important for a safe conduct of flight, since impairments in communication or social interaction within the team on flight deck may lead to severe outcomes.

To cope with the implications of fatigue on flight safety, a legal requirement for Fatigue Risk Management Systems (FRMS) within the safety management structures of civil aviation industries worldwide will come into place in the beginning of 2016. FRMS focuses on the reduction of risk and "aims to ensure that flight and cabin crew members are sufficiently alert so they can operate to a satisfactory level of performance" [15].

2.2 Organizational Climate

Organizational climate can be defined "as a summary of perceptions that employees share about their work environment" [21]. It can be seen as a multidimensional construct for the evaluation of the work environment by individuals [22]. Considering safety aspects within an organization safety climate, a specific form of organizational climate, describes "individual perceptions of the value of safety in the work environment" [23]. It is a snapshot of the "current manifestation of the safety culture in the organization" [23]. The safety climate also influences employee's attitude to report safety relevant occurrences [11]. Safety promotion describes initiative and effort to improve safety [23]. Valid identification and management of risks in aviation strongly depend on gathering individual information [15]. As the FRMS policy highlights a shared responsibility of crew members and the organization itself, a safety climate in which employees are

encouraged to report fatigue related events plays a key role for data collection [15]. Therefore, the motivation of pilots to participate in safety by reporting safety relevant events is crucially important for working and fatigue risk management structures, taking the specific risk within an organization into account.

2.3 Hypotheses

As sleep has been considered the most important influencing factor on fatigue, the present study focused on the relationship between pilots sleep quality, the level of experienced fatigue and acute symptoms of fatigue while working on flight-deck (research question 1). The relationship between the organizational safety climate and the employees' intent to reporting safety-impairing events resulting from human errors has been drawn clear in recent scientific works. The work presented therefore also examined the relationship between safety climate and pilots' attitudes towards reporting safety impairing events, caused by fatigue (research question 2).

Following hypotheses are examined:

H1: The subjective rating of a poor sleep quality correlates positively with a high level of fatigue.
H2: A high level of fatigue correlates positively with a high intensity of acute symptoms.
H3: The perception of a positive safety climate within the organization correlates positively with a more positive attitude to reporting events.

3 Materials and Methods

3.1 Sample

The sample contained of 106 German-speaking pilots coming from Germany, Switzerland and Austria. The sample of N = 106 consisted of 98 male, six female and two participants who did not state their sex, the age of the persons involved raged from 23 to 58 years (M = 38.18, SD = 9.94). The structure of the survey has been explicitly set up to allow future use in fatigue sensible environments, such as hospitals or nuclear power plants.

3.2 Variables

To assess the construct sleep-quality, the German translation of the Pittsburgh Sleep Quality Index (PSQI) was used [8, 24]. The participants were asked to answer on 4-stage Likert-scale with the endpoints 0 = "not during the last four weeks" and 3 = "three time or more per week" (Example item: "How often did you experience sleep problems, because you felt too cold?"). The internal consistency of the PSQI lies in a good range (Cronbach's $\alpha = 0.83$). The diagnostic validity shows a sensitivity of 0.896 and a specificity of 0.865 (kappa = 0.75, $p < 0.001$) [25].

For the diagnostic of the individual fatigue level the German translation of the Fatigue Scale (FS) including 2 subscales mental and physical fatigue was used [26]. The participants were asked to answer on 4-stage Likert-scale with the scale endpoints 0 = "less than usual" and 3 = "much more than usual". (Example item: "I felt a lack of energy during the last 4 weeks"). The internal consistency ranges in a good level (whole scale Cronbach's $\alpha = 0.93$, physical Fatigue $\alpha = 0.92$ and mental Fatigue $\alpha = 0.86$). The convergent validity of the FS has been proven within clinical studies. A relation has been shown between fatigue and a reduced physical function, cognitive impairments and mental load [27].

In order to assess acute symptoms of fatigue, symptoms mentioned by Avers and Johnson [2] were translated by the author and transferred into items. The participants were asked to state the frequency of symptoms on 5-stage Likert-scale with the endpoints 0 = "never" and 4 = "always".

To assess the subjective perception of the safety climate a German translation by the author of the Aviation Safety Climate Scale including 3 subscales Management "commitment and safety communication", "safety training" and "equipment and maintenance" was used [28]. For the assessment of the safety climate a 5-point Likert scale with the end points 0 = "I strongly not agree" and 4 = "I strongly agree" was used. The internal consistency (Cronbach's alpha) for the whole scale is $\alpha = 0.86$ to $\alpha = 0.93$. The diagnostic validity has been observed using a further item asking for experience of overall safety. The correlation was significant and raged by $r = 0.66$, $r = 0.52$ and $r = 0.62$, $p < 0.001$ for the 3 scales [28].

To assess the attitude towards reporting safety relevant events while working on flight deck, three different scenarios were created. Two scenarios represented situations in which flight safety was endangered by Fatigue; one scenario delineated a hazardous situation due to human error. A 5-point Likert scale with the end points 0 = "never" and 4 = "very sure" was used for the assessment of the attitude to reporting these events.

3.3 Study Design

Participants of the survey were German-speaking persons from the social surroundings of the author, which were asked by E-mail to answer an online survey

taking 20 min. Further on, they were requested to promote this survey to a couple of persons of their own social sphere. In order to avoid misunderstandings or ambiguities German language was used. No remuneration for the participation was offered. The survey was online available for 60 days between 1st of August and 30th of September 2015.

4 Results

The sample consisted of N = 106 pilots. 98 participants were male, six were female and two did not state their gender. 69 pilots stated to fly short-range flights, 39 were flying long-range flights. 43 Captains, 11 Senior First Officers and 47 First officers were included coming from Germany (70), Switzerland (20) and Austria (10).

Hypothesis 1 assumed a positive correlation between a subjective rating of a poor sleep quality and a high level of fatigue. This hypothesis could be kept, since the correlation of $r = 0.68$ showed a medium to high effect size (Table 1).

Hypothesis 2 assumed a positive correlation between a high level of fatigue and a high intensity of acute symptoms. The hypotheses could be kept, since the correlation of $r = 0.70$ represented a high effect size (Table 2).

Hypothesis 3 assumed a positive correlation between the perception of a positive safety climate within the organization and a more positive attitude to reporting events. The hypotheses could be kept, since the correlation of $r = 0.47$ ranged in a medium to high level (Table 3).

4.1 Post Hoc Analyses

Further results showed pilots serving long-range flights tended to have higher values for fatigue ($d = -0.74$), a higher extend of acute symptoms while working on flight deck ($d = -0.55$), but also a higher attitude to report events, compared to pilots on short range airplanes ($d = 0.54$). Considering the position in the crew the results showed that captains experienced a worse sleep quality ($d = -0.88$) and suffered from higher levels of fatigue ($d = -0.89$). Captains also tended to report

Table 1 Results hypothesis test 1

Dimension	*M*	*SD*	α	1	2	3	4
1. Sleep quality	0.79	0.52	0.67	–			
2. Fatigue (whole scale)	0.87	0.58	0.92	0.68**	–		
3. Mental fatigue	0.74	0.56	0.78	0.59**	0.97**	–	
4. Physical fatigue	0.94	0.65	0.91	0.65**	0.88**	0.75**	–

Note **-marked coefficients are significant with $p < 0.01$

Table 2 Results hypothesis test 2

Dimension	*M*	*SD*	α	1	2	3	4	5	6	7
1. Fatigue (whole scale)	0.87	0.58	0.92	–						
2. Mental fatigue	0.74	0.56	0.78	0.88**	–					
3. Physical fatigue	0.94	0.65	0.91	0.97**	0.75**	–				
4. Symptoms (whole scale)	1.11	0.48	0.90	0.70**	0.71**	0.63**	–			
5. Mental symptoms	1.14	0.65	0.85	0.59**	0.65**	0.51**	0.89**	–		
6. Physical symptoms	1.19	0.56	0.81	0.67**	0.68**	0.61**	0.90**	0.70**	–	
7. Emotional symptoms	0.92	0.61	0.75	0.53**	0.50**	0.50**	0.80**	0.57**	0.60**	–

Note **-marked coefficients are significant with $p < 0.01$

Table 3 Results hypothesis test 3

Dimension	*M*	*SD*	α	1	2	3	4	5	6	7
1. Climate (whole scale)	2.87	0.64	0.93	–						
2. Management (sub scale)	2.82	0.71	0.92	0.96**	–					
3. Training (sub scale)	2.90	0.66	0.71	0.82**	0.68**	–				
4. Maintenance (sub scale)	2.94	0.72	0.82	0.86**	0.72**	0.68**	–			
5. Reporting (whole scale)	2.26	0.81	0.85	0.47**	0.44**	0.36**	0.47**	–		
6. Fatigue report items	1.66	0.98	0.77	0.33**	0.32**	0.23*	0.32**	0.93**	–	
7. Human error report item	2.87	0.80	0.82	0.55**	0.51**	0.45**	0.55**	0.89**	0.66**	–

Note *-marked coefficients are significant with $p < 0.01$, **-marked coefficients are significant with $p < 0.05$

more intense acute symptoms while working on flight deck ($d = -0.77$). Events due to human error were much more reported than fatigue related events ($d = 1.35$).

5 Discussion

The purpose of the study was to assess the impact of good sleep quality and ways to control fatigue risks in aviation. The results point out that a poor sleep quality correlates with a high level of fatigue and a high level of fatigue leads to a high intensity of acute symptoms. The perception of a positive safety climate within the organization shows a correlation to a positive attitude to report events, whereas the correlation to reporting human factors related events is higher than reporting fatigue related events.

The results concerning the connection between subjective sleep quality and fatigue coincide with sleep being the major key factor to recover from fatigue [20]. Both, mental and physical aspects of fatigue can be seen as key factors leading to potential hazards in aviation environments. The results show a significantly lower sleep quality of captains, supposed to be the older pilots, in comparison to first officers. It could be shown that the intensity of fatigue symptoms depended on the strength of fatigue experienced by the pilots. In the current study fatigue correlates highest with physical symptoms of fatigue. The correlation with mental symptoms of fatigue is crucially important, since mental elements like attention, communication, decision-making or anticipation of events and the execution of well-practiced behaviors are vitally important aspects for the pilots work on flight deck. Concerning the influence of the safety climate within an aviation organization, the results underline the safety climates' influences onto the attitude to report safety relevant occurrences [5, 20]. The smaller correlation with reporting of fatigue events also marks the high necessity for fatigue needing to come into the focus of airlines regarding to their safety performance level, since for a valid individually based hazard identification subjective individual data is crucially important.

From a methodological point of view, in terms of the used measures and instrument, the Pittsburgh Sleep Quality Index (PSQI) [8, 16] was originally invented to measure sleep quality in clinical populations and shows a relatively low Cronbach's $\alpha = 0.67$. Also, the Fatigue Scale (FS) [26] has been tested for diagnostic use and evaluation of therapies [27], but not for an assessment of a fatigue level amongst pilots, who are regularly tested to ensure a comparably high physical health state.

5.1 Implications for Further Investigations and Fatigue Risk Management Systems

Both, individual and environmental factors influencing fatigue may vary strongly from organization to organization. In addition to that, cultural differences might be expected, since also in aviation organizations cultural differences have a great impact on the climate [29]. Since the team in an airplane does not only consist out of pilots, but also from cabin crew members, further research should be done to analyze cabin crew specific aspects and risks of fatigue endangering the whole flight.

Implications for the practical use and FRMs can be found for individuals and environment. Following the shared responsibility concept, individuals and operators shall take afford to protect from fatigue: Since sleep quality has a big impact on individual's fatigue level, pilots should take advantage to obtain a high sleep quality in order to reduce fatigue and thereby reduce the probability of fatiguing symptoms while working. Another aspect of the individual's responsibility is the attitude to report fatigue related events. Pilots need to accept fatigue as a potential hazard to flight safety and feel a necessity to report events involving fatigue in the same way they would report human error related occurrences. The role of the organization is not only to provide an environment, where reports can be made without punishment, but also to work on a safety climate that encourages individuals to file reports.

As fatigue can happen to everybody despite of age or crew position and every pilot definitely has experienced fatigue and fatiguing symptoms in her/his career, the dully need for sleep, what Charles Lindberg stated in his first transatlantic flight, is well known to every pilot. If both, individuals and organizations comply with their responsibility towards flight safety, fatigue and from fatigue arising risks can be brought to a minimum in the close future.

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Part III
Biomechanical Evaluations

Comfort Posture and Position of Push-Pull Operation of the Sagittal Plane in Standing

Ai-ping Yang, Wen-yu Fu, Guang Cheng, Xin Zhang and Hui-min Hu

Abstract Push-pull operation is often used in daily work and life. The position of the operating lever, the grab bar, handrail, and the buckle slot is one of the main factors that affect the push-pull task performance. Through the test analysis of 30 people's push and pull task, the comfort movement ranges of the elbow joint and the shoulder joint, as well as the acceptable height ranges of hand in the sagittal plane were obtained. The research results demonstrated some practical applications for the comfort evaluation of single light load push-pull operation and the ergonomics evaluation of the general manual control layout and position.

Keywords Push-pull operation · Comfort movement range · Joint · Ergonomics

1 Introduction

The push and pull operation of the upper limb is very common and life, such as the application of various operating levers in the transportation, machining operations, construction equipment, medical equipment, and so forth. The performance of push-pull operation is influenced by many factors, such as lever size, position, force and frequency. Some researchers studied the method of investigation for the disorder of local body function caused by operation [1–7]. Other research studies mainly focused on the operation force and frequency [8–11]. There were also some further studies of the operating posture [12–14]. The size ranges of the control levers also have a certain correlation design standard.

The comfort of push-pull operation under a single and light load in standing was studied in this paper. The comfortable attitude angles of the upper limb of the

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operator were tested, as well as the comfortable ranges of height in the sagittal plane. The study results yielded practical applications for the comfort evaluation of the push-pull operation and the ergonomics evaluation of the manual control layout and position.

2 Comfort Test on Push-Pull Operation in Standing

2.1 Subjects

Thirty healthy college students with no movement disorder were recruited as subjects, including 15 males and 15 females. The means and standard deviations of age, stature, and body weight of the subjects' were 21 ± 1 years, 170.6 ± 7.4 cm, and 63.6 ± 9.9 kg, respectively (Table 1).

2.2 Methods

The subjects simulated the push and pull with their right hands in the sagittal plane. Specifically, the subjects held the operating lever with the right hand, moved up and down along the lever, simulated the push-pull task in the direction of the front and rear, and found the upper and lower limits of the acceptable ranges when the task was completed. The angles between the upper arm and the lower arm were measured using goniometer and recorded, as well as the angles between the body and the upper arm, and the height of the comfortable location. Test scenarios were shown in Figs. 1 and 2.

A statistical analysis of the test data was performed. The comfortable attitude angle ranges and the acceptable position ranges of the upper limb in the direction from the front to the back in the sagittal plane were obtained. Then the results were analyzed and verified.

3 Results

Test results were shown in Table 1 and Figs. 3, 4 and 5. Of the thirty (30) people were tested, the valid data number was 28 (15 males, 13 females).

When the subjects performed push-pull action in the sagittal plane, the comfort ranges of the angle between the upper arm and the forearm were from 119° to 145°, and the ranges of the median were from 120° to 146°. These results were consistent with the corresponding values in the upper limb evaluation method in the literature

Table 1 Experimental test data as well as subjects' profile and anthropometric information

Order number	Gender	Age	Weight (kg)	Height (mm)	Shoulder (mm)	Elbow height (mm)	Angle between upper arm and lower arm (°)			Angle between upper arm and body (°)			Acceptable height (mm)		
							Low position angle	High position angle	Difference	Low position angle	High position angle	Difference	Low position height	High position height	Difference
1	FM	20	60	153	125	97	137	132	5	43	81	38	80	164	84
2	FM	20	72	164	146	106	140	127	13	28	45	17	100	170	70
3	FM	21	74.0	166	143	110	130	117	13	40.5	75.5	35	84	170	86
4	FM	20	48.5	160	132	102	124	109	15	26	84	58	84	162	78
5	FM	20	50	168	135	108	134	114	20	31	61	30	98	138	40
6	FM	21	60	168	136	113	144	92	52	27	56	29	108	156	48
7	FM	21	48	164	136	105	117	110	7	44	56	12	105	135	30
8	FM	21	52	163	137	102	124	106	18	46	71	25	95	145	50
9	FM	21	50	162	134	100	129	121	8	54	70	16	105	145	40
10	FM	21	52.1	160	133	103	126	119	7	58	68	10	115	135	20
11	FM	20	75	172	143	106	123	105	18	44.7	64.5	19.8	90	155	65
12	M	22	69.1	175	154	115	157.7	135.2	22.5	28.2	64.2	36	111	147	36
13	M	21	70	181	154	115	132	119.3	12.7	31.1	76.9	45.8	113	164	51
14	M	20	73.1	180	157	119	158.4	119.8	38.6	53.8	64.5	10.7	118	153	35
15	M	23	60.2	170	135	100	150	120	30	17	35	18	105	120	15
16	M	21	65.0	178	148	111	160	125	35	14	38	24	115	135	20
17	M	20	90.5	173	142	110	150	110	40	25	41	16	110	135	25
18	M	23	66	171	141	105	155	110	45	16	31	15	105	125	20
19	M	22	70	174	145	108	160	115	45	20	34	14	110	130	20
20	M	22	65.0	177	148	110	160	120	40	18	36	18	115	135	20
21	M	24	65.0	186	156	118	165	135	30	38	47	9	115	140	25
22	M	22		172	140	114	144	130	14	42	63	21	100	120	20

(continued)

Table 1 (continued)

Order number	Gender	Age	Weight (kg)	Height (mm)	Shoulder (mm)	Elbow height (mm)	Angle between upper arm and lower arm (°)			Angle between upper arm and body (°)			Acceptable height (mm)		
							Low position angle	High position angle	Difference	Low position angle	High position angle	Difference	Low position height	High position height	Difference
23	FM	21	59	170	140	109	142	135	7	37	66	29	95	120	25
24	FM	22	60	167	138	110	145	136	9	49	54	5	100	120	20
25	M	21	64.3	173	145	109	158	117	41	34	41	7	103	118	15
26	M	21	65	176	146	108	160	120	40	18	36	18	98	128	30
27	M	21	70.0	178	140	114	160	125	35	14	38	24	93	128	35
28	M	20		175	139	113	160	115	45	20	34	14	98	128	30
Average		21.1	63.608	170.571	141.71429	108.57143	144.4678571	119.2607143	25.20714286	32.76071429	54.7	21.9392857	102.4285714	140.0357143	37.60714
Standard deviation		1.04	9.9387	7.40585	7.6925031	5.5472954	14.6362324	10.53612267	14.90749075	13.22011204	16.40627703	12.2396847	10.26474936	16.27877997	21.28874
Median		21	65	171.5	140.5	109	144.5	119.55	21.25	31.05	56	18	104	135	30

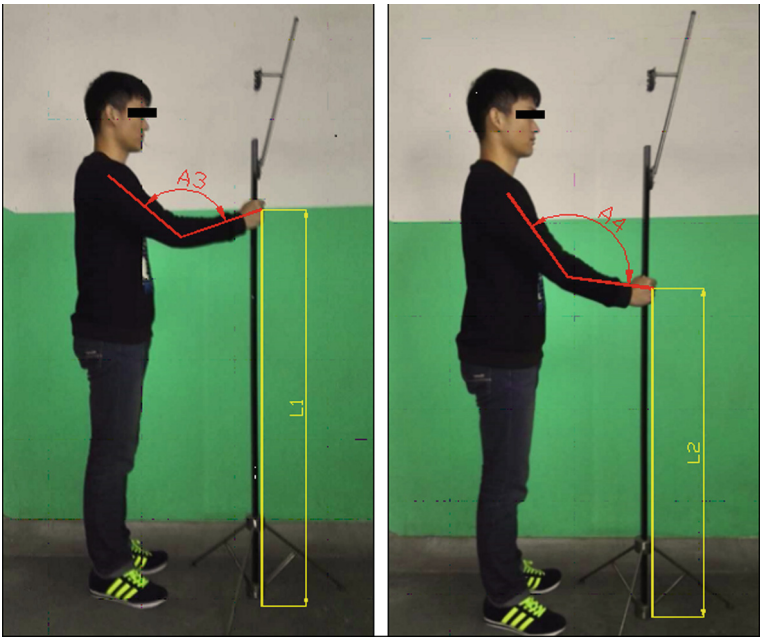

Fig. 1 The angles between the upper arm and lower arm. *A3* indicates the angle at high position, *A4* for the angle at low position. *L1* indicates the height at high position, *L2* for the height at high position

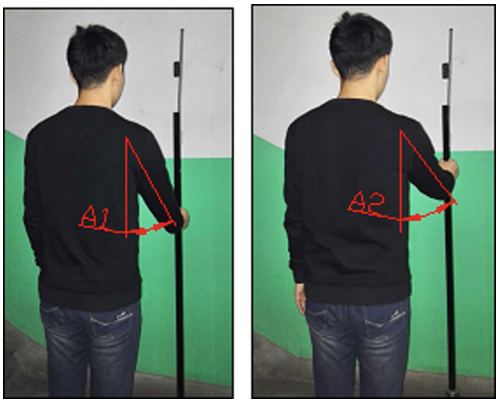

Fig. 2 The angles between the upper arm and body. *A1* indicates the angle at low position, *A2* for the angle at high position

[1] showing that the acceptable ranges of angle between upper arm and forearm were from 100° to 140°.

The comfort ranges of the angle between the upper arm and the body were from 33° to 55°, and the ranges of the median were from 31° to 56°. When these angles were projected into the sagittal plane of the human body, the ranges of the mean

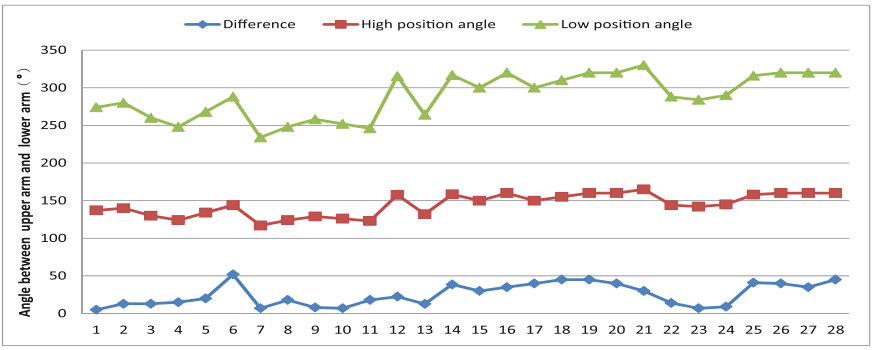

Fig. 3 The angle value between the upper arm and lower arm of the subjects

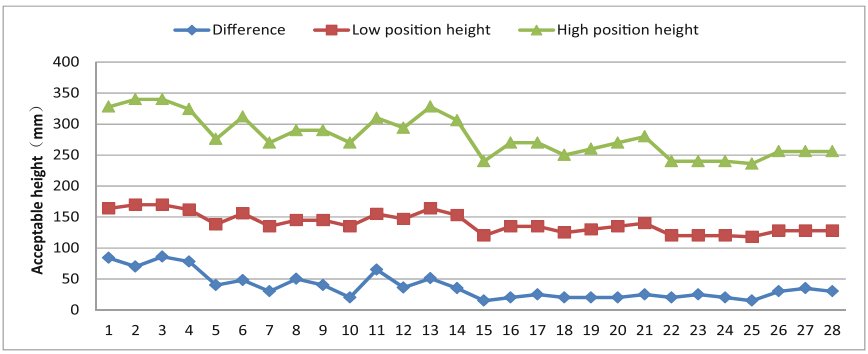

Fig. 4 The angle value between the upper arm and body of the subjects

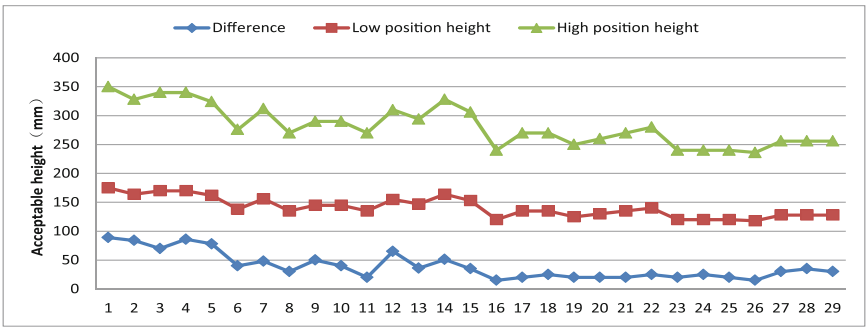

Fig. 5 Acceptable height ranges when the subjects do push pull action

were from 23° to 34°, and the ranges of the median were from 22° to 40°. These results were basically consistent with the comfort angles of the arm (45°) in the literature [1].

The ranges of the mean value of the positions from the middle fingers of subjects to the ground were from 102 to 140 cm, and the ranges of the median were from 104 to 135 cm. The mean and the median of the shoulder height of the subjects were about 142 cm. The average and the median of the elbow height were about 109 cm. The comfortable ranges of the height on the test were below the height of the shoulder, and they were closed to the height of the elbow. They conformed to the operation laws of general human cognition and the literature reviews in Refs. [1–5], indicating that the study results were valid.

4 Conclusion and Discussion

In this paper, the test study of the comfort about the push pull movement in the sagittal plane of the human body was carried out. The ranges of the angle between the upper arm and body, the angles between the upper arm and the forearm, and the acceptable height ranges of the hand were obtained. The results had some practical application for the comfort evaluation of single light load push-pull operation and ergonomics evaluation of the general manual control layout and position.

There were some limitations in the test. The comfort levels of the push-pull action of the ten (10) subjects were higher than those of the shoulder height. This result was different from the relevant conclusions mentioned in the literature [1], which noted that it was easy to cause the upper limb discomfort when the arm was higher than the shoulder in manual operation. As the experimental task was designed for a single light load operation, it was possible to accept a relatively high position of the push pull operation, and the results had to be further supplemented and verified.

There would usually be some measurement error due to manual measurement with goniometer in the experiment. More accurate measurement methods should be adopted in the follow-up experiments.

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Effectiveness of a Balance Chair for Maintaining a Seating Posture During Light-Duty Work

Noriyasu Hirokawa, Takahiro Tanaka, Ken'ichi Itose, Tadashi Shibue, Takashi Hayami, Toru Sawai and Mitsushi Ohmasa

Abstract This study discusses the effectiveness of using a balance chair and adjusting a desk height and working position for maintaining seating posture during light-duty work. It is important for a worker to maintain good posture to improve work efficiency and protect his or her health. However, the worker's body trunk tends to lean forward unconsciously when he or she is working on an ordinary chair. Meanwhile, a person sitting on a balance chair, which comprises a forward-declined seat and a knee pad, can maintain a posture that resembles that of standing. This study measures the body trunk angles of a subject performing light-duty work while seated on an ordinary chair and a balance chair and discusses the influence of desk height and working position.

Keywords Balance chair · Seating posture · Light-duty work · Body trunk angle · Pelvis tilt angle

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1 Introduction

Many people work while seating on chairs. It is important for workers to maintain good postures to improve the work efficiency and protect their health. While it is desired to maintain the posture as like the standing still, the workers' body trunks tend to lean forward unconsciously when they are working on chairs.

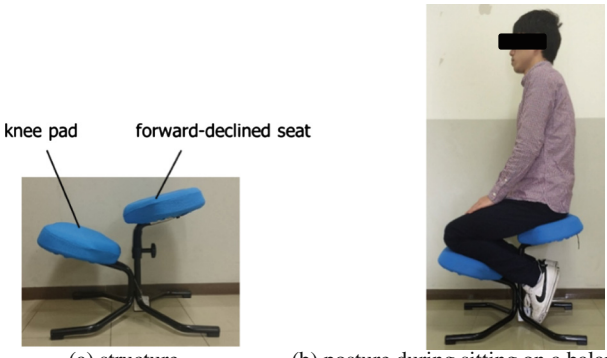
Naito evaluates the sitting posture at desk work by using a depth sensing and the pressure distribution on a chair, and develop a recommendation system to make a good seating condition [1]. Matsumoto classifies the writing state by ambient sedentary behavior sensing using a load call sensors on a chair [2]. Although there are several studies [3, 4] on the workers' seating postures, most of them just evaluate the seating state using sensors on an ordinary chair.

Meanwhile, several types of chairs have been developed to maintain the seating posture such as a balance chair [5], iPole7 [6] and ayur chair [7]. A balance chair comprises a forward-declined seat and knee pad, and a person working on a balance chair can maintain a posture that resembles that of standing, i.e., the spine forms an s-shaped curve and the pelvis remains upright. The aim of this study is to improve the seating posture during light-duty work by using a balance chair considering working conditions such as desk height and working position. This study measures the body trunk angles and estimates pelvis tilt angles of a subject performing light-duty work while seated on an ordinary chair and a balance chair. The effectiveness of the balance chair is then evaluated by calculating the differences of the body trunk seating on a balance chair and standing still. Finally, the influences of a balance chair and working conditions is discussed considering desk height and working position.

2 Posture During Light-Duty Work

2.1 Problems on Seating Posture During Light-Duty Work

People take various postures such as standing posture, seating posture, and lying posture in their daily lives. In office work, many people take seating posture. Daily bad postures such as crossing legs, lean on elbows may invoke lumbar pain, oppression of inward organs, etc. and lead to worker's ill health. Therefore, it is important to maintain a good posture for keeping his or her health [8, 9]. However, light-duty work such as office work do not hurt worker's body seriously and instantly. It rather harms worker's health gradually for a long time and a worker does not think deeply his or her own posture.



(a) structure (b) posture during sitting on a balance chair

Fig. 1 Balance chair. **a** Structure, **b** posture during sitting on a balance chair

2.2 Balance Chair

Figure 1a shows a balance chair used in this study. It comprises a forward-declined seat and a knee pad. As shown in Fig. 1b, a person sits on the declined seat with his or her knees on the knee pad. The person can maintain a posture that is similar to that of standing still, i.e., the spine forms an s-shaped curve and the pelvis remains upright.

3 Evaluation of a Seating Posture Using Acceleration Sensors

3.1 Overview of the Study

Figure 2 shows the overview of the study. The study comprised two experiments. In experiment 1, the angles at T7 (the seventh vertebra from the top, which corresponds to the breast) and L4 (the forth lumbar vertebra, which corresponds the lower back) are measured while a subject is sitting still on an ordinary chair and a balance chair, and they are compared to show the effectiveness of a balance chair for maintaining a good posture. In experiment 2, these angles are measured while the subject is sitting on a balance chair and doing light-duty work under the conditions combining the several desk heights and working positions to discuss their influences. In the experiment, the subject input a newspaper article on a notebook PC as a light-duty work and the working position is changed by the PC location on the desk.

In both of the experiments, it is desired that the subject's posture on a chair resembles to that when standing still. The average absolute value of difference of

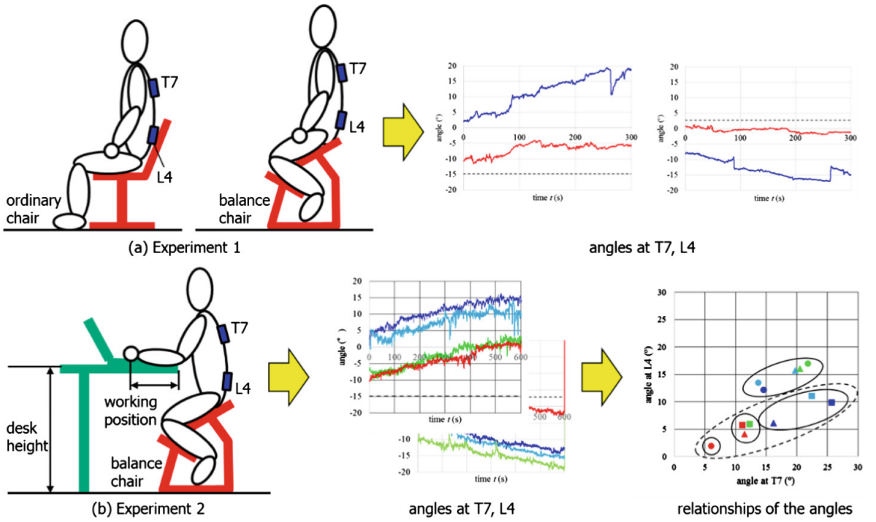


Fig. 2 Overview of the study

the angles between seating posture and standing still posture is calculated and it is desired to be small.

3.2 Measurement Systems

Figure 3 shows the measurement systems for experiment 2. (In experiment 1, the measurement systems are almost same except for the following point: neither of the desk nor the PC are not used and the subject is just sitting still on a balance chair or an ordinary chair.) It consists of acceleration sensors, a web camera and a notebook PC. The acceleration sensors are attached on the back of a subject at T7 and L4. They detects the components of the gravity acceleration at T7 and L4 and send them to the PC via Bluetooth communication while the subject is seating on a balance chair or an ordinary chair. The angles at T7 and L4 are calculated by a computer software DataConverter (ATR Promotions, Inc.) using the x-, y-, z-components of the gravity. If the angles are positive, the subject leans forward his or her body trunk. While the pelvis tilt angle should be measured directly by using a tiltmeter, it requires much skills and it cannot be measured during the experiment, the angle of L4 is used as a substitute for the tilt angle. And the web camera captures the posture of the subject from the side.

In this study, TSND121 (ATR Promotions, Inc.) is used as an acceleration sensor. Its maximum resolution is 200 Hz. It is attached to the body as its z-axis directs to the body, and its x-axis directs to the upward. The data sent from the acceleration sensors are recorded by SyncRecord (T) (ATR Promotions, Inc.) installed in the PC with the scene captured by the web camera, HD Pro Webcam

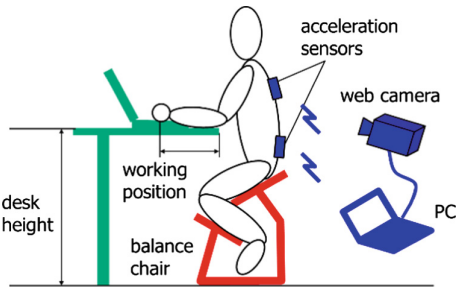


Fig. 3 Measurement systems for experiment 2

C920t (Logitech). Balance Study Support 5064 [5] (HAG) is used as a balance chair and KKV-251AE-T4N5 (Itoki Corp.) is used as an ordinary chair. Both of the angles of the seat and the knee pad of the balance chair are 30°. Lift2 90LBR (Nitori Co. Ltd.) is used as a working desk. Its height is 69 cm and the height is changed by inserting magazines under its legs.

3.3 Procedures of the Experiments

Experiment 1: Seating Postures on an Ordinary Chair and a Balance Chair. In experiment 1, the effectiveness of a balance chair to maintain a good posture in sitting still is investigated. The procedure of the experiment is described below:

1. The acceleration sensors are attached to the subject's body at T7 and L4.
2. The body trunk angles at T7 and L4 are measured while the subject is standing still for 10 min. The values at time t (s) are denoted by $\Theta_{T7}(t)$ and $\Theta_{L4}(t)$, respectively and their averages $\overline{\Theta_{T7}}$ and $\overline{\Theta_{L4}}$ are calculated.
3. The body trunk angles at T7 and L4 are measured while the subject is sitting still on an ordinary chair for 5 min. The values at time t (s) are denoted by $\theta_{T7}(t)$ and $\theta_{L4}(t)$, respectively.
4. The differences of the body trunk angles between those of sitting on a chair and standing still are calculated by the averages of $\left|\theta_{T7}(t) - \overline{\Theta_{T7}}\right|$ and $\left|\theta_{L4}(t) - \overline{\Theta_{L4}}\right|$, which are denoted by $\overline{\left|\theta_{T7}(t) - \overline{\Theta_{T7}}\right|}$ and $\overline{\left|\theta_{L4}(t) - \overline{\Theta_{L4}}\right|}$, respectively.
5. The subject takes a rest for 5 min.
6. Steps 3–5 are executed when the subject is sitting on a balance chair.

Experiment 2: Appropriate Desk Height and Working Position on a Balance Chair during Light-duty Work. In experiment 2, the relationships between the subject's posture and a desk height and a working position during seating on a chair and doing a light-duty work is investigated to discuss the influences of the desk height and the best working position. The procedure of the experiment is described below:

1. The acceleration sensors are attached to the subject's body at T7 and L4.
2. The desk height is set to the ordinary height (A1: 69 cm from the floor) and the PC keyboard is located at the near working position (B2: 3 cm from the front edge).

3. The body trunk angles at T7 and L4 are measured while the subject is sitting still on a balance chair and input characters on a PC keyboard for T = 10 min. The values at time t (s) are denoted by $\theta_{\mathrm{T7}}(t)$ and $\theta_{\mathrm{L4}}(t)$, respectively.
4. The differences of the body trunk angles between those of standing still and sitting on a chair are calculated by the averages of $\left|\theta_{T7}(t) - \overline{\Theta_{T7}}\right|$ and $\left|\theta_{L4}(t) - \overline{\Theta_{L4}}\right|$, which are denoted by $\left|\overline{\theta_{T7}(t) - \overline{\Theta_{T7}}}\right|$ and $\left|\overline{\theta_{L4}(t) - \overline{\Theta_{L4}}}\right|$, respectively.
5. After the subject takes a rest for 20 min, steps 3–4 are executed for the ordinary working position (B1: 10 cm from the front edge).
6. After the subject takes a rest for 20 min, steps 3–4 are executed for the far working position (B3: 19.5 cm from the front edge).
7. After the subject takes a rest for 20 min, steps 3–6 are executed for the ordinary desk height +5 cm (A2: 74 cm from the floor).
8. After the subject takes a rest for 20 min, steps 3–6 are executed for the ordinary desk height +10 cm (A3: 79 cm from the floor).
9. After the subject takes a rest for 20 min, steps 3–6 are executed for the ordinary desk height +15 cm (A4: 84 cm from the floor).

4 Experimental Results

This section reports the experimental results and discusses the effectiveness of a balance chair to maintain the posture during a light-duty work.

4.1 Subjects

Two subjects (Subject A and B) participated the experiments. Subject A is a 22 year old male student whose height is 169 cm and weight is 65 kgf. Subject B is also a 22 year old male student whose height is 171 cm and weight is 58 kgf. This report mainly presents the result of subject 1.

4.2 Experiment 1: Seating Postures on an Ordinary and a Balance Chairs

Figure 4 shows the seating postures of subject A on an ordinary chair and a balance chair at t = 0 (s) and t = 5 (min), respectively. It shows that the upper trunk leaned forward when the subject was sitting on an ordinary chair as shown with the yellow line, while it did not lean forward when he was sitting on a balance chair.

Figure 5 compares the angles at T7 and L4 with those at standing still. It shows that when the subject was sitting on the balance chair, the variances of the angles on

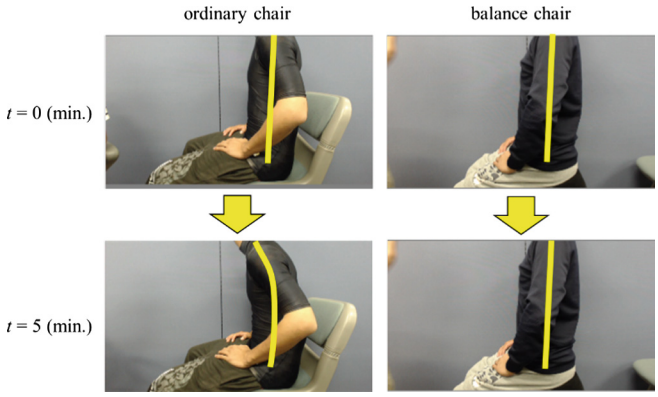


Fig. 4 Seating posture on an ordinary chair and a balance chair (Subject A)

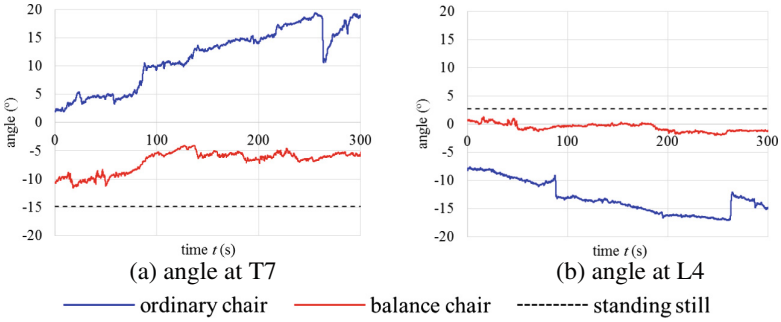


Fig. 5 The angles at T7 and L4 during sitting on an ordinary chair and a balance chair (Subject A). These graphs show the moving averages of the angles within ±0.3 (s) at each time. The dashed lines means the angles at standing still. They are $\overline{\Theta_{T7}} = -14.89(^{\circ})$ and $\overline{\Theta_{L4}} = -2.74(^{\circ})$. **a** Angle at T7, **b** angle at L4

the balance chair from those during standing still were smaller than those on an ordinary chair. These facts mean that the balance chair is more effective for maintaining a good posture than the ordinary chair.

4.3 Experiment 2: Influences of Desk Height and Working Positions on a Balance Chair During Light-Duty Work

Figure 6 show the postures of subject A for twelve experimental conditions, which are combinations of four desk heights in the rows ((A1): ordinary height (69 cm), (A2): ordinary height +5 cm (74 cm), (A3): ordinary height +10 cm (79 cm), and (A4): ordinary height +15 cm (84 cm)) and three working positions in the columns

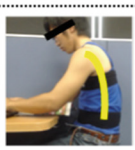
desk height	time t (min.)	(B3): far from the body (19.5cm from the front edge)	(B1): ordinary position (10 cm from the front edge)	(B2): near to the body (3 cm from the front edge)
(A4): ordinary height +15 cm (84 cm from the floor)	$t = 0$			
	$t = 10$			
(A3): ordinary height +10 cm (79 cm from the floor)	$t = 0$			
	$t = 10$			
(A2): ordinary height + 5 cm (74 cm from the floor)	$t = 0$			
	$t = 10$			
(A1): ordinary height (69 cm from the floor)	$t = 0$			
	$t = 10$			

Fig. 6 Postures for twelve experimental conditions (Subject A)

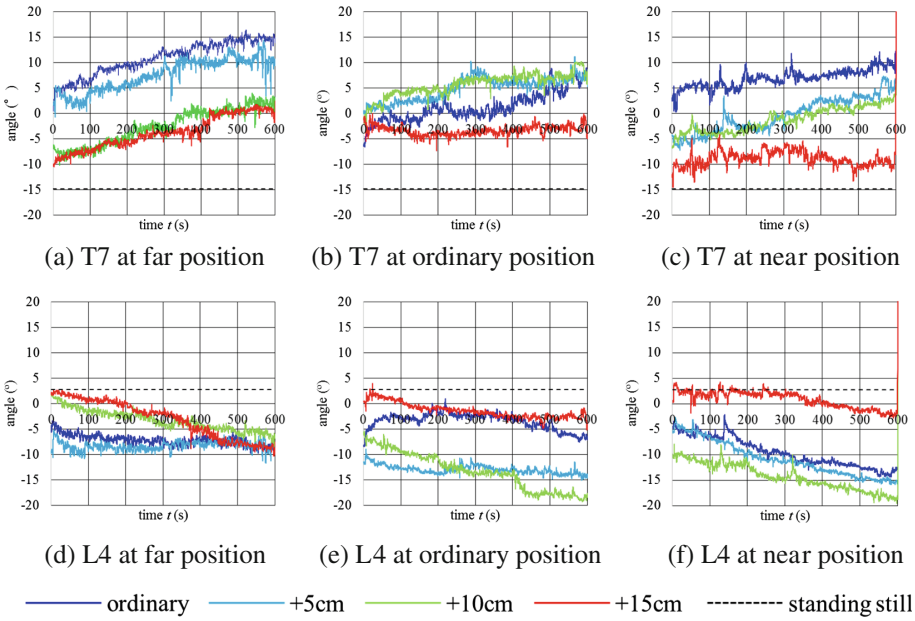


Fig. 7 Angles at T7 and L4 in experiment 2 (Subject A). **a** T7 at far position, **b** T7 at ordinary position, **c** T7 at near position, **d** L4 at far position, **e** L4 at ordinary position, **f** L4 at near position

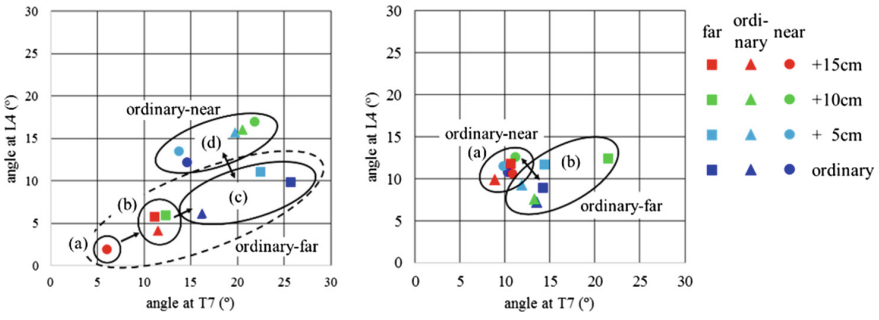
((B1): ordinary position (10 cm from the front edge), (B2): near to the body (3 cm from the front edge) and (B3): far from the body (19.5 cm from the front edge)). In the figure, postures at time t = 0 and 10 (min) are presented for each condition. In most of the cases, body trunk postures leaned at t = 10 (min) and lean angles seems to be small if the desk height is high and the working position is near to the body.

To compare the lean angles numerically, Fig. 7 show the body trunk angles at T7 and L4, $\theta_{T7}(t)$ and $\theta_{L4}(t)$, for twelve experimental conditions. In the figures, the horizontal axis shows the time t (s) and the vertical axis shows the angle $\theta_{T7}(t)$ (°) or $\theta_{L4}(t)$ (°). The red, green, sky blue and blue lines show those of conditions disk height, (A1): ordinary height (69 cm), (A2): +5 cm (74 cm), (A3): +10 cm (79 cm), and (A4): +15 cm (84 cm), respectively. And the dashed black lines show the body trunk angle at T7 or L4 when the subject is standing still, $\overline{\Theta_{T7}}$ (°) or $\overline{\Theta_{L4}}$ (°). $\theta_{T7}(t) > \overline{\Theta_{T7}}$ means that the upper body trunk at T7 leaned forward and $\theta_{L4}(t) < \overline{\Theta_{L4}}$ means that the lower body trunk at L4 leaned backward. From the figures, in most of the cases, the red lines which represent (A4): ordinary height +15 cm are closer to dashed black line, standing still. The fact indicates that higher desk helps to maintain a good posture.

4.4 Discussion

The influences of the desk height and working position are discussed in this subsection. Figure 8a, b show the relationships between $\left|\theta_{T7}(t) - \overline{\Theta_{T7}}\right|$ (horizontal axis) and $\left|\theta_{L4}(t) - \overline{\Theta_{L4}}\right|$ (vertical axis) of subjects A and B, respectively. Each value is preferred to be small and the lower-left region is better. In Fig. 8a, the data of the subject A are divided into four groups, (a), (b), (c) and (d). The group (a) contains just one datum (desk height is (A4): +15 cm and working position is (B1): near to the body) and it is superior to the others. The group (b) contains three data and is the second best group. Other results are divided into two groups (c) and (d). While $\left|\theta_{T7}(t) - \overline{\Theta_{T7}}\right|$ (horizontal axis) of the data in groups (c) and (d) are almost same, $\left|\theta_{L4}(t) - \overline{\Theta_{L4}}\right|$ (vertical axis) of the data in group (d) is larger than those of group (c). The groups (a), (b) and (c) align linearly as shown with the dashed circle in Fig. 8a, which indicates that $\left|\theta_{T7}(t) - \overline{\Theta_{T7}}\right|$ and $\left|\theta_{L4}(t) - \overline{\Theta_{L4}}\right|$ increase proportionally in these order. Figure 9a shows the schematic postures of subject A in the longitudinal section with the above-mentioned groups. In group (a), the posture is relatively upward. As the groups move from (a) to (b) and (c), the upper body trunk leans forward and the lower body trunk leans backward more proportionally. The lower body trunk in group (d) leans backward more than those in group (c) while the upper body trunk in both of the groups are almost same.

In Fig. 8b, the data of the subject B are divided into two groups, (a) and (b). $\left|\theta_{T7}(t) - \overline{\Theta_{T7}}\right|$ (horizontal axis) in group (a) are relatively small than those in group (b). Figure 9b shows the schematic postures of subject B in the longitudinal section with the above-mentioned groups. The upper body trunk in group (b) leans forward more than those in group (a) while the lower body trunk in both of the groups are almost same.



(a) Subject A (b) Subject B

Fig. 8 Relationships between the angles at T7 and L4 in experiment 2. **a** Subject A, **b** subject B

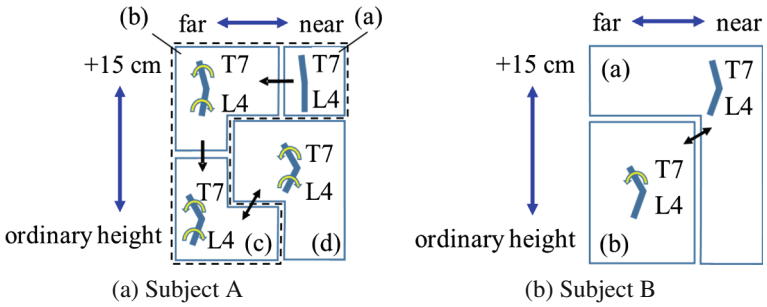


Fig. 9 Schematics of the postures in the longitudinal section. **a** Subject A, **b** subject B

In both of the subjects, it seems that the data are roughly divided into two posture tendencies that correspond to "ordinary-near" and "ordinary-far." It is observed that the postures lean more in "ordinary-far" region, which means the desk height is lower and the working position is far.

5 Conclusion

This study investigates the posture of a worker doing a light-duty work on a balance chair considering the desk height and working position. In the study, first the effectiveness of a balance chair during sitting still is evaluated comparing to that of an ordinary chair. Then, the influence of a desk height and working position using a balance chair is investigated. As a result, it is observed that higher desk height and nearer working position is desired for maintaining a good posture. As a future work, to investigate the effectiveness of a balance chair, the authors plan to continue the research on more subjects considering other working conditions such as type of light-duty work except for typing on a notebook PC, its efficiency, physical load.

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Analysis and Evaluation of Physical Workload Regarding Non-cyclic Tasks

Lukas Bier, Katharina Rönick, Dorothee Müglich, Andrea Sinn-Behrendt, Verena Bopp and Ralph Bruder

Abstract Most of the ergonomic methods to rate the physical strains of jobs (EAWS for example) can only be used for traditional production workplaces such as assembly lines. Craft professions are difficult to rate with these methods, since the tasks of these professions are long cycled or uncycled and do not repeat after a short time. This work will show a new way, making it possible to conduct a work place assessment for long or uncycled tasks using the example of roofers and carpenters. The so called SOP method uses short sections of a working day to define the whole strain of a day.

Keywords Human factors · Workload · Construction workers · Video analysis · Posture · Manual material handling · Action forces

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1 Introduction

Within the project HANDgerecht, funded by the German Initiative New Quality of Work (www.INQA.de) of the Federal Ministry of Labour and Social Affairs, it was the objective to find bottlenecks rin the work structure of roofers and carpenters from a perspective regarding health. Therefore the workload intensity had to be measured. But since the work of carpenters and roofers can be defined long cyclic as non-cyclic or, common methods to analyse the workload were not applicable.

Long tasks have a cyclic time of >10 min, however, non cyclic tasks do not have any recognizable cycle. One can find these kinds of tasks in areas of manufacturing, maintenance or in the repair of trains, buses or planes. The characteristics of these tasks are that the workload intensity is highly variable, and includes workload peaks as well as physiological bottlenecks (see Fig. 1). In contrast short-cycle tasks, which are known as assembly lines, are usually tasks in the automotive industry. They are characterized by a cyclic time of >3 min and a steady periodic workload intensity.

When compared with the analysis of a short cycle task it can be stated, that data collection and data analysis of long or non-cyclic tasks is much more complex and difficult. In addition existing ergonomic evaluation methods [e.g. the Ergonomic Assessment Worksheet (EAWS)] have only limited relevance for long cyclic tasks [1]. Therefore, only little research on long or non-cycle tasks and their evaluation exists. The IAD [2] analysed about 100 long cyclic workplaces with video recording. Kuhlang et al. [3] analysed about 20 long cyclic workplaces with a work sampling method.

The conclusion of Wells et al. [4] and Schaub et al. [1] is that long or non-cyclic tasks need to be separated into steps in order to be analysed.

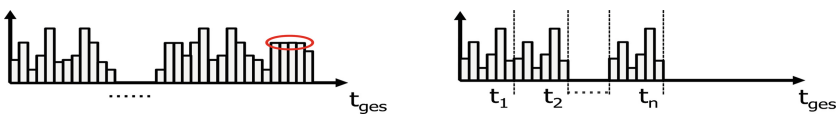


Fig. 1 Workload disposition of long or non-cyclic tasks (*left*) and short cyclic tasks (*right*)

2 Method

As described above, the main problem of non-cyclic tasks is, that the postures and other types of workload do not occur in a repeating pattern. Therefore it is not sufficient to analyse and evaluate a small segment of the day, because this could lead to wrong conclusions about the workload. Furthermore it is assumed, that the workload of small tasks shows those certain patterns in which the postures etc. recur. For example if a roofer reconstructs a flat roof during one day he has to fulfil certain tasks as shown in Table 1. Those tasks are accompanied by very different workload characteristics.

This results in elaborate analysis, where not only whole working days have to be examined but also many times that amount of time has to be invested for possible video analysis.

Buchholz et al. [5] tried to reduce this expenditure by developing the PATH method, assuming that ergonomic exposures are a function of the task. The concept of the PATH method is to evaluate the workload within tasks and to observe postures every 45–60 s.

Table 1 Example of tasks and steps during reconstruction of a flat roof

Tasks	Time	Steps
Teardown old roof	08:05–08:09	Remove nails
	08:09–08:21	Cut tracks
	08:21–08:47	Cut bitumen with saw
	08:47–08:51	Remove safety caps
	08:51–09:48	Remove insulation
	09:48–09:55	Remove wooden planks around skylight
	09:55–10:00	Fill trash bin
	10:00–10:07	Vacuum the roof
	10:07–10:10	Load bags of old insulation to crane
Fit vapor barrier	10:10–10:58	Lay and glue vapor barrier on the roof surface
	10:58–11:20	Glue vapor barrier of skylight and other corner pieces
Mount insulation	11:20–11:28	Move insulation on the roof
	11:28–11:40	Cut and lay insulation around skylight
	11:40–13:15	Lay insulation on roof surface in two layers
Install roof sheeting	14:05–14:15	Move roof sheeting rolls
	14:15–14:25	Fit roof sheeting
	14:25–14:37	Weld roof sheeting by use of welding machine
	14:37–15:00	Fit roof sheeting
	15:00–15:12	Weld roof sheeting by use of welding machine
	15:12–15:30	Cut roof sheeting
	15:30–15:46	Fit and weld corner pieces by hand

Even though this method enables a less stressful job analysis it is limited to analysis of body postures. The PATH method is assumed to not be sufficiently accurate for the analysis of postures in combination with the manual handling of loads and action forces, since it can only account for moments when a load was handled, but does not document for how long the load was handled. In addition the PATH method requires the observer's constant attention.

2.1 Scientific Approach—The SPO Method

A different method to the PATH method assumes, that a short period of time includes more information than a single moment. Particularly Short Periods of Observation (SPO) have been expected to be more accurate and also more informative regarding action forces and the handling of loads. As a consequence work on constructions sites was recorded with cameras and later analysed with the TEA Captiv software. Instead of analysing the whole workday, the workday was analysed using only a sequence of each task.

Figure 2 displays the possible reduction of time needed for video analysis. The lower part of the figure shows the SPO sequences. Since video analysis, on average, takes four times the time of the analysed video sequence, the saved time will be multiplied by four as well.

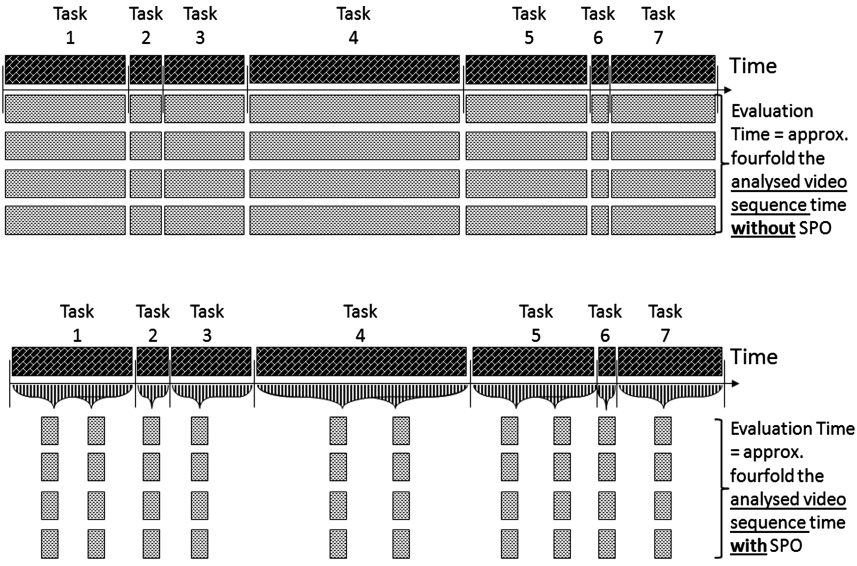


Fig. 2 Comparison of the video evaluation time with and without SPO

The main goal of this study was to research how long those sequences have to be to give the most accurate results in comparison to a complete analysis of the data. Therefore the videos were analysed completely, as well as in sections.

2.2 *Procedure During the Field Study*

Evidently it is inevitable for an ergonomic job analysis of non-cyclic work—in this case for carpenters and roofers—to define the work content at first. For this purpose, at the beginning of each working day a brief meeting was held between the three observers of the institute and the staff at the construction site. The staff then defined the objective of the working day and the tasks (see Table 1) needed to achieve the goal. The actual steps (also see Table 1), taken by the observed workforce were monitored and named by one of the observing researchers.

One researcher was filming a specific person the whole day, as it was determined to be more necessary to document the actual workload of one single person rather than document all the different tasks on a construction site. The focus during this filming was to capture the observed as close as possible in full-body perspective. The video was expected to deliver information on postures as well as action forces and handling of loads. The camera in use was an action cam of the latest generation, since action cams are small, light and water resistant. With these cameras, which were mounted on a light tripod, it was possible to be flexible and even follow the workers on the scaffold. Flexibility was important in order to avoid disturbance to the construction worker in his routine.

It is certain that loads and action forces cannot be measured through a video, which is why the second and third observer defined the work steps and wrote down all the material measurements, tools used and loads handled during those steps. The procedure for weight documentation is depicted in Fig. 3. It was always preferred to

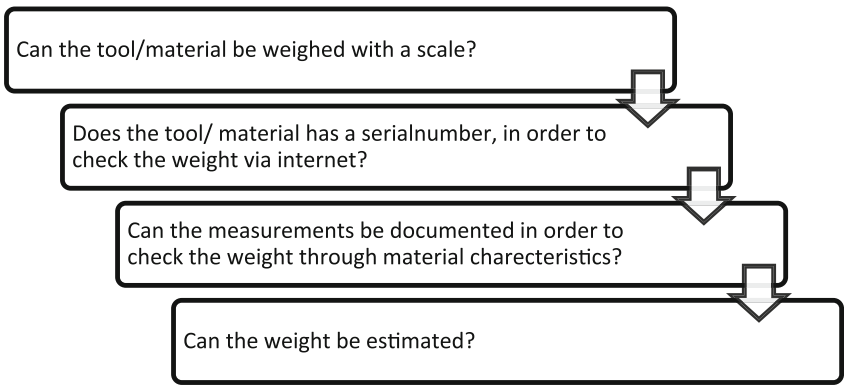


Fig. 3 Hierarchy of weight documentation during the field study

use a scale, but constant measuring would disrupt the workflow too much. That is why a hierarchy of weight documentation was developed.

Admittedly such a procedure is not adaptable for action forces. Yet it is necessary to take action forces into account. For this reason estimated action forces to the machine handling of a power drill. The manual force itself needed to operate a power drill was tested in a small lab study with 5 people and discerned to be 100 N for downward drilling.

During the study further notes were taken and questionnaires used, which did not contribute to the research of this paper.

2.3 *Video Analysis with the TEA CAPTIV Software*

The software CAPTIV allows video evaluation in real time, based on predefined shortcuts (see Fig. 4). For this study the shortcuts enabled the evaluation of postures, asymmetry effects, action forces and manual material handling, based on the sections 1–3 of the EAWS form v1.3.3 [6].

Following EAWS principles a worker cannot execute work load types from different categories simultaneously (The only exception is the Asymmetry Section,

Fig. 4 User interface and evaluation elements sorted by categories in CAPTIV

which is combined with the Posture Section). However for the video analysis it is important that this principle is suspended, since in later evaluation it matters in which posture Action Forces and Material Handling was executed. As a result Postures were analysed constantly and only Action Forces and Material Handling foreclosed each other.

This eventually resulted in difficulties for some instances when it was important to decide, which work load type prevailed. To give an example; a worker is holding a heavy drill while walking around. In this case "Carrying" from the category Manual Material Handling will outweigh. If in contrast he works with the drill, it may be that "Body Forces in direction B-" from the category Action Forces prevail. Since the decision which type of load predominates in a moment cannot always be met with sufficient certainty the evaluation results may vary with different evaluators.

If, during general evaluation, a load is heavy enough to be categorized as material handling/load handling, the video analysis was supported using the notes taken by second and third evaluator. The EAWS requirement is that a load has to weigh at least 3 kg to be categorized as a load and Action Forces have to exceed 30 N for Finger Forces or 40 N for Body Forces.

Following the principle described above, a total of eight working days of carpenters and roofers were evaluated.

The software illustrates the selected workloads in a timeline and the timeline can later be exported to an Excel worksheet where the time slices of each work load are shown in percentage.

In addition CAPTIV offers the possibility to combine the data of different selected timeframes into one tabular output. This function was further used to extrapolate the data of short periods across a whole working day. For this matter the tasks and steps as shown in Table 1 were used in the following ways:

- 2 Random hours of a work day where extrapolated to a whole workday.
- 10 % of each step were selected, evaluated and extrapolated to a whole workday.
- 20 % of each step were selected, evaluated and extrapolated to a whole workday.
- 30 % of each step were selected, evaluated and extrapolated to a whole workday.

10, 20 and 30 % where randomly chosen as iterative steps. The results were later compared to the data of the complete evaluation, in order to see which SPO procedure delivers the most accurate results (Fig. 5).

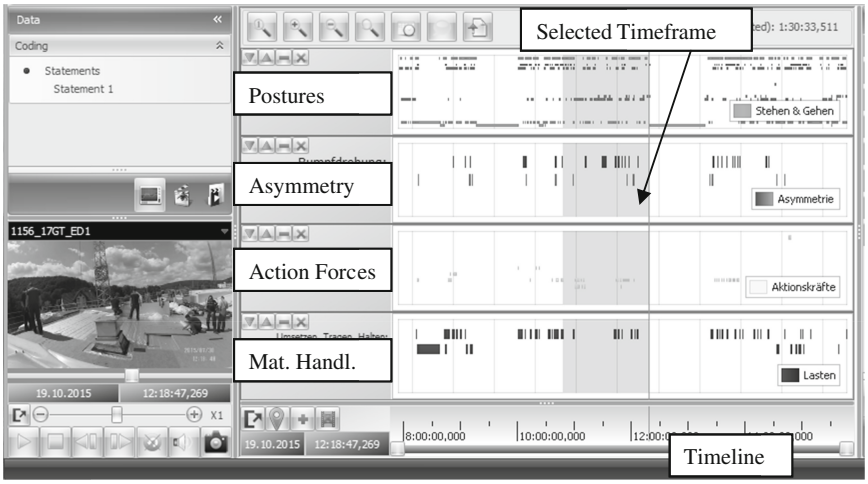


Fig. 5 Work load depicting timeline in CAPTIV

3 Results

The data revealed, that the extrapolation of only 10 % of the tasks failed to reach the accuracy of the overall evaluation. As shown in Table 2 the values for the Standing Section differed when:

- standing, no body support by 15.45 %,
- bent forward (20°–60°) by 0.78 %,
- strongly bent forward (>60°) by 14.13 %,
- walking by 4.34 %,

from each other. These results recurred with different workers and sections.

With a higher percentage of time analysed per steps, the values became more accurate. For the 30 % extrapolation the values differed from each other as shown in the following:

Table 2 Comparison of the workload data of one worker by extrapolation compared to accurate data for the EAWS section standing

	Standing, no body support	Bent forward (20°–60°)	Strongly bent forward (>60°)	Walking
Overall	29.58	23.71	16.29	28.19
10 % extrapolation	14.13	22.93	30.42	32.53
20 % extrapolation	17.03	22.99	31.46	27.94
30 % extrapolation	22.24	23.51	28.93	23.89

- standing, no body support by 7.34 %,
- bent forward (20°–60°) by 0.2 %,
- strongly bent forward (>60°) by 12.64 %,
- walking by 4.3 %.

The values from the 30 % extrapolation showed the best accuracy and were compared again, but this time to a more random approach. Since the 30 % method required that a whole working day was filmed in order to document all the steps taken, it was of interest to see, if it is enough to analyse only a random part of a working day. By using this method it would be sufficient to just film a random part of the working day.

Figure 6 depicts the body postures for one worker during one working day divided into the different extrapolation methods compared to the overall evaluation. The graph only shows the postures with a proportion of not less than 3 %.

The comparison shows, that the extrapolation for two random hours is far off the actual values in parts, while the 30 % extrapolation results in very accurate values.

The values for the Action forces are depicted in Fig. 7. The difference between the Forces presents the direction in which the force is applied. Therefore other muscle groups are activated and consequently the analysis was taken separately.

The extrapolation of both the 30 % rule and the RAM 2 h rule applied to Action Forces and Material Handling (see Fig. 8) gave similar results. Nonetheless, the 30 % extrapolation seems to be more accurate.

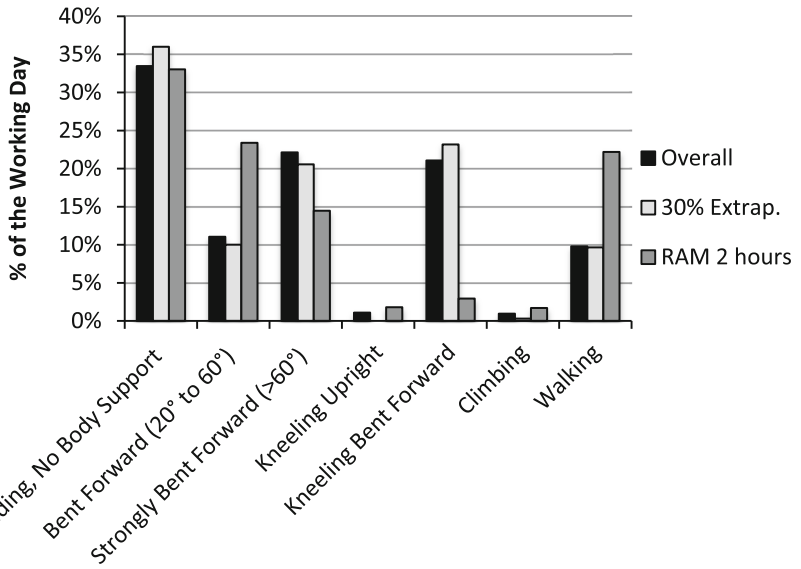


Fig. 6 Comparison of the distribution of posture for one worker

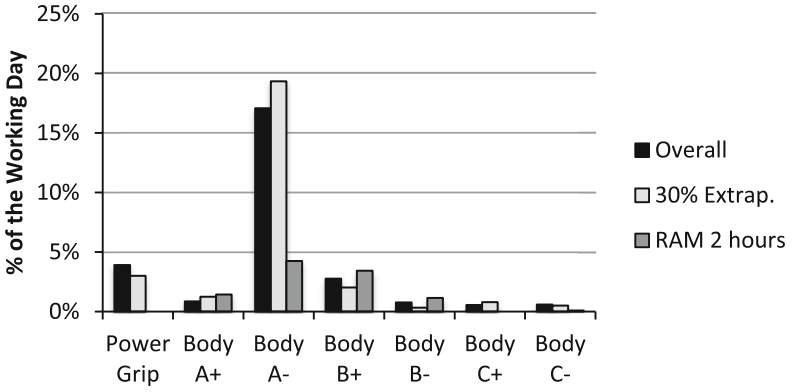
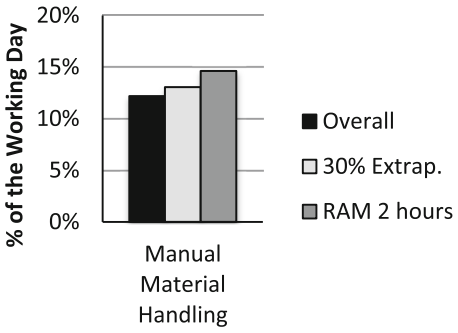


Fig. 7 Comparison of the distribution of action forces for one worker

Fig. 8 Comparison of the distribution of manual material handling for one worker



4 Discussion

In the evaluation of the two projection models it can be concluded that the extrapolation model that considers 30 % of the total time of each step, is the more accurate.

The extrapolation model "Random 2 h" provides good approximate results, but the occurring deviations are more significant. Smaller or rarely occurring postures and loads are not reliably detected. This could result in wrong conclusions about the workload actions that lead to false assumptions and unnecessary work design adaptations.

Figure 9 reveals why the SPO using the 30 % rule might be the best choice. Within different steps of tasks even the work at a construction site shows certain patterns. If this pattern is partly analysed and extrapolated the results will be sufficiently accurate.

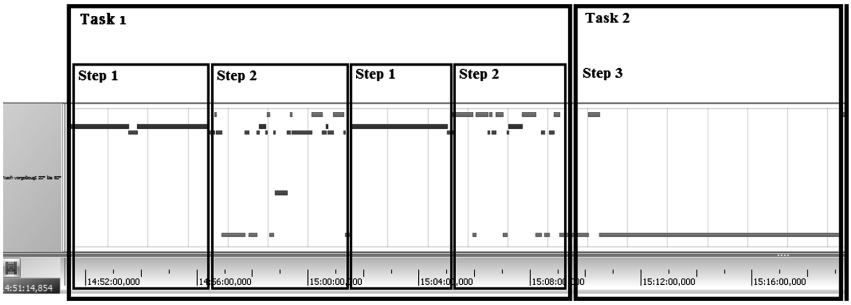


Fig. 9 Timeline of postures divided by tasks and steps

It can be stated, that it is necessary to record and document a whole working day, when non cyclic work is to be analysed and evaluated. The key to success is the identification of different tasks and steps within those tasks. For the video analysis it is enough to analyse 30 % of the video. In order to evaluate material handlings and action forces it is necessary to measure and document as many weights as possible. Objects that cannot be measured should be estimated or calculated. Those weights and forces need to be paired with the emerged video data.

In conclusion the time needed to collect the necessary data could not be reduced using the SPO method. But there is a significant reduction in the amount of work in analysing the video data. Considerably reducing the analysis effort with the software CAPTIV is an important achievement. Considering that an exact evaluation of an approximately 7-h work day required at least 20 h, the reduction by SPO leads to an analysis effort of about 6 h.

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Investigation of the Office Environment with Ergonomics Products

Reiko Mitsuya, Shunji Morita, Kunihito Matsuura, Satomi Fukuda, Kanya Sakuraba and Manami Nozaki

Abstract In previous research, we investigated the fatigue degree of humans when they are in the environment with the ergonomics products and other environment without, by the typing task using the EMG (electromyography) measurement and the body fatigue questionnaire and the interview. As a result, we found that the environment that human feels the least fatigue is furnished with ergonomics products. We found out that it leads to reduction in fatigue degree by using more ergonomics products continually. Following this, we conducted the research how the workers use the ergonomic products and experienced the change of the fatigue using the original questionnaire. The results show that the use of an ergonomics product showed leads to the reduction in degree of fatigue and the creation of comfort. However, the results will show a different picture when we examine the effect of the continuous use of an ergonomics product.

Keywords Ergonomics · Office environment · Fatigue alleviation · Comfort · Questionnaire

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1 Introduction

Recently, office environment has been greatly changed, and there are many varieties of work style by introducing telework or ICT (information and communication technology) [1]. Introducing ergonomics products is a factor to change the office environment by considering workers' efficiency and intellectual productivity [2]. Ergonomics products are developed to make more comfort in using and to reduce the fatigue degree of use them taking into account humans' physical features and a way of using a product. Each ergonomics product has been evaluated in recent investigations, however, little has been reported on evaluating situations where multiple ergonomics products are used [3]. Then we evaluated the office environment where multiple ergonomics products are used by comparing other environments where non-ergonomic products are used studied in previous studies. This was achieved by measuring muscle electromyogram, probing the degree of body part fatigue, and questionnaire [4]. As a result, it was found that the environments where multiple ergonomics products are used reduce more muscle load than the other environments for a long time period of use and also the combination use of ergonomics products increases the fatigue degree [5]. Following this, we conducted the research how the workers use the ergonomic products and experienced the fatigue alleviation.

2 Research by Questionnaire

2.1 Method of Research

A questionnaire was conducted targeting 38 people who use ergonomics products in their office. The questionnaire was made up of a free writing about respondent's hope for ergonomics products in the future and three items; the characteristics of respondent, the evaluation of the change of fatigue degree in respondent's seven body parts after introducing ergonomics products, and the evaluation of the change of comfort with VDT operation after introducing them.

2.2 Attributes of the Respondents

Figure 1 shows the age distribution of the respondents.

As shown in Fig. 1 the most were in their thirties. Figure 2 shows a scattering plot of the height and weight percentile by age and sex. As shown in Fig. 2, respondents' height and weight are distributed evenly [6, 7].

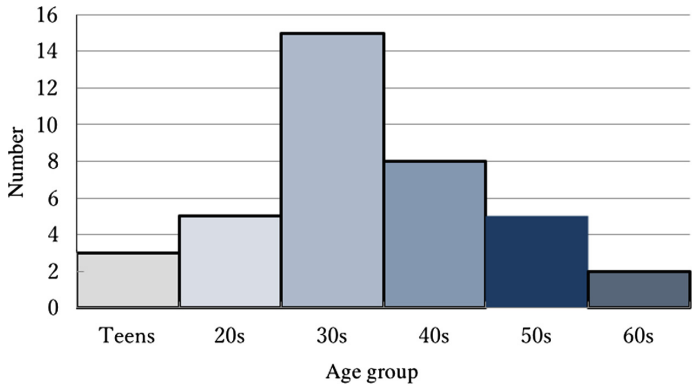

Fig. 1 The age distribution of the respondents

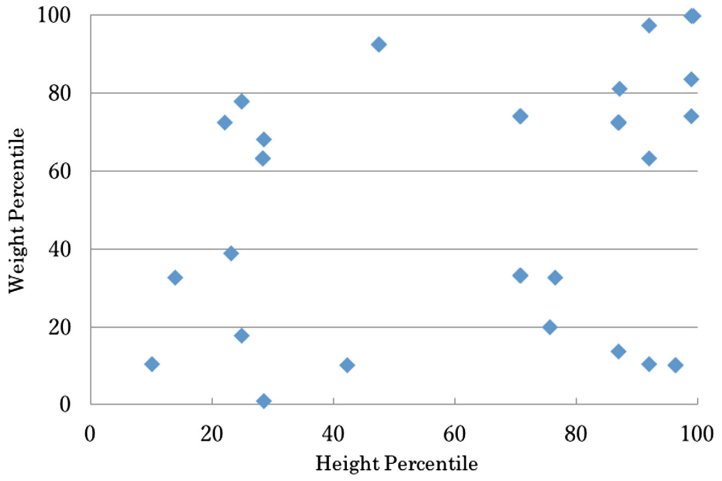

Fig. 2 The scattering plot of the height and weight percentile by age and sex

3 Results

3.1 The Number of Users by Product

Figure 3 shows what ergonomics products the respondents use. As shown in the Fig. 3, it was found out of the total respondents, all the respondents use an ergonomics chair, and 14 respondents use monitor arms. However, they don't use ergonomics desk, mouse, keyboard, writing materials much.

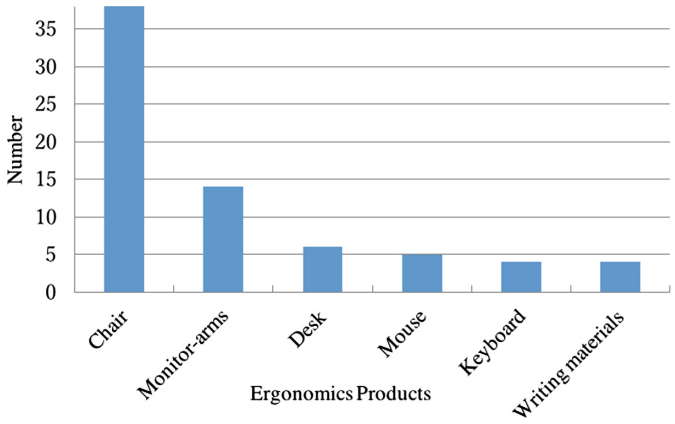

Fig. 3 The number of users in respondents by product

3.2 *Time Period of Uses*

Figure 4 shows how long each respondent had been using ergonomics products. As shown in Fig. 4, 50 % of the respondents had been using for more than two years, and about 80 % had been using for more than a year. Therefore, respondents use ergonomics products frequently for a long period.

3.3 *The Change of Fatigue Degree in Each Body Part*

In this study, the fatigue degree was defined as a degree indicating the perceived physical conditions of respondents compared with their former perceived physical

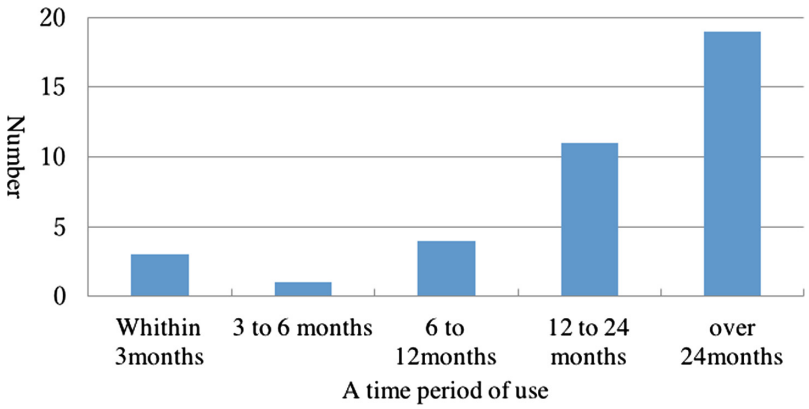

Fig. 4 A time period of use of ergonomics products

conditions, when they hadn't use ergonomics products. Therefore, if a respondent had used ergonomics products for three months, he/she indicated his/her fatigue degree comparing with their perceived physical conditions three months ago. The seven body parts were chosen from the point of objective and subjective perception of the fatigue alleviation effect based on the previous research. Figure 5 shows the respondents' fatigue degree in each body part.

The reference line at the 3 points shows that the fatigue degree didn't change even after respondents started using ergonomics products, and the less point respondent mark, the more fatigue alleviation they felt by using ergonomics products. It was found out that the most fatigue alleviated part was waist. As a result of ANOVA, there were significant differences ($p < 0.01$) and at waist part, fatigue alleviation was maximum. Moreover, nonparametric test was also performed because the questionnaire was five-point-scale and respondents were not sufficient (38 respondents). After the nonparametric test, multiple comparison test was conducted on waist, buttocks and other body parts, whose points do not differ largely. As a result, it was found that there were significant differences ($p < 0.01$).

Next, it was performed to assess how much respondents feel fatigue alleviation at a body part by using ergonomics product aiming to reduce the body part. Two-way ANOVA was performed to find out whether there is a difference in fatigue alleviation of wrists and fingers between respondents using ergonomics desk and respondents who don't use it. As a result of that, there was a significant difference ($p < 0.05$).

Similarly, the same analysis was performed between respondents using ergonomics keyboard and mouse and respondents who don't use them and it was found that there was a significant difference ($p < 0.05$). Besides, ANOVA was performed to test a difference of fatigue alleviation between respondents using monitor arms and the others and as a result, there was also a significant difference ($p < 0.05$). For

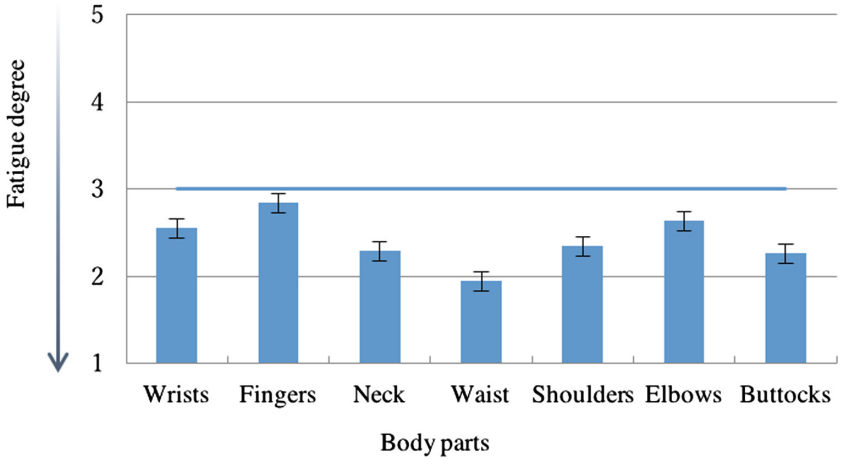

Fig. 5 The respondents' fatigue degree in each body part

these analyses, it was found that respondents feel fatigue alleviation at a body part by using ergonomics product aiming to reduce the body part.

3.4 The Relation Between a Fatigue Degree and a Period of Use

Figure 6 shows the relation between a fatigue degree and a period of ergonomics products uses.

As seen in Fig. 6, respondents using ergonomics products for six months or less seem to feel fatigue alleviation more than respondents using for more than six months. This result contradicts the previous study indicating that a long period of use of ergonomics products makes users feel more fatigue alleviation. This discussion should be deepened. Firstly, by a period of use of ergonomics products, respondents were divided into two groups: within-six-months group, and over-six-months group. Then, we illustrated each group's relation between a fatigue degree and a period of ergonomics products uses in Fig. 7.

ANOVA was done in within-six-months group and over-six-months group by each body part, and there was a significant difference only in waist ($p < 0.05$). Additionally, to examine a difference in two groups about the change of comfort with VDT operation, ANOVA was performed and it was found the significant difference ($p < 0.05$). Therefore, respondents of within-six-months group feel more fatigue alleviation and comfort than the others. This results also differed from previous studies.

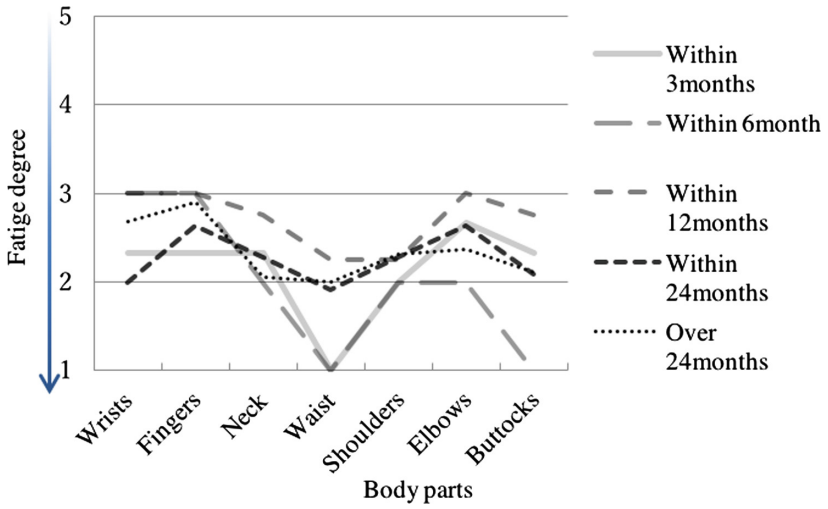

Fig. 6 The relation between a fatigue degree and a period of ergonomics products uses

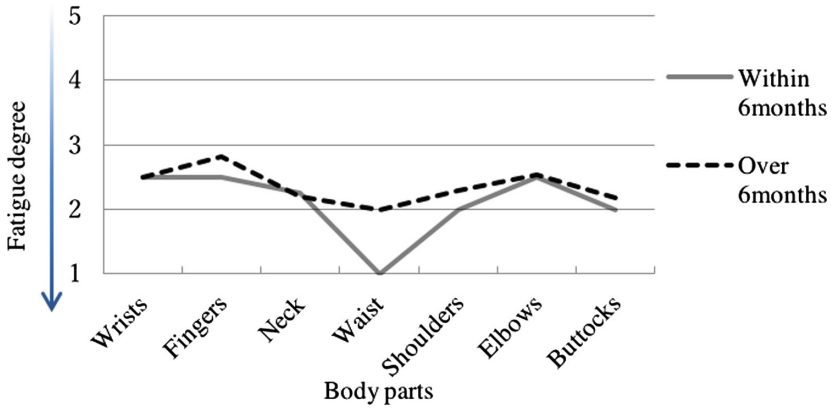

Fig. 7 The difference of the fatigue degree by groups

For a possible cause of this contradiction, we suggest "the honeymoon effect". The honeymoon effect is a technical term of office layout, which has a concept that respondents tend to evaluate new office layout highly in the satisfaction survey done in a period of three to within six months. This effect seemed to affect some respondents in this study. Moreover, there was only one respondent in within-six-months group using ergonomics products except for chair, which affect the result that we didn't find significant differences in any body parts except waist.

3.5 Ergonomics Products in the Future

We asked the respondents "What do you expect ergonomics products in the future?" in the questionnaire. As answers, some respondents need improvements of the products in design and color variations, and interestingly, others want ergonomics products targeting particular users such as Japanese, children and so on. As another answer, it is needed to know how ergonomics products and office environment effect workers' performances.

4 Conclusion

In this study, 38 respondents were gathered to do a questionnaire performed to examine the fatigue alleviation of ergonomics products and the relation between the fatigue alleviation and a period of use. As a result, it was found that respondents feel fatigue alleviation at a body part subjectively by using ergonomics product aiming to reduce the fatigue degree of the body part. Moreover, it was found that respondents using ergonomics products within six months feel more fatigue

alleviation effect than the other respondents. This result contradicted our previous study, which suggested that the honeymoon effect affect respondents' feelings. Meanwhile, there were few respondents using ergonomics products except for chair, and the respondents were office workers dealing in furniture. Therefore, further studies are needed in order to find out whether the results apply to other people and other office environments.

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Electromyographic and Kinematic Patient Handling Risk Assessment: Overhead Lift Versus Floor Lift

Francesco Draicchio, Giorgia Chini, Agnese Marchesi, Alessio Silvetti and Alberto Ranavolo

Abstract The use of mechanical patient lifting devices has already been proved to reduce the risk of caregiver injury during patient transfers. Despite this evidence, nowadays this equipment is still underused in the working environment. This study aims to compare sEMG activities and trunk kinematic, obtained by means of an optoelectronic system, between overhead lift devices versus floor lift devices and to verify if the patient movement with a mechanical lift may be safely performed. Seven experienced operators were studied by means of surface electromyography during an 85 kg surrogated patient handling from the bed to the wheelchair and vice versa by a single caregiver at a time using both a floor lift and an overhead lift. Results show that the use of these devices allows the operator to work safely and could be helpful in case of reduced fitness for work.

Keywords Patient lifting · Surface electromyography · Trunk kinematic · Low back disorders · Mechanical lifts

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1 Introduction

Among all workers, healthcare workers have the highest incidence rate for nonfatal occupational injury and illness involving days away from work [1] and low back disorders (LBD) are referred as the most common type of damages, [1]. A broad consensus is spreading on the fact that these injuries are mostly caused by the patient handling [2]. It has been shown that older workers perform tasks differently than younger workers due to declines in muscle properties [3]. These age based differences are particularly important to account for, since the risk of back injury increases with age [4]. Similarly, it is important to recruit trained operators as subjects since experience has been shown to change the way operators perform tasks [5].

It has been demonstrated that the use of mechanical devices (lifts) to handle patients reduces the risk of incurring accidents during patient moving by healthcare operators, hence it would be a good practice to use these devices to prevent injuries [6]. Moreover, this solution has direct economic benefits as a result of reduced compensation claims [6]. Patient handling with the help of overhead and/or floor lift has been extensively analyzed, [5, 7–9]. There are no studies, that actually evaluate the patient handling during the entire task, from the corset insertion to its removal, when it is performed wholly by one operator. This study evaluates the activity of trunk antagonist muscles and trunk kinematic of experienced workers with a overhead and a floor lift, during the movement of an 85 kg-completely dependent patient. The aim of this work is to investigate the compression at L5/S1, by computing a co-activation index, and to compare the measured trunk kinematic with the values prescribed by the European standard in order to give a practical instrument to compare different kind of devices and to test if a patient handling device could be used by the operator to work safely.

2 Materials and Methods

2.1 Participants

Seven experienced health workers were enrolled in this study (5 men and two women, age: 39.86 ± 13.02 years, height: 1.73 ± 0.09 m, weight: 72.29 ± 13.15 kg, body mass index, BMI: 23.86 ± 2.65 kg/m^2). None of them had a history of either musculoskeletal disorders or neurological diseases or had recently taken any drugs. The participants voluntarily performed the study trials in the laboratory. They signed an informed consent form prior to participation in the study after receiving a detailed explanation of the study procedure. The study was approved by the local ethics committee and conformed to the Helsinki declarations. An 85 kg man simulated an entirely dependent patient in all trials.

2.2 Instrumentation

The surface myoelectric signals were acquired with a sampling rate of 1000 Hz, using a 16-channel Wi-Fi transmission surface electromyograph (FreeEMG 1000 System, BTS, Milano, Italy). After skin preparation, bipolar surface electrodes Ag/AgCl (H124SG, Kendall ARBO, Donau, Germany), prepared with electroconductive gel (diameter 1 cm, distance between the electrodes 2 cm), were placed bilaterally over the muscle belly of the erector spinae (longissimus) and rectus abdominis (medium). Electrodes were placed in the direction of the muscle fibres, according to the European Recommendations for Surface Electromyography (SENIAM) [10]. The activity of each muscle was expressed as percentage of the maximal voluntary isometric contraction (MVCi). The MVCi contraction exercises were executed according to the European Recommendations for Surface Electromyography (SENIAM) [10]. Each subject performed the MVCi exercise for each muscle two times.

The kinematic acquisition was performed using a six infrared cameras opto-electronic system (SMART-DX 6000, BTS, Milano, Italy), [11]. Spherical markers, covered with aluminum powder reflective material, were placed over prominent bony landmarks, according to the International Society of Biomechanics (ISB) recommendations [12, 13]. In particular, markers were positioned over the left and right acromion, the spinous process of the 7th cervical and 5th lumbar vertebrae, and over the right and left posterior superior iliac spinae. Kinematic data were acquired with a sample rate of 340 Hz. Spatial accuracy was 0.2 mm in the three spatial dimensions. To be able to carry out the practical tests with the overhead lift, a frame that simulates the operation obtainable with the mounting of the overhead track has been assembled in the laboratory. The lifting frame for withdrawals with corset is equipped with an electrical device that allows the postural change of the patient, from sitting to the supine position and all intermediate positions.

The overhead lift is equipped with remote control, which controls all functions of the equipment: rising/descending, forward/ back, height adjustment of the lifting frame and setting of the device for the patient's postural change. The equipment is also equipped with a quick coupling which allows to replace the various lifting frames according to the requirements. The overhead lift used, is characterized by: (i) power supply 24 V; (ii) workload security kg 272 kg.

In order to perform the experimental procedure described below, even with floor lift, a completely electric multipurpose floor with a vertical telescopic lifting column lift was used. The lifting frame for withdrawals with corset is equipped with an electrical device that allows the patient postural change from sitting to supine and all intermediate positions. The lifter is equipped with remote control and a push button panel placed on the additional lifting column. The two handsets regulate all aspects of the lift: rising/descending, legs' opening/closing and patient's postural adjustment. The equipment is provided with a quick coupling which allows to change the various lifting frames according to the requirements. The floor lift also allows the operator to change electrically, through the use of a remote control, the

posture of the patient to be moved. The floor lift has the following technical features: (i) power supply 24 V with removable battery; (ii) overall dimensions 1118 × 718 mm; (iii) wheels' diameter 100 mm; (iv) overall lift weight 70 kg; (v) workload security kg 227 kg.

2.3 Experimental Procedure

The biomechanical assessment of the operator during the handling of the patient with overhead and floor lift was carried out by splitting the task into a series of sub-tasks.

Furthermore, two scenarios were considered: when the patient is moved from the bed to a wheelchair and vice versa.

As far as the floor lift is concerned, the following sub-tasks were analyzed in each scenario:

1. Enter the corset on the bed/on the wheelchair;
2. Transportation of the floor lift at the bed (on which the patient is lying)/to the wheelchair (on which the patient is seated);
3. Attaching the corset to floor lift;
4. Transporting the patient with floor lift from the bed to the wheelchair/from the wheelchair to the bed;
5. Release of the corset on the wheelchair/on the bed;
6. Removal of the corset from the wheelchair/from the bed.

As regards the overhead lift, the analyzed sub-tasks are the same tested with the floor lift except for the moving of the lift to the bed and to the wheelchair without the patient, that were not considered in this scenario because the operator did not do anything relevant from the biomechanical point of view. Each operator has carried out the patient handling in each scenario for each type of lifter twice. All the tests were performed using a 70 cm-fix-height bed, which model the worst condition that can be found in hospitals.

2.4 Data Analysis

After a tracking procedure (Smart Tracker, BTS, Milano, Italy), which was required to assign a label to each marker, data were processed using Analyzer software (Smart Analyzer, BTS, Milano, Italy) and MATLAB software (MATLAB 7.4.0, MathWorks, Natick, MA, USA).

Electromyographic signals recorded during all tasks performed by each operator were bandpass filtered (cutoff frequencies of 30 and 450 Hz), rectified with respect to the mean value, low pass filtered with a Hamming filter having a cutoff frequency

at 5 Hz, normalized to the maximum value of MVCi (processed according to the same procedure), normalized to the cycle duration and reduced to 100 samples using a polynomial procedure during each sub-task. Then, for each subject, the following indices were computed for each muscle and each sub-task: maximum value of the signal, average rectified value (ARV) and muscle co-contraction function (TMCf), [14].

The kinematic evaluation was based on trunk movements on the sagittal, frontal and transverse anatomical planes. In each anatomical plane, trunk Range of Motion (RoM) for each sub-task was defined as the difference between the maximum and minimum value of trunk angles within the corresponding sub-task.

2.5 Statistical Analysis

The statistical analysis was performed using PASW software (PASW Statistic 17, formerly SPSS, Chicago, USA). For each scenario, the average of all the kinematic and electromyographic parameters was calculated.

Shapiro–Wilk test was applied to verify the null hypothesis that the acquired sample (in relation to the parameters calculated) came from a normally distributed population. Parametric paired t-tests were performed to detect any significant differences between the use of overhead and floor lift during the following three subtasks: corset attaching to the lift, patient moving, from the bed to the wheelchair and vice versa, and corset release. p-values less than 0.05 were considered statistically significant. All the results are expressed as mean ± standard deviation.

3 Results

The Shapiro–Wilk test showed that all the considered variables were normally distributed.

As regards the electromyographic data, the maximum value of the right erector spinae normalized signal was statistically greater during the corset removal, in the first scenario, with the floor lift than with the overhead lift (0.23 ± 0.11 and 0.18 ± 0.08, $p = 0.04$, respectively), Table 1. During the patient movement from the wheelchair to the bed, the maximum value of both the right and left side was statistically greater with the wheeled lift than for the overhead lift (right erector spinae: wheeled lift 0.18 ± 0.08, overhead lift 0.12 ± 0.06, $p = 0.047$; left erector spinae: wheeled lift 0.17 ± 0.07, overhead lift 0.12 ± 0.05, $p = 0.002$, respectively), Table 2.

In the second scenario, during the sub-task of corset attachment to the wheeled lift a statistically higher value of the maximum of the TMCf was found than during the sub-task of corset attachment to the overhead lift (4.78 ± 1.45 and 4.19 ± 1.40, $p = 0.009$, respectively), Fig. 1.

Table 1 sEMG maximum and ARV values of the four muscle activity (mean ± standard deviation) for each sub-task in the first scenario (patient moved from the bed to the wheelchair)

sEMG maximum value					
Activity	Lift type	R rectus abdominis	L rectus abdominis	R erector spinae	L erector spinae
Corset insertion	–	0.100±0.068	0.119±0.067	0.318±0.139	0.319±0.134
Lift transport	Floor	0.037±0.027	0.034±0.019	0.152±0.071	0.149±0.054
Corset attachment	Floor	0.089±0.122	0.076±0.122	0.303±0.159	0.282±0.110
	Overhead	0.042±0.028	0.055±0.073	0.274±0.158	0.269±0.089
Patient transport	Floor	0.042±0.028	0.038±0.017	0.178±0.084	0.180±0.066
	Overhead	0.035±0.026	0.051±0.076	0.163±0.108	0.158±0.076
Corset release	Floor	0.155±0.245	0.065±0.095	0.225±0.109	0.225±0.081
	Overhead	0.048±0.052	0.059±0.091	0.184±0.084	0.193±0.076
Corset removal	–	0.245±0.345	0.289±0.557	0.308±0.101	0.309±0.130
sEMG ARV					
Corset insertion	–	0.023±0.013	0.022±0.008	0.115±0.056	0.119±0.042
Lift transport	Floor	0.018±0.014	0.016±0.010	0.052±0.029	0.049±0.012
Corset attachment	Floor	0.020±0.015	0.018±0.013	0.103±0.054	0.107±0.038
	Overhead	0.019±0.015	0.018±0.016	0.089±0.038	0.109±0.039
Patient tran sport	Floor	0.019±0.015	0.016±0.011	0.056±0.031	0.056±0.021
	Overhead	0.017±0.014	0.016±0.015	0.047±0.031	0.057±0.034
Corset release	Floor	0.023±0.021	0.019±0.018	0.081±0.045	0.077±0.022
	Overhead	0.018±0.015	0.018±0.019	0.072±0.037	0.072±0.022
Corset removal	–	0.022±0.018	0.025±0.024	0.114±0.048	0.111±0.035

As regards the kinematic data, trunk flexion-extension RoM showed in the first scenario, a statistically higher value with the floored lift than with the overhead lift during the sub-tasks of corset attaching and removal (corset attaching: 52.03 ± 9.57 and 36.52 ± 6.06, $p = 0.003$, respectively, corset removal: 43.93 ± 8.74 and 32.69 ± 6.49, $p = 0.038$, respectively) while in the second scenario trunk flexion-extension RoM showed a statistically higher value with the floored lift than with the overhead lift during the sub-tasks of patient moving and corset removal (patient moving: 29.99 ± 9.59° and 15.85 ± 9.11°, $p = 0.03$; corset removal: 40.68 ± 11.23° and 22.84 ± 8.21°, $p = 0.002$, respectively), Fig. 2. As far as trunk lateral bending RoM is concerned, both in the first and second scenario, a statistically higher value was found during the corset removal with the floored lift that with the overhead lift (first scenario: 61.98 ± 15.13° and 33.72 ± 8.73°, $p = 0.001$, respectively; second scenario: 46.53 ± 6.59° and 35.59 ± 5.67°, $p = 0.001$, respectively). Trunk rotation RoM showed a statistically higher value during the corset removal with the floored lift that with the overhead lift in the first scenario (31.36 ± 19.67° and 21.97 ± 15.87°, $p = 0.023$, respectively) and during patient moving in the second scenario (28.73 ± 13.37° and 20.57 ± 10.33°, $p = 0.034$, respectively), Fig. 2.

Table 2 sEMG maximum and ARV values of the four muscle activity (mean ± standard deviation) for each sub-task in the second scenario (patient moved from the wheelchair to the bed)

sEMG maximum value					
Activity	Lift type	R rectus abdominis	L rectus abdominis	R erector spinae	L erector spinae
Corset insertion	–	0.058±0.036	0.150±0.199	0.304±0.135	0.292±0.075
Lift transport	Floor	0.050±0.045	0.050±0.043	0.116±0.051	0.140±0.046
Corset attachment	Floor	0.063±0.077	0.083±0.199	0.207±0.096	0.215±0.084
	Overhead	0.047±0.054	0.057±0.085	0.202±0.092	0.211±0.091
Patient transport	Floor	0.042±0.033	0.093±0.152	0.183±0.087	0.175±0.073
	Overhead	0.034±0.025	0.035±0.029	0.122±0.066	0.122±0.055
Corset release	Floor	0.056±0.044	0.069±0.074	0.202±0.094	0.241±0.081
	Overhead	0.059±0.070	0.060±0.086	0.218±0.134	0.257±0.102
Corset removal	–	0.145±0.122	0.160±0.096	0.272±0.199	0.274±0.108
sEMG ARV					
Corset insertion	–	0.019±0.035	0.023±0.127	0.106±0.209	0.109±0.172
Lift transport	Floor	0.023±0.019	0.022±0.018	0.042±0.018	0.051±0.014
Corset attachment	Floor	0.018±0.016	0.019±0.015	0.075±0.039	0.079±0.036
	Overhead	0.018±0.014	0.018±0.018	0.083±0.044	0.082±0.031
Patient transport	Floor	0.018±0.058	0.017±0.013	0.051±0.025	0.057±0.024
	Overhead	0.018±0.016	0.015±0.014	0.051±0.032	0.048±0.022
Corset release	Floor	0.019±0.015	0.021±0.013	0.076±0.025	0.091±0.024
	Overhead	0.020±0.016	0.018±0.017	0.082±0.052	0.093±0.038
Corset removal	–	0.032±0.027	0.034±0.025	0.094±0.040	0.102±0.034

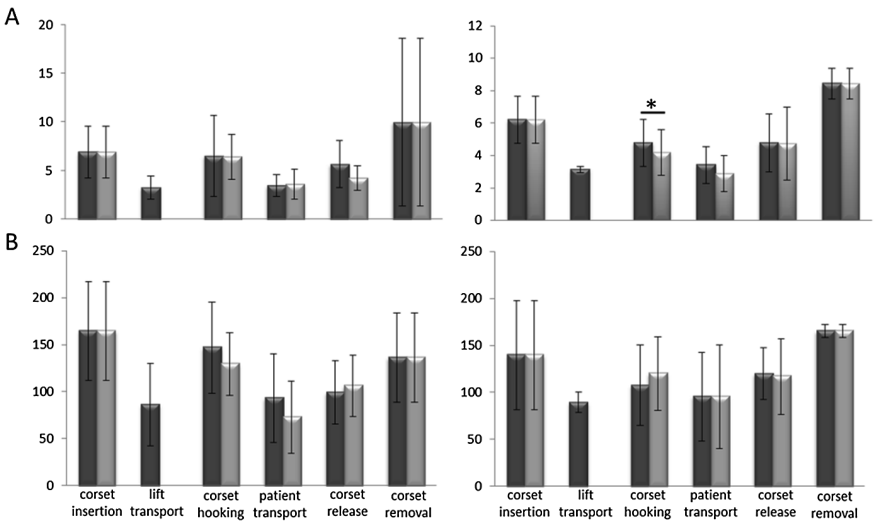

Fig. 1 Panels A (both *left* and *right*): maximum value of the TMCf (mean ± standard deviation) during all the sub-tasks. Panels B (both *left* and *right*): area of the TMCf (mean ± standard deviation) during all the sub-tasks. In all the panels, *dark grey bar* are relative to the use of the floor lift and *light grey* ones to the overhead one

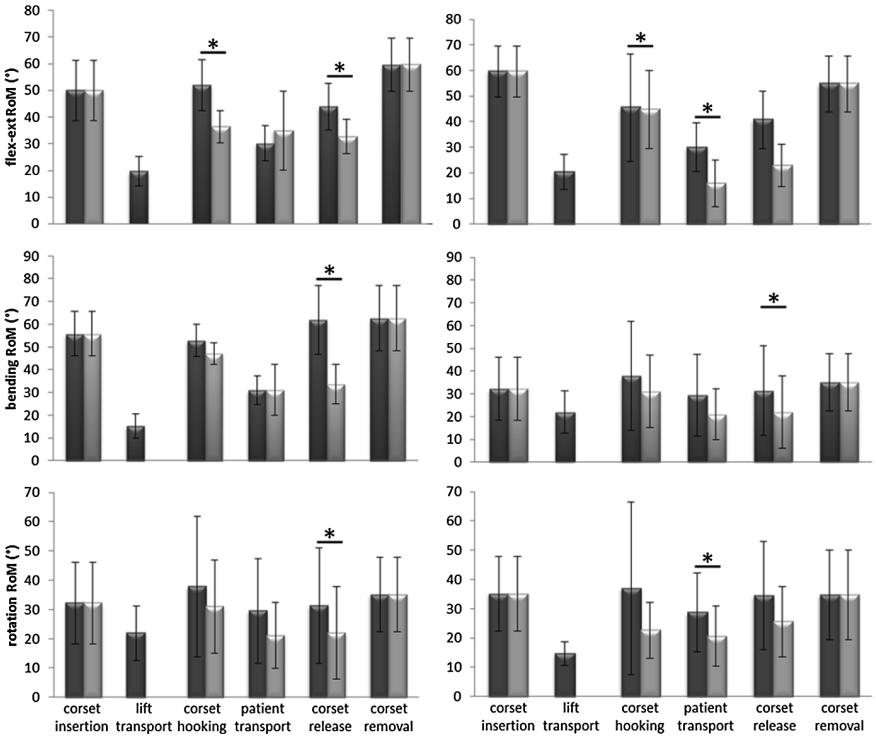

Fig. 2 Mean and standard deviation of the trunk RoMs in the three spatial planes in the first (*right panels*) and second (*left panels*) scenario with floor (*dark grey bars*) and overhead (*light grey bars*) lift

4 Discussion

In the present study, we evaluated the biomechanical differences resulting from the use of an overhead and floor lift using a quantitative approach based on advanced motion analysis methods.

Concerning the recorded electromyographic activity, the Middle Rectus Abdominis (both right and left) were, on average, slightly activated during all the analyzed sub-tasks with both floor and overhead lifts, while the Erector Spinae (both left and right) were more engaged than the abdominal muscles in all the sub-tasks with both wheeled and overhead lifts, although they also showed values of assets on average modest, Table 1.

The higher maximum value of the right erector spinae normalized signal during the corset unhooking, when patient is moved from the bed to the wheelchair, with the floor lift than with the overhead lift, may be due to the different operator posture caused by the trolley size. The statistically significant higher maximum value of

both the right and left side with the floor lift than for the overhead lift during the patient movement from the wheelchair to the bed, as for the higher maximum value of the TMCf, could be due to the fact that the operator, with the floor lift, is involved in push and pull tasks in order to move the trolley and the patient, while with the overhead lift the operator should only operate a remote control and limit patient's oscillations. Anyway, the muscle effort is on average very low even with the floor lift, in fact there is no difference between the two lifts when the patient is transported from the bed to the wheelchair, because both the lifts allow to electrically modify patient's posture and this implies a reduction of the muscle effort while using the lift.

As far as trunk kinematic is concerned, trunk flexion/extension ROM data were consistent with the UNI EN ISO 1005-4 [15] indications, in both scenarios and with both types of lift, thus ensuring a safe healthcare operator posture, during all the procedure from the corset insertion to its removal. Instead, trunk lateral bending and rotation RoM fall in the range considered only conditionally acceptable according to the UNI EN ISO 1005-4 [15], which means that the values are acceptable only if the position is not kept for long durations by the same person. Hence, the lift allows globally the healthcare operator to work safely. Moreover, the lower values obtained with the overhead lift with respect to the floor lift may be due to the different operator postural conditions because of the trolley size. However, as can be seen in Fig. 2, the trunk lateral bending and rotation RoM, are very far from the recommended value of 10°, therefore it could be better to invest on a proper training in order to avoid, even for few seconds, wrong postures, characterized by high trunk lateral bending and twisting as suggested by the UNI EN ISO 1005-4 [15]. In this way it could be possible to better use the mechanical aids in order to actual reduce the risks from manual handling of patients. Finally, it can be observed that for both electromyographic and kinematic parameters the highest values were found during the corset insertion and removal, which are the two sub-tasks without the help of the mechanical aid. A solution to face this problem could be a proper training or the employment of two operators.

5 Conclusions

The results obtained confirm the data in the literature on the effectiveness of the use of mechanical aids to maintain the biomechanical effort during the patients handling at low values.

There are some differences in the biomechanical load when using the overhead lift, with which the muscle effort, although it is low with both lifts, is further reduced with respect to the floor one. The differences between the two lifts are due to the lack of the push and pull sub-tasks with the overhead lift and to the different operator posture caused by the trolley size with the floor lift. Globally, the muscle effort is low, hence the co-activation index is the most adequate and representative

of different load conditions. In conclusion, the results obtained could be a practical tool for the physicians, when they have to express an opinion in case of reduced fitness for work.

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Postural Analysis and Assessment of Perceived Musculoskeletal Pain of Cleaners in Metro Manila, Philippines

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Abstract Risk of Work related Musculoskeletal Disorders (WMSD) due to the nature of cleaning work has been proven abroad. The study aims to determine the prevalence of WMSD and the correlation between perceived discomfort and actual risk faced by cleaners due to daily routine tasks in the Philippine context. For the study, cleaners in educational institutions and commercial establishments in Metro Manila were analyzed using a survey based on the Standardized Nordic Questionnaires for the Analysis of Musculoskeletal Symptoms, Rapid Upper Limb Assessment (RULA), and Rapid Entire Body Assessment (REBA). Survey results show that there is high WMSD prevalence among Filipino cleaners while RULA and REBA scores indicate medium to very high risk. Results of both objective and subjective assessment had no correlation. This suggests an improvement in the method and tools used in identifying the risks of WMSD, and the possibility of other factors affecting the perceived pain of Filipino cleaners.

Keywords Ergonomics · Musculoskeletal disorders · Postural analysis · RULA · REBA · Nordic · Filipino · Cleaning

1 Introduction

1.1 Statement of the Problem

In the Philippine setting, there is currently no existing study on the prevalence of WMSD among Filipino cleaners. Also, the correlation between known risk assessment measures and perceived discomfort due to work has not yet been explored in the cleaning industry.

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1.2 Significance of the Study

Cleaners abroad have been proven to be susceptible to and affected by musculoskeletal disorders as evidenced by high prevalence rates ranging from 74 to 83 % [1, 2]. With the absence of quantitative research that assesses the condition of cleaners in the Philippine setting, there exists a lack of awareness regarding the occupational hazards, in quantitative terms, associated with cleaning work. In pursuing this study, the welfare of the Filipino cleaners may be improved through providing information that directs attention to cleaning methods that require investigation and change from an ergonomic standpoint. Furthermore, a study focused on the Philippine setting would consequently produce results specific to the methods, tasks, and tools being used in the said setting.

1.3 Scope and Limitations

The study dealt with indoor cleaners with at least one year experience in commercial establishments and educational institutions located in Metro Manila. RULA and REBA methods were used for the objective analysis of postures. The use of a survey based on the Standardized Nordic Questionnaire served as the basis for the measure of the cleaners' perceived discomfort. Furthermore, the tasks considered in the questionnaire and the analysis covered only those that are part of the cleaners' daily routine.

2 Methodology

For the objective assessment, the proponents utilized Rapid Upper Limb Assessment (RULA) and Rapid Entire Body Assessment (REBA) as these methods yield reliable results while allowing for a quick and easy assessment. RULA has been used in studies conducted abroad on cleaners and provides insights on the upper limb as a sole contributor to MSD risk [3]. Alongside this, the use of REBA gives an assessment that incorporates all regions of the body in measuring MSD risk [4]. A video-recording device was used to capture the postures associated with the cleaners' tasks. Afterwards, the postures observed for the tasks that were deemed most difficult and most frequently done by the cleaners were evaluated using the RULA and REBA score sheet.

For the subjective assessment, a survey based on the Standardized Nordic Questionnaires for the Analysis of Musculoskeletal Symptoms was used to gather information about the cleaner, the nature of his/her work, and the perceived pain or discomfort [5]. To overcome the language barrier, the questionnaire was translated into Filipino. The minimum number of respondents required for the survey is 97

respondents, as determined using Cochran's equation [6] with a 95 % level of confidence, 0.10 margin of error and a conservative value of 0.5 for p. The actual number of respondents was 99 respondents.

$$n_o = \frac{z^2 pq}{e^2} \tag{1}$$

The survey was comprised of two parts: General and Specific. The general part collected the basic information about the cleaner. These included the cleaner's age, sex, height, weight, dominant hand, working hours per day, tasks done, proportion of time spent on each task, most difficult and most frequently done tasks, and years spent in the cleaning industry. In addition to these, questions on the prevalence of pain or discomfort in the past year and week for the whole body were included in the general part.

For the specific part of the survey, the occurrence of pain or discomfort within the past year and week were asked for specific body regions. These specific body regions are the neck, shoulders, upper back, lower back, wrist/hands, upper arm, lower arm, legs, and knees. More to this, an 11-point numerical rating scale was included to gauge the intensity of pain or discomfort perceived by the cleaner, and two 5-point numerical scales were used for the duration and frequency. The 11-point numerical rating scale provides ease of use and high responsiveness for pain intensity measurement [7]. Meanwhile, the use of 5-point numerical scales gives the needed accuracy for duration and frequency.

The comparison between the objective and subjective results was done through the use of statistical measures that determined the correlation between the objective and subjective results. As the subjective and objective measures include ordinal level data, the Spearman's correlation coefficient was deemed as an appropriate correlation measure [8].

$$\rho = 1 - \frac{6 \sum d_i^2}{n(n^2 - 1)} \tag{2}$$

For the subjective results, the survey score for each task was computed through obtaining the average of the rating scores from cleaners who deemed the specified task as the most difficult or most frequently done task. The rating scores were calculated by multiplying the intensity, duration, and frequency values, which may yield a maximum score of 250 and a minimum score of 0. The multiplication method was adapted from the score calculation used for the Cornell Musculoskeletal Discomfort Questionnaires and produces values with amplified differences and more comparable results [9].

The subjective results have two corresponding scores for each task: upper limb survey score and entire body survey score. The upper limb survey score only takes into account the rating scores for the neck, shoulder, upper back, lower back, wrists/hands, upper arm, and lower arm for the computation. As for the entire body survey score, the computation included all body regions.

The RULA score, which represents the objective result, was compared to the upper limb survey score, representing the subjective result. Equivalently, the REBA score was compared to the entire body survey score. For both of the comparisons, a corresponding correlation coefficient was obtained.

3 Results and Discussion

Based on the survey, the prevalence of Work-related Musculoskeletal Symptoms (WMSS) amongst Filipino cleaners is 89.90 and 59.60 % during the 12 months and 1 week prior to the conduct of the study, respectively. The 12-month prevalence is higher than values reported from similar studies abroad, which range from 74 to 83 %. This suggests that methods and tools used in the cleaning industry in the Philippines may be less favorable from an ergonomic standpoint. The prevalence of WMSS for specific body regions were also obtained. Body regions experiencing high prevalence of discomfort are as follows: shoulders (67.68 %), lower back (58.59 %), legs (56.57 %), wrists/hands (54.55 %), and neck (52.53 %). A summary of the prevalence percentages are shown in Table 1.

The tasks that were deemed most difficult and most frequently done by the cleaners are as follows: sweeping, mopping, wiping, litter picking, and garbage disposal. For each task, numerous postures were evaluated using RULA and REBA, and the maximum scores were used for the statistical comparison with the survey scores. The RULA and REBA scores and the survey scores for each task are shown in Table 2.

Considering all postures, the RULA scores range from 4 to 7, while the REBA scores range from 4 to 11. For the maximum scores for each task, the RULA scores range from 6 to 7, while the REBA scores range from 7 to 11. The RULA scores suggest that investigation be performed and changes be implemented, while the REBA scores indicate medium to very high risk and also suggest the need for investigation and change. Basing entirely on the RULA scores, the associated implication is that the upper limb body regions significantly contribute to the MSD

Table 1 Prevalence percentage of WMSS on specific body regions

Prevalence (%)		
Body region	12 months	1 week
Shoulders	67.68	46.46
Lower back	58.59	35.35
Legs	56.57	39.39
Wrists/hands	54.55	32.32
Neck	52.53	31.31
Upper back	50.51	30.30
Upper arm	45.45	28.28
Knees	42.42	30.30
Lower arm	39.39	23.23

Table 2 Task postures with RULA and REBA scores and survey scores

Task	Posture# 1	Description	RULA 7	REBA 8	Upper limb survey score	Entire body survey score
Sweeping	1	Back swing (arm behind)	7	8	22.99	22.72
	2	Front swing (arm in front)	7	8		
	3	Front stroke (start)	7	8		
	4	Front stroke (end)	7	8		
Mopping	1	Arms raised	7	11	24.8	24.58
	2	Down stroke	7	10		
	3	Mop wringing	5	5		
Wiping	1	Vertical surface (high)	6	5	14.03	13.42
	2	Vertical surface (middle)	4	4		
	3	Vertical surface (low)	5	7		
	4	Horizontal surface (far)	5	7		
	5	Horizontal surface (near)	4	5		
Litter picking	1	Picking up trash on the floor	*7*	11	10.04	9.89
	2	Picking lip trash midway	5	6		
	3	Putting trash in garbage bag	6	8		
Garbage disposal	1	Carrying garbage bags	5	5	11.53	11.64
	2	Carrying garbage bin	6	8		
	3	Putting down garbage bin	5	9		
	4	Picking up garbage bin	6	10		
	5	transferring trash from bin to bag	7	7		

risk of the cleaners. The tasks posing the highest risk to the cleaners are mopping and litter picking, with a RULA score of 7 and a REBA score of 11. It should be noted that both values correspond to the maximum scores of the respective assessment methods.

The reported survey scores range from 9.89 to 24.8 out of a possible maximum score of 250. This provides evidence that the Filipino cleaners perceive the tasks as tolerable in terms of pain and discomfort. Upon comparing the upper limb survey score with the entire body survey score, a maximum difference of 0.6 was observed

and implies that the contribution of the lower body to the discomfort of the cleaners is not significant.

For the comparison between the maximum RULA and REBA scores for each task and the corresponding survey scores, a Spearman correlation coefficient of 0 was calculated for the upper body, while a Spearman correlation coefficient of −0.10 was obtained for the entire body. These values imply that the amount of risk presented by the tasks is not properly identified by the Filipino cleaners through pain perception. Moreover, Filipino cleaners perceive the tasks as tolerable even though they are being exposed to high risks of WMSD.

4 Areas for Further Studies

Analyzing cleaning tools may be tackled by future studies to determine the most suitable design of these tools that will minimize the risk of having MSDs. Comparisons using known posture assessment methods may be used in evaluating the different tools. Benchmarking would also provide a useful process in improving the methods of the cleaners. Future studies on discomfort may take into account other factors not included in this study such as age, physical health, and height, among others. Statistical analysis may be employed to determine the significant factors contributing to WMSD prevalence.

5 Conclusion

The study has determined an 89.90 % 12-month and 59.60 % 1-week prevalence of Work-related Musculoskeletal Symptoms among Filipino cleaners in commercial establishments and educational institutions located in Metro Manila. In line with this, postural analysis conducted for the most difficult and most frequently performed tasks through the use of Rapid Upper Limb Assessment and Rapid Entire Body Assessment methods resulted in maximum RULA scores for each task ranging from 6 to 7 and maximum REBA scores ranging from 7 to 11. These values indicate that the Filipino cleaners are exposed to medium to very high risk and suggest the investigation of the tasks and implementation of change in methods.

Subjective assessment was also conducted to assess the perceived discomfort of the Filipino cleaners. The upper limb survey scores and entire body survey scores are relatively low, indicating that the pain is perceived as tolerable by the cleaners. Consequently, the computed correlation coefficients for the upper limb and entire body comparison signify that there is no relationship between the objective and subjective assessment scores.

Appendix

Appendix A. General Part of the Survey

Date:_____

Good day! We are students from the University of the Philippines, Department of Industrial Engineering and Operations Research. We request that you answer this survey to aid in our study on the safety of cleaners. Thank you very much!

Instructions: Fill in the blanks or put a check mark inside the box beside the most appropriate answer.

Name: _____

First Part: Information on the Employee

1. Age _____
2. Sex
   ☐ Female ☐ Male
3. Weight _____kg
4. Height _____ft _____in
5. Dominant hand
   ☐ Right ☐ Left
6. How long have you been working as a cleaner?
   _____year/s _____month/s
7. How long do you work in a day?
   _____hour/s
8. Put a check mark on the tasks that you do. On the blank beside it, indicate how long you do the specific task within a day.

	Task	Duration (hours)
	Sweeping	
	Mopping	
	Wiping	
	Picking up trash	
	Disposing of trash	
	Others: _____	

9. Among the tasks that you do, which is the hardest?
   _____
10. Among the tasks that you do, which is the one that you do the most often?
    _____
11. Have you experienced pain in the last twelve (12) months?
    ☐ Yes ☐ No
12. Have you experienced pain in the last seven (7) days?
    ☐ Yes ☐ No

Appendix B. Specific Part of the Survey

Body part	Have you experienced pain in the specified body part within the last twelve (12) months?		Have you experienced pain in the specified body part within the last seven (7) days?		Rate the pain you feel in the specified body part 0-no painat all 10-extremely painful											How long does the pain last? 1-never 2-less than 12 h 3-12-24 h 4-2-6 days 5- 1 week or more					How often does the pain occur? 1- never 2- rarely (om = nce every couple or more months) 3- Sometimes (omce a month) 4- Often (omce a week) 5- Always (everyday)				
Neck	YES	NO	YES	NO	0	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	1	2	3	4	5
Shoulder	YES	NO	YES	NO	0	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	1	2	3	4	5
Upper back	YES	NO	YES	NO	0	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	1	2	3	4	5
Lower back	YES	NO	YES	NO	0	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	1	2	3	4	5
Wrists/hands	YES	NO	YES	NO	0	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	1	2	3	4	5
Upper arm	YES	NO	YES	NO	0	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	1	2	3	4	5
Lower arm	YES	NO	YES	NO	0	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	1	2	3	4	5
Knees	YES	NO	YES	NO	0	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	1	2	3	4	5
Calf	YES	NO	YES	NO	0	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	1	2	3	4	5

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The Experimental Research on Joint Range of Motion

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Abstract Joint ROM is one of the foundational data for product interface design and working space design. The active ROM of 8 large joints were measured by VICON and BTE system. The statistical analysis showed that females had significant larger values over males in the joint ROM, especially in the lower limb and spine. Young participants had larger joint ROM than old participants on most of the upper limb items dramatically. No significant age difference was found in lower limb and spine. The larger joints showed more significant difference (overall) in gender and age. The significance testing for symmetrical items revealed that all participants had perfect conformity on joint ROM of two sides. The comparison of VICON measurement and BTE measurement indicated that the BTE seemed like

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more precise than VICON. The results are helpful for design and evaluation of product interface and working space.

Keywords Joint range of motion · Gender and age · Human factors

1 Introduction

Human joint range of motion (ROM) refers to the maximum angular distance that a joint can move between the flexed position and the extended position. It contributes to the body reach range, so it is one of the foundational data for product interface design and working space design [1, 2]. Previous researches showed that ROM is influenced by vaious factors, including age, gender, physical condition and ethnic group [3]. That might be the reason that the ROM data in different literature has great discrepancy.

Unfortunately, there is no ROM data for Chinese people yet. The lack of ROM data makes the designers wonder where exactly would be the best location for arranging the products that primary used by Chinese users, especially controls or something that need to reach by hand or foot. Based on the concern above, the experimental measurements, addressing on the Chinese adult joint ROM, were designed and carried out. By collecting and analyzing the data, the principal joint ROM data of Chinese adult was represented. The results are helpful for understanding Chinese people joint ROM. They can provide foundational support for design and evaluation of product interface and working space, especially the issued related with location and layout, as well as medical rehabilitation.

2 Method

2.1 Design

Joint ROM can be divided into active motion range and passive motion range according to whether a joint moving is active or passive. This research is aimed solely at the active motion, which means that the movement is the result of joint muscle voluntary contraction, rather than the result of external force.

The measured items were the active ROM of 8 large joints in the body, including:

1. shoulder (both sides): flexion, extension, abduction, internal and external rotation (in horizontal plane)
2. elbow (both sides): flexion
3. wrist (both sides): flexion, extension, radial deviation and ulnar deviation
4. hip: flexion and flexion with 90° knee flexion

5. knee: flexion
6. ankle: dorsiflexion and planter flexion
7. cervical spine: flexion, extension, left and right lateral bending
8. lumbar spine: flexion, extension, left and right lateral bending

The VICON motion capture system and BTE elevator system (with portable goniometer and dual inclinometer) were used for data collecting. The items from (1) to (3) were measured by VICON system. The rest of the items were measured by BTE system. In order to see the differences of the two measurement methods, the shoulder data was collected both by VICON system and by BET system.

2.2 Participants

Total 184 participants were recruited for this experiment through online, email, and poster advertisements. Participants were eligible if they were between 18 and 30 (regarded as young) or between 45 and 60 (regarded as old) years old, without a history of any disease of large joints. All participants were Chinese residents and lived in Beijing, China.

The items from (1) to (3) in 2.1 were measured by VICON system on 152 participants. Their basic features are shown in Table 1. There was no significant age difference in gender ($p > 0.05$), and no significant height difference in age ($p > 0.05$). There was a significant age difference in weight ($p < 0.01$).

The items from (4) to (8), and (1) in 2.1 were measured by BET system on 32 participants. They were 16 females (all young) and 16 males (11 young and 5 old).

2.3 Procedure

Prior to measuring, the experimenter guided the participant through the following: confirming the eligibility, informed consent, filling personal information, giving participants an overview of the experiment, teaching the participant how to perform the task. The participant should avoid strenuous exercise before the measurement. When measurement start, the joint should move slowly and uniformly to required posture, then all parts of the body should keep still to minimize the measurement

Table 1 Participants' basic features

	Female	Male	Young	Old
Participants number	80	72	113	39
Age	31.4 ± 15.0	27.7 ± 12.9	21.5 ± 1.9	53.2 ± 3.5
Height (cm)	157.8 ± 5.1	170.2 ± 5.4	164.2 ± 8.1	162.0 ± 8.1
Weight (kg)	57.9 ± 9.2	68.0 ± 10.8	60.2 ± 9.9	69.9 ± 11.6

error. The measurement of each joint ROM was performed three times with the same data collecting equipment by the same experimenter. The test room was quiet and warm to make the participant feel comfortable and relax.

For the measurement by VICON, the marks were pasted on proper point carefully. The shoulder joint ROM (both sides) was measured firstly, then the elbow (both sides), and the wrist (both sides) lastly. For the measurement by BTE, the measuring order was hip, knee, ankle, cervical spine, lumbar spine and shoulder.

3 Results

3.1 The Joint ROM of Upper Limb

The joint ROM data of upper limb (shoulder, elbow and wrist) were collected by VICON. The means and standard deviations of the data with classification of gender and age are shown in Table 2. The shoulder data used here was collected by VICON system, rather than BTE.

Using absolute value, the joint ROM data of upper limb classified with gender is presented as Fig. 1. The star signals (*) at the rear of some items note the significant difference of the involved item in gender, which were obtained through significance testing. One star (*) means there is significant difference ($p < 0.05$) of this item between females and males; two stars (**) means the difference is very significant ($p < 0.01$); three stars (***) means the difference is highly significant (<0.001). No star means no significant difference.

It could be seen from Fig. 1 that there was highly significant difference ($p < 0.001$) in joint ROM of shoulder internal rotation between females and males, as well as significant difference ($p < 0.05$) in joint ROM of shoulder external rotation between females and males. The internal and external rotation of the shoulder joint movement was done in the horizontal plane. The data showed that the average joint ROM of shoulder internal rotation of females was −111.6° on left side and 111.5° on right side. The same item of male was −125.6° on left side and 123.0° on right side. It showed that males' joint ROM of shoulder internal rotation was 11–14° larger than females' on both sides. The value was about 4–5° for the joint ROM of shoulder external rotation. For the elbow flexion, females' joint ROM was 2–3° larger than males on both sides, but the difference was significant only on left. Except the items mentioned above, other items showed no significant difference to gender.

According to Table 2, the joint ROM data of upper limb classified with age can be presented as Fig. 2 (using absolute value). The meaning of star signals in Fig. 2 was same as in Fig. 1.

According to Fig. 2, 11 out of 20 items showed various level of significant difference to age. It demonstrated the young participants had larger joint ROM than the old participants on most of the upper limb items dramatically. For the shoulder

Table 2 The joint ROM of upper limb

Joint	Item	Side	Gender		Age	
			Female	Male	Young	Old
Shoulder	Flexion	Left	148.5 ± 13.1	150.8 ± 11.7	152.2 ± 11.1	142.0 ± 13.2
		Right	148.9 ± 11.5	152.2 ± 11.4	153.0 ± 10.4	143.2 ± 11.8
	Extension	Left	−47.0 ± 10.4	−49.4 ± 7.3	−48.2 ± 7.5	−47.9 ± 12.8
		Right	−49.9 ± 8.2	−49.3 ± 7.6	−49.3 ± 7.7	−50.4 ± 8.5
	Abduction	Left	132.2 ± 11.7	135.7 ± 10.3	137.6 ± 8.4	123.0 ± 11.0
		Right	132.0 ± 10.5	135.7 ± 11.8	137.7 ± 8.1	122.5 ± 11.5
	Internal rotation	Left	−111.6 ± 14.0	−125.6 ± 13.5	−121.6 ± 12.5	−105.0 ± 14.7
		Right	111.5 ± 11.1	123.0 ± 14.8	120.6 ± 13.4	106.9 ± 11.3
	External rotation	Left	46.6 ± 11.5	51.1 ± 11.1	49.1 ± 10.9	48.0 ± 13.3
		Right	−51.1 ± 11.3	−55.4 ± 12.4	−54.3 ± 11.4	−49.9 ± 13.0
Elbow	Flexion	Left	116.2 ± 6.8	113.8 ± 6.0	116.3 ± 6.7	111.5 ± 4.7
		Right	115.9 ± 8.2	113.6 ± 6.5	116.2 ± 7.0	110.7 ± 7.4
Wrist	Flexion	Left	53.9 ± 10.5	54.4 ± 8.7	55.1 ± 9.7	51.3 ± 9.2
		Right	54.8 ± 8.8	53.9 ± 9.1	55.6 ± 8.9	50.8 ± 8.2
	Extension	Left	−60.1 ± 10.7	−56.3 ± 12.8	−59.6 ± 12.1	−54.6 ± 10.4
		Right	−56.7 ± 12.2	−56.1 ± 11.3	−57.4 ± 10.9	−53.4 ± 13.7
	Radial deviation	Left	−14.7 ± 5.0	−14.2 ± 4.1	−14.4 ± 4.6	−14.6 ± 4.6
		Right	14.5 ± 4.2	15.0 ± 4.4	14.6 ± 4.0	15.1 ± 5.0
	Ulnar deviation	Left	25.3 ± 4.5	26.0 ± 5.2	25.9 ± 4.9	25.0 ± 5.0
		Right	−26.0 ± 5.9	−25.0 ± 5.3	−26.0 ± 5.7	−24.3 ± 5.3

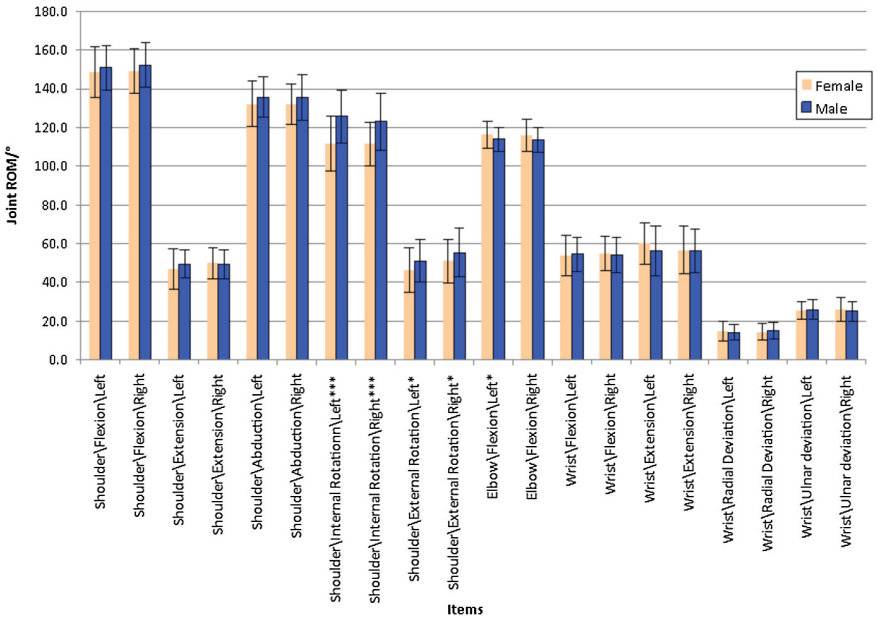

Fig. 1 The joint ROM data classified with gender

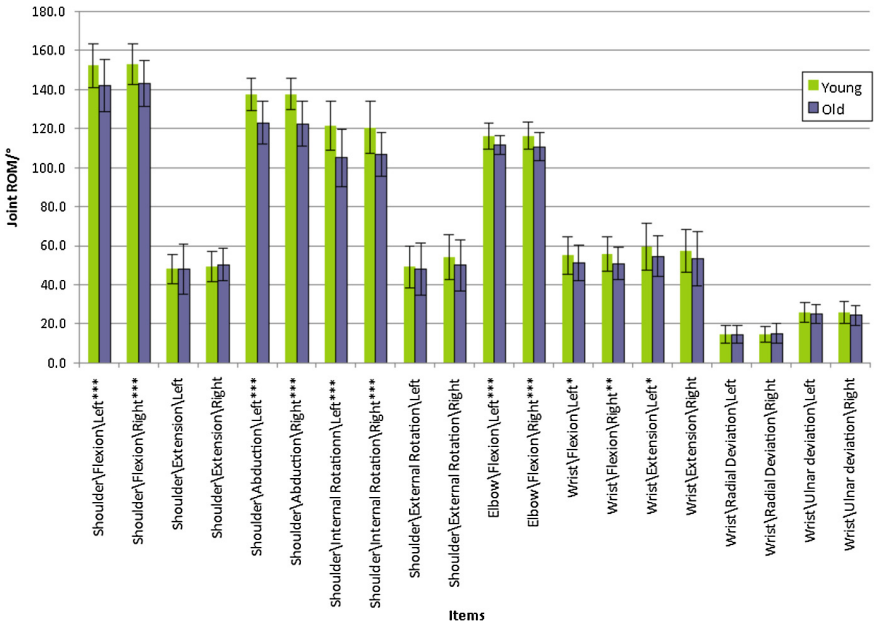

Fig. 2 The joint ROM data classified with age

joint ROM, all of the items showed highly significant difference ($p < 0.001$) between young and old participants, except for extension and external rotation. For the elbow, the solely item, elbow flexion, showed highly significant difference ($p < 0.001$) to age. For the wrist, the flexion and extension were significant different ($p < 0.05$) or very different ($p < 0.01$) to age. It could be seen that the larger the joint was, the more likely that the ROM items showed significant difference, and the larger different values of ROM appeared. For instance, young participants' shoulder joint ROM of flexion was 10° larger than old participants', abduction was 15° larger,and internal rotation was 14–16° larger. But for the elbow and wrist joint ROM of flexion, the young participants' was only 4–6° larger than old participants'.

3.2 *The Joint ROM of Lower Limb and Spine*

The joint ROM data of lower limb and spine were collected by BTE. The means and standard deviations of the joint ROM with classification of gender and age are shown in Table 3. Because there was no old female participant attended in the BTE measuring, the data collected by the BTE was not uniform in gender and age. In order to make it coordinate to compare, for the data in Table 3, the female refers to young female, the male refer to young male, and the old refers to old male.

According to Table 2, the joint ROM data of lower limb and spine can be presented as Fig. 3. The meaning of star signals in this figure is same as in figures above. The significance testing indicated that there was no significant age difference in any of the lower limb and spine items. The star signals here only note the significant gender difference in the related items.

Table 3 The joint ROM of lower limb and spine

Joint	Item	Side	Female (young)	Male (young)	Old (male)
Hip	Flexion		87.9 ± 10.5	72.6 ± 12.9	73.1 ± 11.6
	Flexion with 90° knee flexion		114.2 ± 8.9	102.1 ± 15.0	100.3 ± 4.3
Knee	Flexion		128.3 ± 7.8	118.7 ± 6.8	113.7 ± 8.5
Ankle	Dorsiflexion		19.1 ± 5.1	20.2 ± 6.3	14.7 ± 4.1
	Planter flexion		65.1 ± 9.2	59.8 ± 9.0	59.1 ± 10.1
Cervical spine	Flexion		51.9 ± 8.1	47.7 ± 10.2	42.3 ± 11.2
	Extension		63.4 ± 10.4	56.4 ± 8.0	59.5 ± 4.8
	Lateral bending	Left	46.9 ± 5.7	43.1 ± 7.0	44.2 ± 10.2
		Right	47.6 ± 6.3	41.5 ± 4.6	44.5 ± 6.8
Lumbar spine	Flexion		63.0 ± 13.6	46.0 ± 7.6	48.3 ± 7.4
	Extension		24.2 ± 4.8	17.0 ± 6.3	17.7 ± 4.1
	Lateral bending	Left	26.5 ± 5.8	17.5 ± 6.1	16.3 ± 4.7
		Right	26.9 ± 6.3	20.6 ± 6.9	16.4 ± 5.6

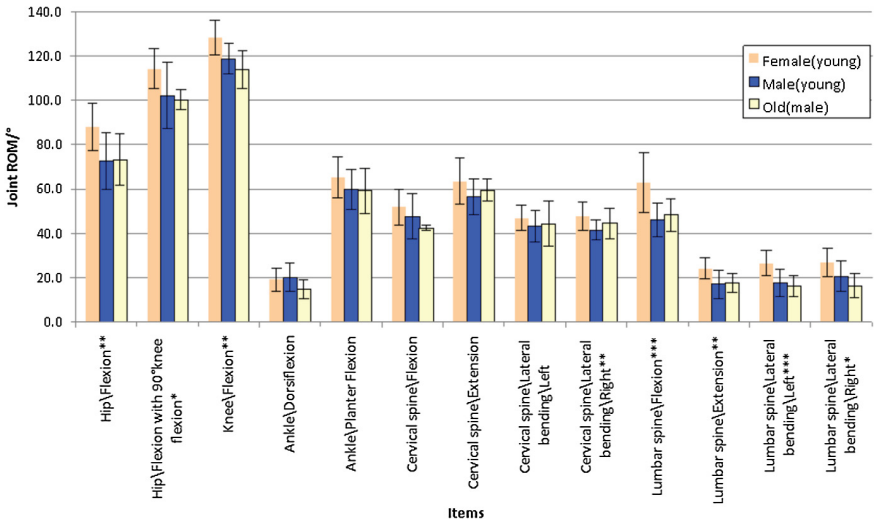

Fig. 3 The joint ROM data of lower limb and spine

It could be seen from Fig. 3 that females had larger ROM than males in all of the lower limb and spine items. The significant difference was found in items of two types of hip flexion, knee flexion, cervical spine lateral bending (on right side), lumbar spine flexion, extension and lateral bending. Similar with the upper limb, larger the joint was, more likely the significant difference appeared. The largest two joints of human body, hip and lumbar spine, show much more significant gender difference in the items than other smaller joints. Females have absolute advantages over males in the items related with waist and legs. For instance, females' ROM of hip flexion was 25° larger than males'; females' ROM of hip flexion with 90° knee flexion was 12° larger than males'; females' ROM of knee flexion was 10° larger than males; females' ROM of cervical spine lateral bending was 6° larger (on right side) than males; females' ROM of lumbar spine flexion was 17° larger than males; females' ROM of lumbar spine extension was 7° larger than males; females' ROM of lumbar spine lateral bending was 6–9° larger than males.

3.3 Comparison on the Two Sides of Symmetrical Items

For items of the left and right side are symmetrical, the significance testing was carried out to find out the significant gender difference and significant age difference between two sides. All of the symmetrical items in Tables 2 and 3 were tested, including shoulder flexion, extension, abduction, internal and external rotation; elbow flexion; wrist flexion, extension, radial deviation, ulnar deviation; cervical spine lateral bending; lumbar spine lateral bending. The shoulder data used here

was collected by VICON system, rather than BTE. The absolute value was used when the significance testing was doing.

The significance testing results indicated that there was no significant difference between left side and right side in the joint ROM of any symmetrical item to group of young female, old female, young male and old male. All participants showed perfect conformity on joint ROM of two sides.

3.4 Comparison on the Measurement Methods

The shoulder data was collected both by VICON system and by BTE system, so that the differences of the two measurement methods could be analysed using the shoulder data. Because no significant difference was found in two sides of the shoulder joint ROM (see Sect. 3.3), the comparison was only addressed on the items of right shoulder.

The participants attended BET measurement could classified as three groups: young female, young male, and old male (no old female attended the BTE measurement). The comparison was carried out as these three groups.

The comparison results between VICON and BTE are shown in Table 4. In which, one star (*) means there is significant difference ($p < 0.05$); two stars (**) means the difference is very significant ($p < 0.01$); three stars (***) means the difference is highly significant (<0.001); hyphen (-) means no significant difference. The means and standard deviations measured by VICON (V) and BTE (B) are given in the brackets if there is significant difference.

It can be seen that 10 out of 15 items show the significant difference between VICON and BTE. Most of the differences were highly significant ($p < 0.001$). The values of most ROM collected by VICON were larger than the values collected by BTE. Most of the standard deviations measured by VICON were also larger than BTE. Thus, it seems like the BTE measurement is more precise than VICON measurement. However, there were some uncertain factors that effected the result. The participants attended the two types measurement were not same. The measurement was a between groups measurement. So the participant might bring

Table 4 The comparison results between VICON and BTE

Joint	Item	Young female	Young male	Old male
Shoulder	Flexion	***(V 151.4 ± 10.2; B 161.2 ± 7.7)	–	*(V 142.3 ± 10.8; B 155.6 ± 10.8)
	Extension	–	–	–
	Abduction	***(V 136.8 ± 7.8; B 165.0 ± 4.6)	***(V 138.5 ± 8.4; B 156.7 ± 7.4)	**(V 122.7 ± 16.3; B 151.2 ± 13.2)
	Internal rotation	***(V 113.3 ± 10.7; B 131.2 ± 6.1)	–	**(V 104.7 ± 11.8; B 125.2 ± 9.7)
	External rotation	***(V 51.6 ± 10.1; B 37.0 ± 7.4)	***(V 56.6 ± 12.1; B 37.7 ± 9.8)	***(V 49.8 ± 12.5; B 30.7 ± 4.7)

individual impact on the comparison result. Besides, there were only five participants in the old male group of BTE measurement. The ROM values might deviate a lot from the normal average value because of the small size sample.

4 Conclusion

For the product interface and working space design, the location and layout of controls affect the operating efficiency and using satisfaction significantly. It even has negative impact on operating safety and user's health if the design is bad. The joint ROM plays an important role in the design period. The gender difference and age difference should be payed more attention to result in better performance, more convenience and better experience for the user. The results could provide helpful reference for human-machine design.

According to this research, some characteristics of joint ROM were revealed. The comparison in gender showed that females had absolute advantages (significant larger values) over males in the joint ROM of lower limb and spine. For the joint ROM of upper limb, males joint ROM of shoulder internal rotation was significant larger than females', while males joint ROM of elbow flexion was smaller than females'. The comparison in age indicated that the young participants had larger joint ROM than the old participants on most of the upper limb items dramatically. There was no significant age difference in any of the lower limb and spine items. The larger joints showed more significant difference (overall) in gender and age. The significance testing for symmetrical items revealed that all participants had perfect conformity on joint ROM of two sides. The comparison of VICON measurement and BTE measurement indicated that the BTE seemed like more precise than VICON, but deep study was needed to confirm because of the limitation in this research.

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Upper Limbs Exposure to Biomechanical Overload: Occupational Risk Assessment in a Poultry Slaughterhouse

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Abstract Brazil is the largest poultry meat exporter, especially in the form of cut-up parts. Thus, the aim of this study was to evaluate the risks associated with repetitive movements of the upper limbs in meat processing tasks. The study was conducted in a slaughterhouse with 3000 workers that slaughtered 300000 chickens/poultries per day. The OCRA checklist was used to evaluate work tasks. The 22 work tasks analyzed were the following: cutting (n = 11); chiller (n = 1); freezing tunnels (n = 1); reception (n = 3) and packing (n = 6). The average of occupational repetitive actions performed by poultry workers was 59.1 ± 18.0 per minute. The average score of OCRA's checklist was 16.8 ± 4.2 (moderate risk). The scores for the right upper limb (18.3—moderate risk) were significantly higher ($p = 0.003$) than the contralateral limb (15.3—moderate risk). Two work tasks were considered high risk (9 %); 17 represented moderate risk (77 %), and 3 were considered low risk (14 %).

Keywords UL-WMSDs · Poultry slaughterhouse · Risk assessment · Ergonomics · OCRA

1 Introduction

Brazil is a world's major chicken meat exporter, 54.71 % in the form of cuts, 4.6 % as processed meat, 4.51 % as salted meat and 36.18 % as whole chicken [1]. Thus, most of the chicken meat produced in Brazil is processed by means of hand tools

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(knives) or specific machines (chainsaws). However, improvements in the working conditions in this sector have not grown at the same rate as production growth [2].

The slaughterhouse workers are exposed to biomechanical risk factors for development of work-related musculoskeletal disorders of the upper limbs (UL-WMSDs) such as repetitiveness, high-frequency of technical actions, excessive force, awkward postures, insufficient time for recovery, use of tools and exposure to cold [3]. Tirloni et al. [4] found that the majority of the workers of a poultry slaughterhouse in Brazil reported some kind of bodily discomfort (67.2 %), mainly on the shoulders (62.6 %) and neck (46.2 %). In another Brazilian slaughterhouse, Reis et al. [5] found that the workers felt discomfort in the shoulder (45 %), neck (29 %), spine (26 %), arms (23 %), and hand and wrists (20 %). Corroborating with this findings, Mohammadi [6] established that 67 % of Iranian workers of poultry slaughterhouse were exposed to high-risk activities that contribute to the development of UL-WMSDs.

The OCRA checklist was developed to analyze the workers exposure to various risk factors of developing UL-WMSDs (strength demand, repetitiveness, inappropriate posture and inadequate movements, lack of recovery periods, and others, defined as "complementary") related to activities performed [7, 8]. This checklist was based on a consensus document of a technical committee in musculoskeletal injuries of the International Ergonomics Association (IEA) [7, 8].

Thus, the aim of this study was to evaluate the risks associated with repetitive movements of the upper limbs in different meat processing tasks in a poultry slaughterhouse, using the checklist OCRA.

2 Method

The procedures in this study were approved by the local Ethics Committee in Research with Human Beings, according to the Helsinki Declaration.

The study was conducted in a poultry slaughterhouse with 3000 workers in which 300000 poultries were hovered daily, divided into two shifts. In order to evaluate the risks associated with repetitive movements of the upper limbs, 10 % of the workforce was evaluated while carrying out their work tasks, using the checklist proposed by OCRA method (Table 1) [9]. Videos of 10 task cycles were recorded for each worker evaluated for subsequent analysis of the activity.

For data presentation, descriptive statistics in terms of mean, standard deviation and percentage was used. In order to compare the risk between the sides of the workers body, the Student t-test (SPSS 17.0) was used, adopting $p \leq 0.05$.

Table 1 Score description of the OCRA checklist, risk classification and respective incidence of UL-WMSDs [9]

Color	Risk	Checklist points	Incidence of UL-WSDs (%)
Green	Acceptable	<7.5	<5.26
Yellow	Borderline or very low	7.6–11	5.27–8.35
Light red	Low	11.1–14	8.36–10.75
Dark red	Moderate	14.1–22.5	10.76–21.51
Purple	High	>22.5	>21.51

3 Results and Discussion

Considering the work load adopted by the company, the two shifts of 528 min each with a lunch break (60 min), six recovery breaks (10 min each) and the time to change clothes/uniform (clock in and clock out), the net time of repetitive work considered for the application of OCRA Checklist was 458 min. Thus, to compute the final risk score, the multiplier factor "one" was assigned, due to the shift's customary duration (between 421 and 480 min).

Assumed that the company adopts a total of 60 min rest break distributed throughout the work shift, for the purpose of computing the "recovery" factor of the OCRA Checklist, a value of "one" (in a scale of 0 to 10) was assigned for all activities analyzed. In order to achieve the ideal score (zero) associated with the "recovery" factor, it would be necessary to adopt another pause of 8–10 min. Considering the conditions arising from repetitive movements, known as RSI (Repeated Strain Injury), the muscular system, joints, ligaments, tendons and nerves are the most affected, especially when the worker has no chance to recover or rest [10].

In relation to the other risk factors, considered by OCRA method (frequency of technical actions, strength demand, posture and related factors), scores were assigned according to the peculiar characteristics of each activity and the technique used by each worker.

According to the analyzes, it was found that the average technical actions performed per minute was 59.1 ± 18.0, which represents 8 points according to the OCRA method scale of frequency (0 to 10 points scale). In a study conducted in a poultry slaughterhouse industry, Colombini, Occhipinti [11] observed similar results, observing an average of 60 actions per minute (with few opportunities for short pauses), which represents 8.2 points in the OCRA Checklist. In another Brazilian slaughterhouse, Reis, Reis and Moro [12] observed 55.2 ± 27.6 technical actions per minute, which represents 7 points in the OCRA Checklist. Researchers of the same study group [13] reported similar results (63.7 ± 25.3 technical actions per minute) for another Brazilian slaughterhouse.

According to Kilbon [14] the worker should not exceed 25–33 actions per minute, considering that frequencies above these values disrupt the physiological

recovery mechanisms from operating efficiently, increasing the incidence of injury to tendons.

Poultry processing includes strenuous and repetitive work, with workers at risk for overuse injuries. Upon entering the plant, the living chickens are received and then passed through a production line that requires workers to hang, kill, pluck, clean, eviscerate, cut, package, and box poultry parts at a rapid pace. In addition, the workers clean and repair equipment, assemble boxes, and move pallets of poultry packaged. Thus, potential risk for overuse injuries exists with each of these occupational duties [15].

Meat processing and slaughtering work tasks involve high loading intensities and cyclic repetitive muscle actions of the upper limbs. Combined with limited time for recovery and temporary episodes of work disability, the prevalence of musculoskeletal pain in the hand, arm and shoulder is high among slaughterhouse workers [16].

The average result of the OCRA for all jobs analyzed in the company was 16.8 ± 4.2 points in the Checklist, which was considered as a moderate risk. The Checklist scores for the right upper limb (18.3 ± 3.5—moderate risk) were significantly ($p = 0.003$) higher than the left (15.3 ± 4.4—moderate risk), therefore it is safe to assume the higher risk on the right side of the body. Colombini and Occhipinti [11] found similar results in a poultry slaughterhouse industry, an average of 20 points (moderate risk) on the OCRA Checklist, confirming that 22.4 % of the 969 workers were affected by UL-WMSDs (proven with clinical and laboratory tests).

Considering the five risk categories proposed by the OCRA method, 2 work tasks were considered high risk (9 %); 17 represented moderate risk (77 %), and 3 were within an low risk (14 %) (Table 2). When grouping the high risk tasks with the moderate risk tasks, it was verified that the majority of the slaughterhouse workers were vulnerable to ergonomic hazards due to repetitive movements.

Nevertheless, previous studies have reported much higher rates of high risk activities that contribute for the development of UL-WMSDs in Iran slaughterhouses (67 %) [6], Italy (90 %) [11], and also in Brazil (56.5 %) [12]. It is speculated that the findings of a smaller number of high risk activities, observed in this study, have been influenced by the recent implementation of the Standard Regulatory Norm 36 (NR-36) [17], which establishes the minimum requirements for evaluation, control and monitoring risks in activities performed at meat processing industries.

Among the requirements of the NR-36 that directly influence the results of OCRA checklist, there is a requirement for adoption of a total of 60 min rest breaks daily, as it reduces the exposure time to activities that require repeatability and/or muscle overload, and also reduces the score on the variable “recovery”. This speculation is evidenced by the disparity between the results of this study and the results of Reis, Reis, Moro [12] study, as these authors evaluated a Brazilian slaughterhouse prior to implementation of the NR-36, and therefore found greater exposure to repetitive activities (480 min), and a shorter duration for daily rest breaks (10 min).

Table 2 Risk assessment for repetitive movements of the upper limbs performed by the slaughterhouse workers, and simulations for reducing this risk by reducing the working pace

Activities—department	Actual situation observed				Simulations for minimizing the risk			
	Units/min.	Tasks/min.	OCRA	Risk	Units/min.	Tasks/min.	OCRA	Risk
Weight breast fillet 7.5 kg—CU	6.7	60	13.5	Low	5.5	49	11	Very low
Seal packaging boneless leg—CU	3	45	12.5	Low	2.6	39	11	Very low
Re-hanging chicken—CH	20	60	20	Moderate	10	30	11	Very Low
Re-hanging Stork—CU	24	72	22	Moderate	12	35	11	Very low
Remove sassami Stork—CU	30	60	20	Moderate	15	30	11	Very low
Cleaning breast—CU	12	60	19	Moderate	7.5	37.5	11	Very low
Unloading cages—RE	0.63	44	16	Moderate	0.43	30	11	Very low
Hanging—RE	13	39	16	Moderate	10	30	11	Very low
Leg deboning—CU	3	45	17	Moderate	2	30	11	Very low
Re-hanging boneless chicken—CU	9.2	27.7	13	Moderate	6.7	20	11	Very low
Neck removal—CU	8.6	51	15	Moderate	6	36	11	Very low
Transfer of boneless legs—CU	20	80	19	Moderate	9.2	36.9	11	Very low
Halal method—RE	40	80	19	Moderate	18.8	37.5	11	Very low
Boneless leg Packing—CU	6	108	18.5	Moderate	2.3	41.5	11	Very low
Interfold chicken leg—CU	0.86	55.7	19	Moderate	0.46	30	11	Very low
Bowl to cardboard box transfer—TU	17	51	18	Moderate	10	30	11	Very low
Wing automatic scale supply—CU	40	80	19	Moderate	20	40	11	Very low
Transfer breast fillet—CU	60	60	15	Moderate	42	42	11	Very low
Breast fillet packaging 7,5 kg—CU	8	64	20	Moderate	4.5	35	11	Very low
Boneless leg secondary packaging—SP	6.7	73	21.5	Moderate	3.3	36	11	Very low
Closing boxes—TU	6.7	40	26.5	High	*			
Fillet wrapping 20 kg—CU	2.5	45	24	High	*			
Average	15.4	59.1	18.3	Moderate	9.4	34.8	11.0	Very low
Standard-deviation	15.3	18.0	3.5		9.5	6.3	0.0	

Sectors: *SP*—Secondary packaging, *CH*—Chiller, *CU*—Cuts, *RE*—Reception, *EV*—Evisceration, *TU*—Tunnels
*It is necessary to restructure the activity due to the strength demands

Corroborating with this hypothesis, Reis et al. [13] found very similar values for the OCRA Checklist (8 % work tasks Were Considered high risk, 81 % moderate risk and 11 % low risk), when analyzing a Brazilian slaughterhouse after implementation of the regulatory standard—NR-36.

The precursors of the OCRA method [9], based on epidemiological data, developed hypotheses of disease prevalence expected in a particular occupational setting. Therefore, possible percentages were defined for each level of incidence of UL-WMSDs in the Checklist, as described in Table 1. In meat deboning activity, Colombini, Occhipinti and Fanti [9] found an incidence of UL-WMSDs of 47.7 % of workers from workstations classified with 28 points in the OCRA Checklist (high risk).

Musculoskeletal problems arising from poorly organized work environments are of concern, as they lead to the emergence of occupational diseases with negative economic and social repercussions both for companies and for government, and especially for the family. Thus, providing an ergonomically appropriated workplace is of fundamental importance for companies, due to the loss of employees, and for the government, which should provide the payment of welfare benefits for treatment and rehabilitation [18, 19].

Tirloni et al. [4] suggest that some organizational factors of the poultry slaughterhouse should be considered for the prevention of UL-WMSDs, such as: slowing down the production process; job rotation between tasks with different biomechanical requirements and increased number of workers; adoption of rest breaks well distributed along the workday; the use of very sharp knives to reduce the effort required to perform cutting task; use of adequate clothing according to the work environment temperature, respecting biological individuality of workers, promoting thermal insulation and comfort; and finally, there should be a gradual transition between the outside and the work setting in order for the workers to undergo adequate acclimatization. Moreover, Reis et al. [5] affirm that the poultry slaughterhouse workstations do not meet the workers' anthropometric characteristics, and ergonomics adjustments are necessary to promote proper functioning, comfort and safety.

Whereas there are predominant highly repeatable movements of the upper limbs in poultry slaughterhouses [16], and previous studies suggested the reduction in working pace to prevent UL-WMSDs [4, 13], simulations of reduced working pace to achieve very low risk levels utilizing the OCRA Checklist were performed (Table 2).

Performing simulations, in 20 activities it was possible to reduce the risk of UL-WMSDs to very low levels, only reducing the working pace (-38.8 ± 13.3 %). In the remaining activities analyzed, it was not possible to achieve very low risk levels only by reducing the working pace, due to the high demand for strength required to perform the task.

4 Conclusion

Based on results of this study and the postulation of the literature, the following can be concluded:

- Most work activities performed by the employees (77 %) were classified as moderate risk, predisposing the workforce to an incidence of UL-WMSDs of between 10.8 and 21.5 %;
- The risk of developing UL-WMSDs in the analyzed activities was higher for the right side of the body;
- Simulations of reducing the working pace showed the effectiveness of this organizational measure to reduce the risk of UL-WMSDs.

Therefore, considering that there are many identical workstations in the production sectors of this industry, it is estimated that most of the employees were exposed to moderate to high risk, in which the high risk provides 6 times greater chance to develop UL-WMSDs than the population that was not exposed.

Future studies are needed to determine whether our findings can be generalized to other poultry slaughterhouses, given that the current study was limited to analyzing only those employees within the Brazilian slaughterhouse.

Lastly, some organizational measures should be considered to reduce the risk of work-related musculoskeletal disorders of the upper limbs, for example, reducing the working pace, adopting rotation between activities with different biomechanical requirements, adopting breaks well distributed throughout the workday and increase the number of employees.

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Total Forearm Muscle Activities in Various Hand Postures

Kyung-Sun Lee, Jiyeon Ha, Seokhwan Yoo and Myung-Chul Jung

Abstract This study examined total forearm muscle activities in five different hand postures of pinching with two fingers (2P), three fingers (3P), four fingers (4P), five fingers (5P), and power grip (5G). Male students participated in the experiment. EMG signals were recorded by using nine dual surface electrodes to record the activities of forearm muscles of flexor carpi radialis (FCR), flexor carpi ulnaris (FCU), extensor carpi radialis (ECR), extensor carpi ulnaris (ECU), flexor digitorum superficialis (FDS), flexor digitorum profundus (FDP), extensor digitorum (ED), flexor pollicis longus (FPL), and extensor pollicis longus (EPL). The nine muscles were combined to estimate total muscle activities by the summation method of the EMG index. Analysis of variance showed that the total muscle activities were significant for the hand postures. The muscle activities for 2P and 3P hand postures were about 20 % higher than those for the 5P and 5G postures. Overall, the summation value of % MVC decreased as the number of fingers used increased.

Keywords Hand posture · %MVC · Total muscle activity · Forearm muscles

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1 Introduction

The human hand is very useful in activities of daily living (ADL) and occupational or industrial activities [1]. The hand posture in various movement is its most important and basic function. The hand posture is an important factor in working methods and product design because it affects human capabilities. Thus, many researchers in various fields are attempting to assess the physical loads of various hand postures.

The physical load on the hand has typically been evaluated using electromyography (EMG). Finneran and O'Sullivan [2] studied effects of grip type on forearm EMG activity. They concluded that forearm muscle activity shows different maximum voluntary exertion by three different grip type of power grip, middle chuck pinch, right pinch grip. Also, Cho et al. [3] concluded that physical loading in hand can be as much as about five times greater for a pinch grip than for a power grip. Previous studies did not consider various hand postures and common hand postures in ADL and occupational or industrial activities.

Thus, the aim of this study was to identify the total forearm muscle activities in various hand postures of pinching with two fingers (2P), three fingers (3P), four fingers (4P), five fingers (5P), and power grip (5G).

2 Methods

2.1 Participants

Ten male graduate and undergraduate students participated in the experiment. All the participants were right-handed and had no history of illnesses or injuries in their upper extremities. All of them provided informed consent before participation in accordance with the University Institutional Review Board's requirements.

The averages (standard deviations) of their age, height, and weight were 23.3 (SD 5.2) years, 173.0 (SD 5.0) cm, and 64.2 (SD 23.0) kg, respectively. The averages (standard deviations) of their right hand length, circumference, and breadth were 18.3 (SD 1.4) cm, 18.8 (SD 1.5) cm, and 9.4 (SD 0.9) cm, respectively.

2.2 Apparatus

A table made of wood and aluminum framing material was used. The table height followed the recommended standing work surface height for 107 cm of light assembly work task [4]. The objects used were cylinders and rectangles made of

acrylic panels with sizes of 2, 4, 6, and 8 cm. Weights of 1–1000 g were used to control the load levels, which ranged from 400 to 1800 g.

Electromyography (EMG) signal were recorded using nine channels by dual electrodes with Telemyo 2400T DTS telemetry equipment (NORAXON, USA Inc., Scottsdale, Arizona). The dual electrodes were disposable, self-adhesive Ag/AgCI dual snap electrodes. These signals were amplified with a gain of 500, noise of <1 μV, and sampling rate of 1000 Hz with a filtering bandwidth of 20–450 Hz. All the data were acquired on a laptop computer with a 16-bit analog-to-digital converter.

2.3 *Procedures*

After giving informed consent, each participant was provided with a brief description of the experimental objectives and procedures. Dual surface electrodes were used to record the activity in nine forearm muscles; the flexor carpi radialis (FCR), flexor carpi ulnaris (FCU), extensor carpi radialis (ECR), extensor carpi ulnaris (ECU), flexor digitorum superficialis (FDS), flexor digitorum profundus (FDP), extensor digitorum (ED), flexor pollicis longus (FPL), and extensor pollicis longus (EPL) (Fig. 1). The attachment positions of the electrodes were chosen according to surface EMG for non-invasive assessment of muscle (SENIAM) [5], Perotto et al. [6], and Kendall et al. [7].

After the electrodes were attached, the participant performed maximal voluntary contraction (MVC) testing to determine the normalization for each muscle according to Kendall et al. [7] during a 3 s period. A recovery time of at least 2 min was taken between MVC tests to avoid localized muscle fatigue.

The participant stood in front of the table. Participants picked up the objects using the hand posture required by the experimenter. The participants were asked to

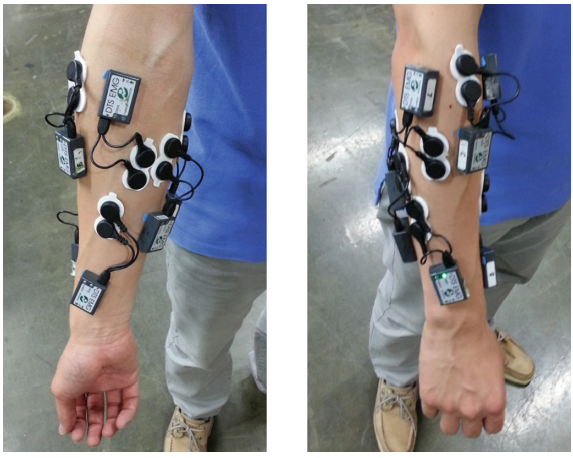

Fig. 1 Attachment positions of electrodes

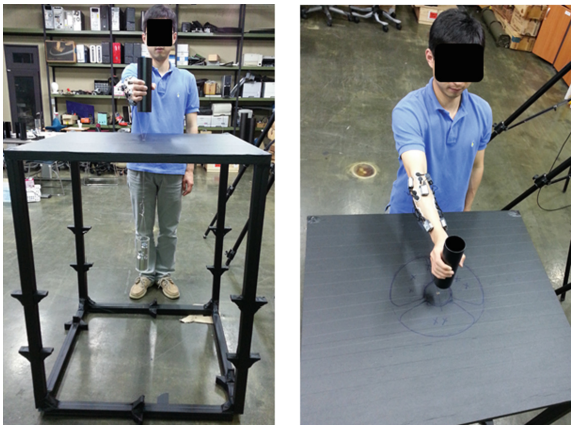

Fig. 2 Experimental setup and pick up task

lift the object to approximately shoulder height and maintain this posture for 3 s. each participant performed only one trial for each experimental condition. Figure 2 Shows the overall experimental setup and pick up task.

2.4 Signal Processing and Experiment Design

The raw EMG signals were pre-amplified, bandpass-filtered (20–450 Hz), and root mean square (RMS) converted (250-ms window size). All the RMS EMG data were software-filtered with low pass, second-order Butterworth by using a cut-off frequency of 5 Hz [8]. The EMG RMS was then calculated and expressed as a percentage of the MVC (%MVC) from individual muscles of nine forearm muscles. To quantify the total hand muscle activity, the individual muscles were combined to provide an estimated of the total muscle activities base on a summation method of the EMG index (Eq. 1) [9, 10]. E_i is the EMG of the *i*th muscle obtained, and N is the number of muscles.

$$EMG_{total} = \sum_{i=1}^{N} E_I \tag{1}$$

The independent variable for analysis of variance were five levels of hand posture (2P, 3P, 4P, 5P and 5G), four levels of object size (2, 4, 6, and 8 cm), and four levels of object weight (400, 800, 1400, and 1800 g). The dependent variable was % MVC of total muscles activities. The Tukey's Studentized Ranged (HSD) test followed ANOVA at significance level of 0.05.

3 Results

The results of ANOVA revealed that there was a significant effect of hand posture on the % MVC of total muscle activities ($p < 0.0001$), the interaction of the hand posture and object size ($p = 0.0027$), and hand posture and object weight ($p < 0.0001$). The Tukey test showed 3 different levels of 2P and 3P, 4P and 5P, and 5G (Fig. 3).

The summation value of the %MVC for the object-holding task range from 92.09 to 124.03 % by hand postures. The interaction of the 2P hand posture and 8 cm object size produced the highest % MVC of total muscle activities (139.23 %). Overall, %MVC of total muscle activities was higher when participants held the 8 cm object. The interaction of the 3P and 2P hand posture an 1800 g object weight produced the highest % MVC of total muscle activities (165.09 and 153.26 %) (Fig. 4).

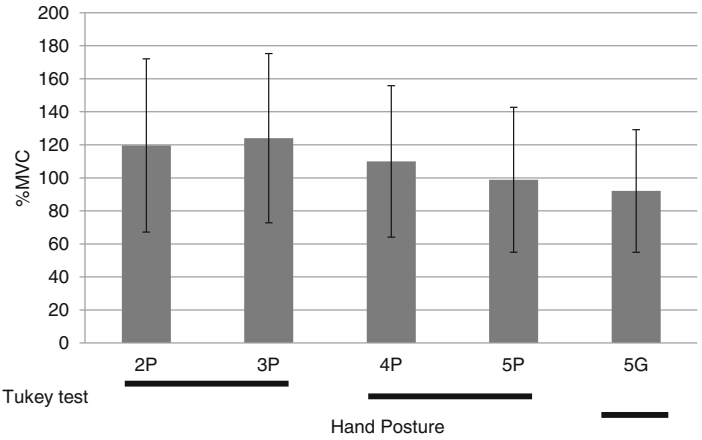

Fig. 3 %MVC of total muscle activities by hand posture

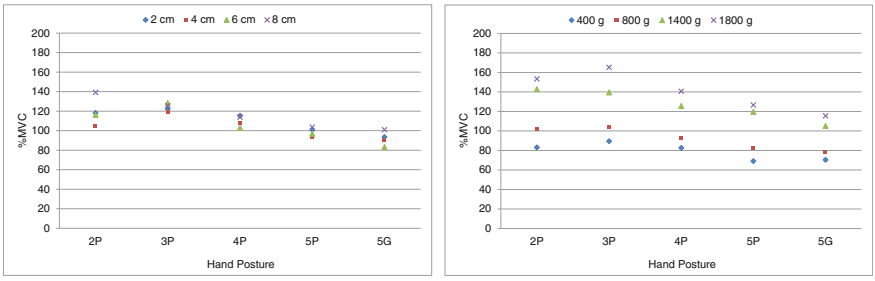

Fig. 4 %MVC of total muscle activities by hand posture and object size, object weight

4 Discussion

The hand posture affected the total muscle activation. When participants held objects using the 2P and 3P hand postures, the muscle activation was largest. Overall, the %MVC decreased linearly as the number of fingers used increased.

This study showed that higher muscle activation appeared when participants held objects using pinch postures than when they used 5G hand posture. Anson et al. [11] observed remarkable functional differences among intrinsic and extrinsic muscles during two different hand postures (pinch grip and the power grip). This is due to the different contributions of the extrinsic muscles when participants held objects using pinch grip and the power grip. The 5G hand posture should be used for power activities engaging the intrinsic and large muscle groups (extrinsic) of the hand because all the fingers are engage in holding the object in a stable grip [2]. In contrast, the pinch postures involve a change in the position of the object, where the hand and wrist are firmly held by the long flexor and extensor muscle, and the intrinsic muscles of the hand perform fine movements of the digits [12].

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Experimental Research for Motion Ranges of Knee Joints

Wen-Yu Fu, Guang Cheng, Yu-Feng Ma and Ai-Ping Yang

Abstract To investigate the range of motion (ROM) of knee joints in the human body, the difference of ROMs between man and woman in subgroups, and how the difference of ROMs relates to age itself; One hundred healthy volunteers of ages 18–60 were recruited to complete the study. They were divided into two groups, with half of them male. The VICON motion capture system was used to measure ROMs of knee joint. The average value of knee joint ROMs for two groups was calculated. The changes in the ROM for two groups were compared along with the differences in the ROM between male and female, and between the left and right knee joints. ROMs of knee joints decreased as the age increased. The difference between the ROMs in the two groups was not significant. Female ROMs of knee joints were bigger than the male in the same age group.

Keywords Range of motion · Knee joint · Motion capture system

1 Introduction

Function sizes of the human body should be considered for design of structure and location in various products to make the operation of products more user-friendly. So far, some Chinese scholars studied the ROMs of the human body, and obtained some data about ROMs, although these data were measured 10 years ago [1–5]. With the improvement of individual Chinese person's living standards, physique and function size may also change especially possible greater changes for labor from 18 to 60 years of age. Therefore, it is necessary to measure and re-analyze ROMs of human limb joints and provide new reliable values regarding ROMs for product design with related industries.

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ROMs are the measurement of movement around a specific joint of human body [6], which can be restricted by age, disease, and trauma [7]. Measurement and data analysis regarding ROM of adult human knee joint were introduced mainly in this paper.

2 Method

2.1 Subjects

One hundred healthy people (50 males and 50 females) agreed to participate in this study, and were divided into the following groups: young, and middle-aged/elderly. Information on the number of subjects, gender and age is shown in Table 1.

2.2 Measurement Items

In this study ROMs of human knee joint was measured.

2.3 Method of Measurement

The ROM of human body joints was measured by using VICON motion capture system from the British Oxford Metrics Limited Company [8–10]. An example of right knee ROM was shown in Fig. 1 to illustrate the location of which ball and marker points in VICON system, and the template of the motion model.

3 Measurement Results

Tables 2 and 3 showed the test results.

As shown in Fig. 2, most ROM of right knee joint concentrated around the median of 134.6°. The upper and lower bounds of the results were based on the deviation of 11.4°. Approximately 96 percent of the subjects were in this range

Table 1 Information about subjects

Age	18–40	41–60
Number of subjects		
Male	40	10
Female	40	10

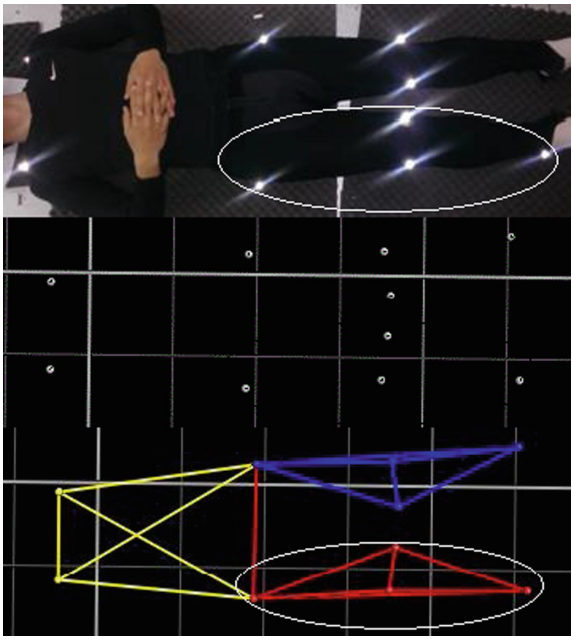

Fig. 1 A sketch about positions of marker points on the human body, the location of which ball, and movement template when measuring right knee ROM (*region inside the ellipse*)

Table 2 ROM of left knee joint

Joint	Knee (left, degree)
Average value	
Male and female	133.98
Female	137.54
Male	130.43
Young	135.96
Young female	139.45
Young male	132.46
Middle-aged and elderly	126.09
Middle-aged and elderly female	129.90
Middle-aged and elderly male	122.29

while results outside this range could be abnormal data caused by the individual differences (i.e. the age or special professional background).

As shown in Fig. 3, most ROM of left knee joint concentrated around the median of 134.4°. The upper and lower bounds of the results were based on the deviation of 10.8°. Approximately 99 percent of the subjects were in this range while results outside this range could be abnormal data caused by the individual differences.

Table 3 ROM of right knee joint

Joint	Knee (right, degree)
Average value	
Male and female	134.72
Female	138.21
Male	131.22
Young	135.85
Young female	138.63
Young male	133.07
Middle-aged and elderly	130.18
Middle-aged and elderly female	136.52
Middle-aged and elderly male	123.84

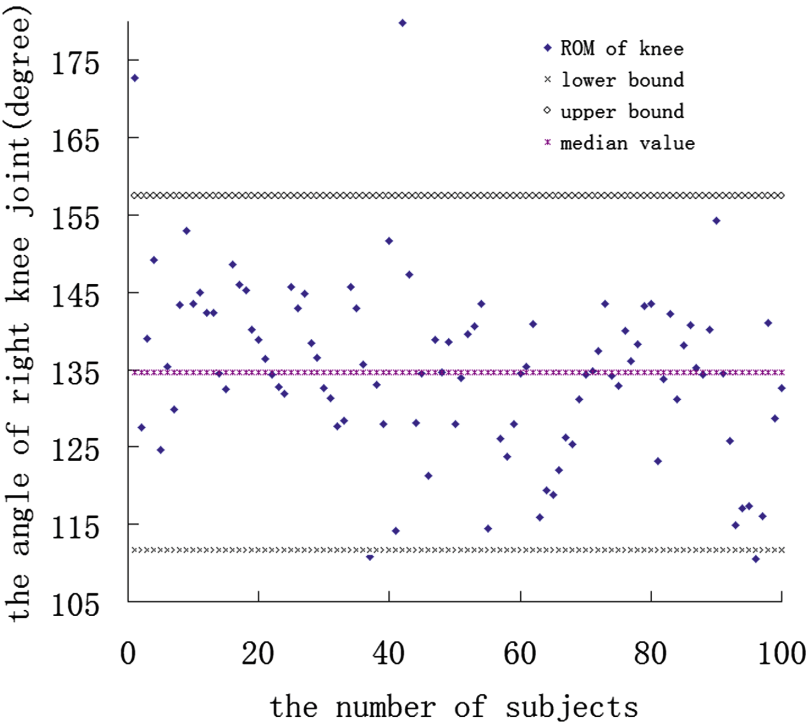

Fig. 2 The distribution of angle of right knee joint

As shown in Figs. 2 and 3, ROM of left knee joint and right knee joint are similar. The difference of median, the upper and lower bounds between left knee joint and right knee joint is very small.

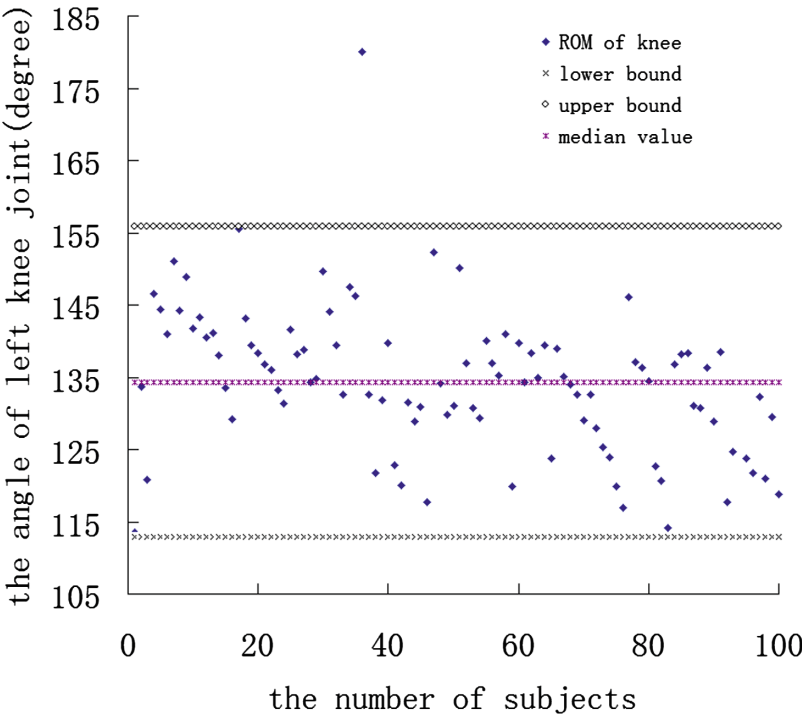

Fig. 3 The distribution of angle of left knee joint

4 Discussion

This study investigated the ROM of knee joints in the human body. However, the low number of subjects ranging from 18 to 60 years old was a major deficiency in this experiment study. Therefore, the results obtained from these data did not represent the entire Chinese population. Further study is needed to obtain accurate results by increasing the number of samples reasonably.

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Measurement of Low Back Muscle Fatigue and Recovery Time During and After Isometric Endurance Test

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Abstract The aim of this study was to examine the relationship between myoelectrical manifestation and muscle oxygenation level by surface electromyography (EMG) and Near-infrared spectroscopy (NIRS), respectively. As well as the recovery time based on tissue oxygenation index (TOI) after isometric exercise on erector spinae muscle (ESM). Eleven healthy females (age = 18.8 ± 0.7 years, height = 1.59 ± 0.0 m, BMI = 20.1 ± 1.8; mean ± SD) performed an isometric back trunk extension (Biering-Sørensen Muscle Endurance test—BSME) of their 40 % of their mean maximal voluntary contraction (MVC) until exhaustion. Muscle oxygenation decreased immediately at the beginning of exercise. Maximal deoxygenation occurred at 100 % BSME time, and decreased about 15 % from the resting value. A strong correlation between frequency content of the EMG signal and TOI was established, $r = 0.78$ (right) and $r = 0.90$ (left). These findings suggest that the fatigue resulting from sustained isometric exercise are related to a decrease in oxygenation level following by the increasing time of contraction of the ESM.

Keywords Isometric contraction · Near infrared spectroscopy · Electromyography

1 Introduction

Identifying physical limitations has long been the focal point of analysis in sport, exercise, rehabilitation, and ergonomics. It is crucial to identify the potential mechanism/sources of exhaustion to prevent musculoskeletal damage. Muscle fatigue, from static and repetitive tasks, is one process that can be implicated as a

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potential source of injury. The Biering-Sørensen muscle endurance test (BSME), an isometric back endurance test, is commonly used to measure the endurance capacity and fatigue of the back muscles [1]. Procedures for the test have been previously reported in subjects with and without back pain to determine their muscle potential [1–4].

Near-infrared Spectroscopy (NIRS) was developed as a noninvasive method to examine muscle oxygenation and oxidative metabolism. NIRS quantifies the changes in hemodynamics by changes in the absorption of near-infrared light by oxyhemoglobin and deoxyhemoglobin. By using this technique, tissue organization can be measured in a discrete region in a working physiological setting, which enhances the specificity of the test (2.5). Several studies have used NIRS to examine trends in erector spinae oxygenation and blood volume during isometric contraction of the lumbar extensors [3, 6–10]. They revealed that low back muscle oxygenation decreased during static contraction with the intensity ranging from 2 to 80 % of the maximum voluntary contraction (MVC) [2, 3, 10].

Using NIRS, Chance et al. [7] reported that recovery time is the balance between oxygen supply and oxygen demand as bioenergetic resources are restored following an exercise interval. Recovery time can also be interpreted as a measure of the time required for repayment of oxygen and energy deficits accumulated during exercise by tissue respiration under ADP control. In relation to recovery time, Kell et al. [3] demonstrated a systematic decrease in oxygenation towards the baseline in the initial phase of the test with values at or near baseline after about 2 min in the erector spinae muscle (ESM). Furthermore, other studies have shown a correlation between recovery time, work load, and lactic acidosis [11–13].

In assessing the effects of ESM fatigue, surface electromyography (EMG) has proven its utility in describing the power spectrum and amplitude changes that occur during volitional exhaustion exercises [14, 15]. EMG power spectral analysis has indicated that muscle fatigue is associated with shifts in the median frequency (MF) and/or mean power frequency (MPF) towards lower values [16, 17]. Additionally, EMG has well established that progressive decline in MF is a strong predictor of back muscle endurance [10, 16].

However, previous studies focused only on the exercise period and not on the recovery period. Furthermore, to the best of our knowledge, the relationship between BSME time and half-time to recovery after exercise, from a NIRS perspective, has not yet been investigated in vivo.

Therefore, the purpose of the current study was to: (1) examine the relationship between EMG MF and the NIRS tissue oxygenation index (TOI) during performance of the BSME test for the ESM, and (2) calculate the half-time to recovery (hTR) from the TOI after exercise.

We hypothesized that both EMG and NIRS can be used to examine low back muscle fatigue by understanding their behavior, which could lead to additional information for improved assessment of muscle fatigue.

2 Methods

2.1 Participants

The purpose of study and potential risks and benefits was explained to all participants and written informed consent was obtained from 11 healthy female college students who volunteered for the study. The inclusion criteria were: age between 18 and 20; no current low-back pain; no metabolic, cardiovascular, pulmonary, or orthopedic disorders; BMI below 22; and skinfold thickness lateral to the L3 spinous process below 18 mm. The protocol was approved by the Prefectural University of Hiroshima Ethical Committee and complied with the ethical standards of the 1975 Helsinki Declaration detailing ethical principles for medical research involving human subjects. Descriptive information for all participants is presented in Table 1.

2.2 Subcutaneous Adipose Tissue Thickness (ATT) Measurements

The subcutaneous adipose tissue thickness was measured by skinfold calipers at the NIRS measurement site (bilaterally, 3 cm from the L3 spinous process as proposed by Kell et al. [8]. Three consecutive measurements were taken and the ATT was defined as the mean value of the subcutaneous tissue thickness [3, 7] (Table 2).

2.3 Exercise Protocol

The protocol was intended to be performed in two days, with each measurement separated by at least 48 h. On the first day, instructions and familiarization were provided, and EMG maximal voluntary contraction (MVC) was measured in all subjects. Maximal neuromuscular activity of the trunk extensors was determined by

Table 1 Physical characteristics of subjects

Variables	Subjects (n = 11)	p value
Age (years)	18.8 (0.71)	0.938
Height (m)	1.59 (0.01)	0.899
Body mass (kg)	50.8 (4.63)	0.961
BMI (kg/m^2)	20.1 (1.83)	0.995
BSME time (s)	155.5 (33.0)	0.997
VAS	7.32 (1.7)	0.566
Right side dominant	11	

Values are mean (±SD)

Table 2 Mean (±SD) values of Skinfold (mm), half-time to recovery (hTR), ΔTOI (%) and Reoxy-rate (%/s) variables with the sides compared

Variables	n = 11	
Side	RL	LL
Skinfold (mm)	17.9 (1.57)	15.7 (1.85)
hTR (s)	28.80 (8.8)	28.06 (6.9)
ΔTOI (%)	12.18 (4.8)	12.10 (4.2)
Reoxy-rate ($\%^{-s}$)	0.35 (0.1)	0.36 (0.1)

MVC and evaluated following posterior analysis as proposed by Vera-Garcia et al. On the second day, subjects performed the endurance test (i.e., the BSME test) until volitional exhaustion. A baseline of 2 min was measured and subsequently 5 min for the recovery period. All subjects performed one single static test.

To perform the BSME test, each subject lay prone on a plinth, aligning their iliac crest with the edge of the table. Three straps (located around the pelvis, knees, and ankles) were used to fix and support the lower body on the table. During the BSME test, the subjects were required to position their hands at the side of their head, with their elbows to the side and level with the trunk (Fig. 1). They were also instructed to look downward at a visual fixation point [2, 4, 6, 17–19]. After the recovery period, subjects were asked to rate their perceived discomfort using a 10 cm Visual Analog Scale (VAS). The scores ranged from 0 (no discomfort) to 10 (greatest discomfort). The VAS is a simple and valid index to assess low back discomfort [20].

2.4 Near-Infrared Spectroscopy (NIRS)

Using the manufacturer's custom-designed optically dense black holder, two Spatially Resolved NIRS probes (NIRO-200NX, Hamamatsu Photonics, Japan)

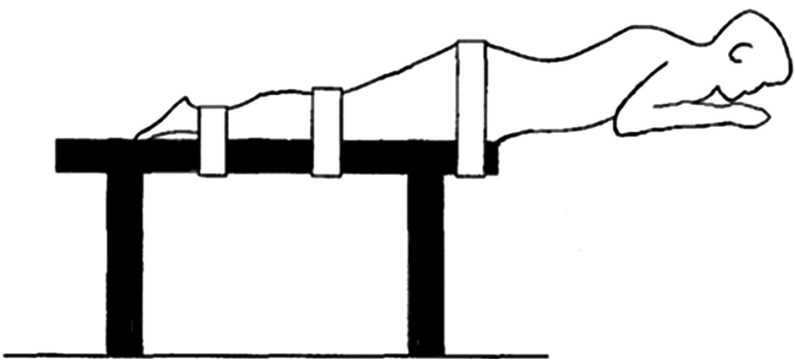

Fig. 1 Illustration of the Biering-Sørensen Muscular Endurance (BSME) test position with the subject strapped at the ankle, leg, and pelvic regions

were placed (via double-sided adhesive tape) bilaterally (RL: Right; LL: Left) at the level of the third lumbar vertebra over the ESM, 3 cm lateral from the spinous process [2, 6]. The NIRO-200NX provides a TOI (expressed in percentage) and displays relative changes in oxyhemoglobin (O2Hb) and deoxyhemoglobin (HHb) (expressed in ΔμM). The NIRO-200NX performs calculations based on the modified Beer-Lambert law and spatially resolved spectroscopy parameters. Hence, the TOI value is a measure of dynamic balance between the distribution and consumption of oxygen [21]. To calculate ΔO2Hb and ΔHHb, the NIRO-200NX uses differences in light absorption characteristics at 775, 810, and 850 nm. The interoptode spacing (between the source and detector) was set to 4 cm. It is not possible to distinguish the relative contributions of hemoglobin and myoglobin because they have identical spectral characteristics. However, it has been reported that the major signal from NIRS comes from hemoglobin [11].

2.5 Calculation of TOI Half-Time to Recovery (HTR)

The hTR is the time required to reach the value halfway between the NIRS TOI level immediately after exercise and that at peak during recovery period. All TOI parameters were analyzed using calculations obtained by monoexponential curve fitting [5, 11, 12, 22, 23].

2.6 Surface Electromyography (EMG)

Two wireless electrodes (WEB-7000, Nihon Kohden, Japan) were attached to the back 3 cm lateral to the L3 spinous process over bilateral ESM, and proximate to the NIRS probes, without compromising any evidence. The signal was collected at a sample rate of 1000 Hz, and low- and high-pass filtered at 30 and 500 Hz. EMG MF was calculated using BIMUTAS software (Kissei Comtec Co., Japan).

2.7 Statistical Analysis

NIRS-derived responses data were filtered using MATLAB Savitzky-Golay filtering prior to analysis by a customized Microsoft Excel program. Baseline values were recorded during the initial test. Baseline tissue oxygenation and MF values were normalized to 100 % to improve inter-subject comparability.

All data was analyzed using SPSS version 12.0 (SPSS Inc., Chicago, IL, USA) with alpha level set at 0.05 ($p \leq 0.05$). Mean and standard deviation were used to describe all variables. Data were analyzed using the statistical software SPSS version 20.0 for Windows (IBM Corp., Armonk, NY, USA). Data normality was

verified by the Shapiro–Wilk test. Repeated measures analysis of variance (ANOVA) was used to evaluate the NIRS TOI and EMG MF values for the protocol for the right and left sides. The Bonferroni test was used when significant differences were found, as well as interactions between the effects. The relationship between EMG MF and NIRS TOI was determined using a Pearson product moment correlation analysis. Similar analyses were conducted to determine relationships between the BSME test time and half-time to recovery (hTR), as well as the ΔTOI. A significance level of $p < 0.05$ was adopted. Data are expressed in the results, tables, and graphs as mean ± standard deviation.

3 Results

Physical characteristics and variables are summarized in Tables 1 and 2.

Mean value for RL and LL of the erector spinae TOI parameters during baseline, BSME test, and recovery period are showed on Fig. 2. The exercise time scale was normalized. Considerable inter-individual variations were observed for NIRS responses during the analyzed test. A fast linear decreasing phase for the TOI was observed at the start of the exercise followed by a constant decreasing phase until the end of the exercise (from 100 to 84.8 % with the right and left sides pooled). Mean BSME test time was 155.5 ± 33.0 s.

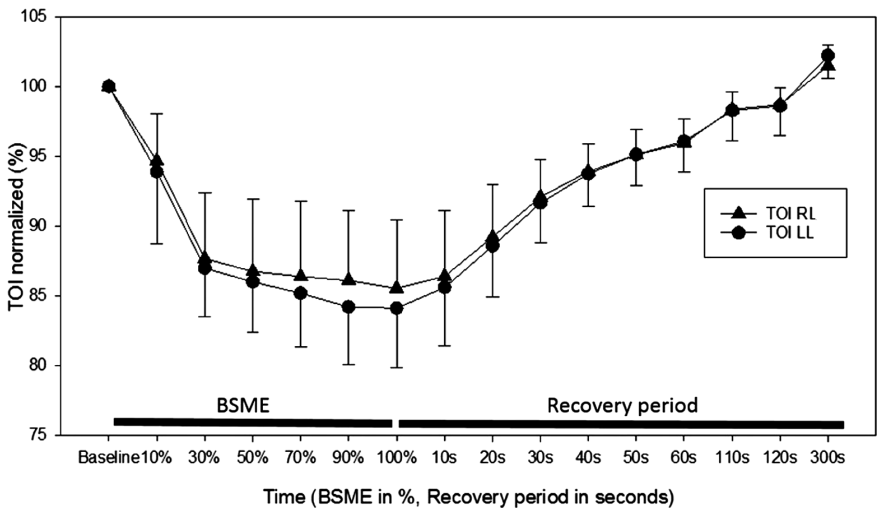

Fig. 2 Mean Tissue Oxygenation index (TOI) normalized trends during the Baseline, BSME (%) and recovery period (seconds). RL: Right Lumbar at third level. LL: Left Lumbar at third level. Error bar indicate one standard deviation of the mean

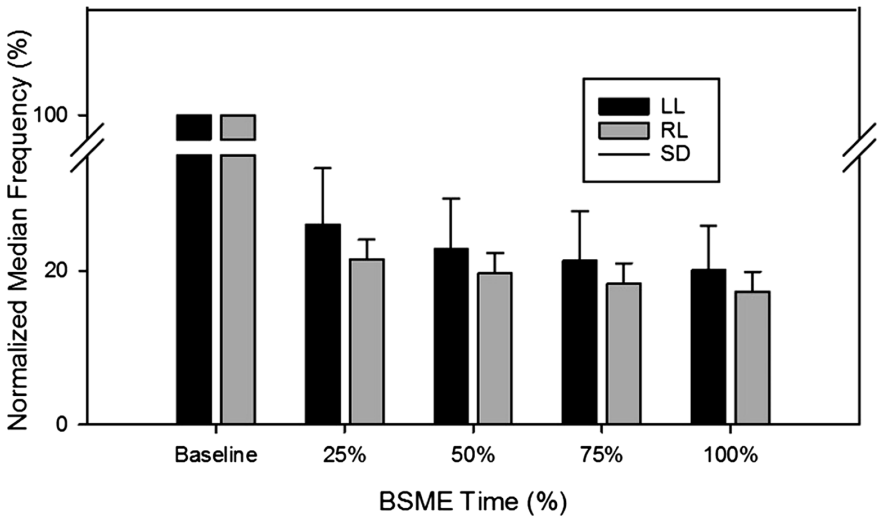

Fig. 3 Mean changes and standard deviation in EMG Media Frequency from right (RL3) and left (LL3) erector spinae muscle during BSME. EMG spectral variables are expressed as % of baseline value (average of first 5 s of BSME test). *$p < 0.05$ for significance of difference between means

The recovery period was followed by a systematic increase in the TOI with values at or near baseline during the final 2 min. The half-time to recovery (hTR) was between 20 and 38 s and 22 and 32 s for the right and left sides of the assessed ESM, respectively.

The NIRS TOI for the RL differed significantly between the stages of the protocol when repeated measures ANOVA with a Greenhouse-Geisser correction was performed (F (1.684, 16.840) = 55.762, $p < 0.0001$). Post hoc tests using the Bonferroni correction revealed that TOI level increased after exercise from the measure at 100 % of the BSME test time to 10 s of the Recovery period (85.52 ± 4.93 % vs. 86.40 ± 4.73 %, respectively) which was statistically significant ($p = 0.03$).

NIRS TOI for the LL also differed significantly between the stages of the protocol when repeated measures ANOVA with a Greenhouse-Geisser correction were performed (F (2.278, 22.784) = 78.963, $p < 0.0001$). Post hoc tests using the Bonferroni correction revealed that TOI level increased after exercise from the 10 s of Recovery period to 20 s (85.58 ± 4.16 % vs. 88.57 ± 3.67 %, respectively) which was statistically significant ($p = 0.04$).

Mean EMG MF decreased progressively to nearly 70 % of the resting value on both sides (Fig. 3). There was no time and side interaction, thus the data from the left and right sides were pooled for subsequent correlation analysis. A positive strong correlation was found between BSME time and hTR, as well as ΔTOI when the values of the two sides were pooled. The correlation coefficient for ΔMF values and BSME time indicated low to moderate correlation (Table 3).

Table 3 Pearson's correlation coefficient between BSME time and half-time to recovery (hTR), change level of tissue oxygenation index (ΔTOI), and change level of median frequency (ΔMF) variables with right and left side pooled

Variables	$n = 11$	p value
hTR	0.845	0.001
ΔTOI	0.894	0.001
ΔMF	0.593	0.055

There was a strong positive correlation between mean TOI RL and MF RL during the period of muscle contraction ($r = 0.78$, $p < 0.05$), and between TOI LL and MF LL ($r = 0.90$, $p < 0.05$).

4 Discussion

In the present study, we used the NIRS TOI to measure erector spinae muscle oxygenation simultaneously with EMG MF measurements during BSME, as well as the half-time to recovery after the BSME test. NIRS TOI and EMG MF decreased progressively as a function of time during the BSME test. This trend is in agreement with previous studies (4.14). Moderate to strong correlation between TOI and MF was demonstrated ($r = 0.78$ and $r = 0.90$, for the right and left sided ESM respectively). Albert et al. [17] suggested a low to moderate correlation between NIRS and EMG, but in their study, muscle oxygenation values were presented in optical density units, which only describe the oxygen concentration change. Therefore, in our study, NIRS TOI (ratio of $HbO_2/(HbO_2 + HHb)$) was given. It was possible to obtain this by using a spatially resolved spectroscopy system. With this system, it was also possible to measure the Reoxygenation rate (i.e., Reoxy rate). The Reoxy rate reflects the change in post-exercise muscle oxygenation levels over time. It has been reported to be a good marker of aerobic muscle function. According to McCully, the Reoxy rate has been shown to have similar recovery kinetics to phosphocreatine (PCr) resynthesis after exercise. It may be possible that a faster Reoxy rate is indicative of an improved ability to supply oxygen at a higher rate during the post-exercise period. Future studies focusing on the relationship of these responses should assess whether there are any inherent differences between the Reoxy rate and the burden related to different types of exercises, which would suggest that this index of oxygen demand and delivery is a marker of aerobic resaturation after exercise [11].

We calculated a hTR of 28.33 ± 9.5 s and 28.06 ± 6.9 s for the right and left ESM, respectively by NIRS tissue oxygenation index. Kell et al. [8], reported a value of 51.17 ± 29.8 s and 58.42 ± 37.1 s for right and left ESM recovery time, respectively, after the BSME test. Although they utilized similar equipment, in their study, muscle oxygenation was calculated as the difference between the concentration change of oxyhemoglobin and deoxyhemoglobin.

In accordance with Albert et al. [17], the TOI for the ESM demonstrated a rapid decrease at the onset of the BSME test, with a more gradual decrease during the middle and later stages. The average ESM response reflected continued utilization of oxygen as illustrated by the decline in oxygen saturation by greater than 10 % throughout the test, in order to provide sufficient energy to perform the protocol. These findings are consistent with previous findings, and can be explained by increased cellular oxygen uptake in the mitochondria due to the increased metabolism of the working motor units, or increased intramuscular pressure [6, 10]. The duration of this decline seems parallel with the use of phosphocreatine (PC) as an energy source for muscle contraction. The energy source during the final phase of the contraction is likely supplied by glycogen in anaerobic glycolysis due to the deficit in oxygen caused by the mechanical obstruction of blood flow to the muscle.

Yoshitake et al. [5] has examined the oxygenation responses of the ESM during static contraction in order to fundamentally understand the fatigability process of the ESM with NIRS. They assumed that the restriction of blood flow due to high intramuscular mechanical pressure was one of the most important factors underlying low back muscle fatigue. Fatigue during static contraction has been attributed to increased intramuscular pressure [10, 14].

Gerr et al., demonstrated a link between musculoskeletal symptoms and disorders and occupational ergonomic exposures, such as sustained static muscle contraction, highly repetitive movements, and insufficient recovery time. According to Chance et al. [7] the hTR is related to a reduction in oxygen concentration and high-energy phosphoric acid level in the muscles. Thus, it is a comprehensive representation of intramuscular capillary density, myoglobin concentration, size and density of mitochondria oxidative enzyme activities, and oxygen transport capacity, and it serves as an index for the oxygen-retaining capacity of muscles. Therefore, in our study, hTR was used to represent the compromised oxygen-retaining capacity in the ESM during the isometric endurance test.

Metabolic factors may be the primary determinant of muscle fatigue in these situations, whereas in low intensity exercise, electrophysiological processes appear to be the limiting factor. Recovery of metabolic supplies is dependent on circulation. Therefore, it can take considerable time for full recuperation of the rest values.

The BSME test times were moderately variable and ranged between 117.5 and 194.7 s (148.5 $\pm$ 26.0 s). These values are slightly lower than has been reported by Albert et al. [17], but they are within the ranges reported by others [2].

The electrode locations were selected to incorporate the activity of the *multifidus*, *iliocostalis*, and longissimus muscles, although it is questionable whether the signal from each underlying muscle was picked up at any of the sites.

The estimated value of the conduction velocity affects the frequency scaling of the spectrum and consequently, the value of the spectral parameters [16]. A decrease in conduction velocity is thought to be caused by an increased concentration of extracellular potassium and metabolic acidosis. Cumulative fatigue develops as isometric contraction time increases [2], as was observed in this study. For bilateral ESM, the MF started to decrease from the moment the muscle contraction was initiated until the end of contraction. This is in line with findings from

Tsuboi et al. [11]; the downward trend in MF is related to an increase in endurance, suggesting that smaller muscle fibers were recruited at high contraction forces. Mannion et al. suggested a predominance of type I over the II fibers in the ESM of women.

As such, greater oxidative potential and decreased production of metabolic by products would result in a slower decline of the EMG MF. No significant difference was found on the right side, which might be explained by the fact that all study subjects had a dominant right side. Nicolaisen and Jorgensen (1985) suggested that the force of the muscle contraction needs to be higher than approximately 50 % of the MVC for blood flow to be occluded. During the BSME test, a 40 % MVC was recorded. Therefore, we could not assume blood flow occlusion.

5 Conclusion

The findings of this study have implications for future investigations on the mechanism of action of the low back muscles. A reduction in the strength (i.e., EMG), endurance, and oxygenation levels (i.e., NIRS) of the low back muscles has been implicated as a contributory factor to fatigue. Adequate blood supply is obviously the most essential component to withstand fatigue and prevent the loss of lumbar muscle function. Furthermore, quantitative estimation of muscle fatigue could provide information for designing proper work/rest ratio in preventing the excessive fatigue.

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Part IV
Clothing and Personal Protective Equipment

Cooling Dynamics of Wet Clothing

Uwe Reischl, Kylie Pace, Conrad Colby and Ravindra Goonitelleke

Abstract Protective clothing is frequently used to provide safety and comfort for persons exposed to various temperature environments. Water absorbed by clothing can significantly influence the heat transfer characteristics of the clothing material. Understanding the dynamics of evaporative fabric cooling is important in the development of new garments. To investigate the cooling dynamics associated with wet clothing, a series of experiments was conducted to document the cooling created by single and multi-layered fabric samples exposed to controlled temperature, humidity and airflow conditions. The results revealed that the onset and the magnitude of evaporative cooling are determined by the amount of water absorbed in a fabric. The number of fabric layers used in turn, determines the amount of water retained within a material. This information can now provide the basis for determining the number of fabric layers to be used in new garment design and development.

Keywords Wet clothing · Fabric layers · Evaporative cooling · Comfort and safety

1 Introduction

Specialized clothing can offer protection, comfort and safety for persons exposed to a wide variety of temperature environments. However, water absorbed by clothing can influence the heat transfer characteristics and potentially impact the comfort and safety provided by the garment. Water cools fabric by evaporation which can result in body metabolic heat loss as the garment material comes in contact with the skin.

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Understanding the dynamics of evaporative cooling of wet fabrics is, therefore, important for the development of new garments.

Evaporation of water (sweat) from the skin can provide a powerful physiological cooling mechanism for persons exposed to hot environments. However, clothing complicates the evaporation process by creating a barrier to metabolic health loss which generates a humid microclimate that may reduce the overall cooling effects of the evaporation of sweat from the skin [1]. Assessing the evaporation efficiency inside clothing systems worn by a human subject is complex because sweat may evaporate on the skin or wick into the clothing where evaporation then takes place on the surface of the clothing. Also, excessive sweat may roll off the skin or remain trapped in the clothing system. However, it is believed that sweat vaporized on the skin surface delivers better cooling than when sweat evaporates from the clothing because the location of the phase change is removed from the skin and the heat is then extracted from the environment instead [2]. Assessment of cooling by sweat evaporation for clothed individuals has been conducted using both human subjects and thermal manikins [3–6]. However, the findings have been difficult to incorporate into clothing design because the outcomes are confounded by heat loss through latent heat of vaporization which must be estimated based on clothing temperature, skin temperature, and water vapor pressure found inside the air space between the clothing and the skin [7]. The cooling dynamics of wet clothing, independent of body metabolic heat loss, and the associated latent heat of vaporization have not been investigated separately. To address this knowledge gap, a test protocol was developed to measure the temperature drop created by evaporative cooling that is not influenced by metabolic heat production or sweating due to garment insulation.

2 Methods and Procedures

A wind-tunnel was used to determine the cooling generated by water evaporation from selected cotton fabric samples maintained under steady-state temperature, humidity, and air velocity conditions. A “control” configuration was established that did not include a fabric sample. This served as a reference (“control”). The temperature drop observed as a result of water evaporation was measured using a thermocouple temperature probe imbedded into the surface of a mounting platform. 10 s prior to each test, the fabric sample was sprayed with irrigation water which was maintained at room temperature. The water was applied until the sample was saturated and the water was observed to drip freely from the mounting platform. For the “control” condition, the same procedures were followed but without a fabric sample. The fabric sample tested for a “moist” condition was first saturated and then pressed to remove all excess water from the fabric. No water was added to any sample at a later time. The temperature drop created by each sample was measured for 15 min. Temperatures were recorded at 0.5, 1.0, 1.5, 2, 5, and 15 min. All tests were performed three times and the data averaged. The tests were designed to achieve the following objectives:

- Documentation of the evaporative cooling from a mounting platform, with and without exposure to airflow, and used as a "control".
- Documentation of the evaporative cooling from a single layer "fabric" sample with and without exposure to air flow
- Documentation of the evaporative cooling from a single layer "fabric" sample for saturated and moist conditions with exposure to airflow
- Documentation of the evaporative cooling from multiple fabric layers with exposure to air flow

2.1 Wind Tunnel

A negative pressure laminar air flow wind tunnel was used in this study. The wind-tunnel measured 230 cm in length, 40 cm in height and 30 cm in width. The fabric samples were placed onto a mounting platform which was positioned in the center of the wind tunnel 120 cm from the air intake. The air velocity was maintained at 1.5 m/s. Air temperature was maintained at 22 °C (±2 °C) and relative humidity was maintained at 15 % (±5 %). A side view and end-view of the wind tunnel are illustrated in Fig. 1.

2.2 Mounting Platform

Cotton fabric samples were placed onto a convex surface which allowed a fabric sample to lay smoothly on the platform surface under its own weight. The platform shape provided gravity run-off for excess water. The device was made of Styrofoam which did not absorb water. Four 100 % cotton samples were used in this test series. Each sample was 5 cm wide and 6 cm long. The fabric samples were secured to the platform using four pins to prevent displacement of the samples

Fig. 1 Side view (*left*) and end view (*right*) of wind tunnel used in the assessment of evaporative cooling of single and multiple fabric samples

Fig. 2 Illustration of fabric sample mounting platform which was placed inside the wind tunnel. The fabric samples were oriented towards the incoming air flow

during exposure to air flow inside the wind tunnel. The irrigation water used for wetting the fabric samples was always maintained at ambient air temperature. The fabric mounting platform is illustrated in Fig. 2.

3 Results

3.1 Control Configuration

Table 1 summarizes the evaporative cooling observed for the "control" configuration with and without air flow of 1.5 m/s. A temperature drop of 4.3 °C was observed within the first 2 min for the no air flow condition while a 6.1 °C drop was observed for the air flow condition. After five minutes of exposure, however, the temperature drop for the no air flow condition stabilized at 4.9 °C while the temperature drop for the air flow condition declined to 4.2 °C.

Table 1 Data summary of the evaporative cooling observed for the "control" configuration with and without airflow exposure

"Control"		
Time (min)	Evaporative cooling (°C)	Evaporative cooling (°C)
	No airflow	1.5 m/s airflow
0	0	0
2	4.3	6.1
5	4.9	5.2
10	4.9	4.5
15	4.9	4.2

Table 2 Data summary of the evaporative cooling observed for the single layer cotton fabric sample with and without airflow exposure

1 Layer 100 % cotton		
Time (min)	Evaporative cooling (°C)	Evaporative cooling (°C)
	0 Airflow	1.5 m/s airflow
0	0	0
2	4.4	8.1
5	5.5	8.6
10	5.8	8.7
15	5.9	8.7

3.2 1-Layer Configuration

Table 2 summarizes the evaporative cooling observed for the single layer cotton fabric sample. A temperature drop of 5.9 °C was observed at the end of the 15 min exposure for the no air flow condition while a 8.7 °C drop was seen for the air flow condition. Both conditions exhibited an equilibrium temperature plateau after 5 min of exposure.

3.3 1-Layer Saturated and Moist Configurations

Table 3 summarizes the evaporative cooling observed for the single layer cotton fabric sample when saturated with water and when moist. An initial temperature drop of 8.3 °C was observed at the end of the 1.5 min for the moist sample while the saturated sample reached a temperature drop of 8.2 °C. However, after 5 min an equilibrium temperature drop of 8.5 °C was seen for the moist configuration while an equilibrium temperature drop of 8.8 °C was seen for the saturated sample.

Table 3 Data summary of the evaporative cooling observed for the single layer cotton fabric sample "saturated" and "moist" with airflow exposure

Exposure time (min)	Cotton sample (moist) (°C)	Cotton sample (saturated) (°C)
0	0	0
0.5	6.7	5.7
1.0	7.8	7.4
1.5	8.3	8.2
2	8.4	8.5
5	8.5	8.8
10	8.5	8.8
15	8.5	8.8

Table 4 Data summary of the evaporative cooling observed for the control, 1-layer, 2-layers, and 4-layers cotton fabric samples exposed to airflow

Exposure time (min)	"Control" configuration (°C)	1 Layer configuration (°C)	2 Layer configuration (°C)	4 Layer configuration (°C)
0	0	0	0	0
0.5	3.4	4.2	3	2.1
1	4.4	6.2	4.9	3.5
1.5	4.7	7.3	6.1	4.5
2	4.8	7.9	6.9	5.4
5	5.1	8.5	8.4	7.6
10	4.5	8.6	8.5	8.2
15	4.4	8.6	8.5	8.4

3.4 Multi-layer Configurations

Table 4 summarizes the evaporative cooling observed for the 1-layer, 2-layer, and 4-layer configurations in comparison to the "Control" conditions. At 1.5 min of exposure, a temperature drop of 7.3 °C was observed for the 1-layer configuration, 6.1 °C for the 2-layer configuration, and a 4.5 °C temperature drop for the 4-layer configuration. A temperature drop of 4.7 °C was observed for the "Control" configuration. While the evaporative cooling continued to increase for all of the fabric configurations, the evaporative cooling declined for the "Control" configuration after 5 min of exposure to air flow.

4 Analysis

Of special interest are the cooling dynamics exhibited by the "Control" configuration during no airflow and under the airflow condition. As illustrated in Fig. 3, the cooling observed for the no-airflow condition exhibited equilibrium after 5 min of exposure while the airflow condition peaked at 2 min and then declined afterwards. This decline can be attributed to the evaporation of the remaining water on the surface of the mounting platform. In contrast, the 1-layer cotton fabric configuration exhibited greater cooling under both conditions. As seen in Fig. 4, the magnitude of cooling observed for the no-airflow condition and the airflow condition was greater. It is clear that the cotton fabric layer provided additional water for evaporation which not only increased the cooling capacity of the no-airflow condition but also prolonged the evaporation process for the air flow condition.

The relationship between water retention and the cooling capacity of the sample is illustrated in Fig. 5. The "saturated" (high water content) sample exhibited greater cooling than the "moist" (low water content) sample. However, as shown in

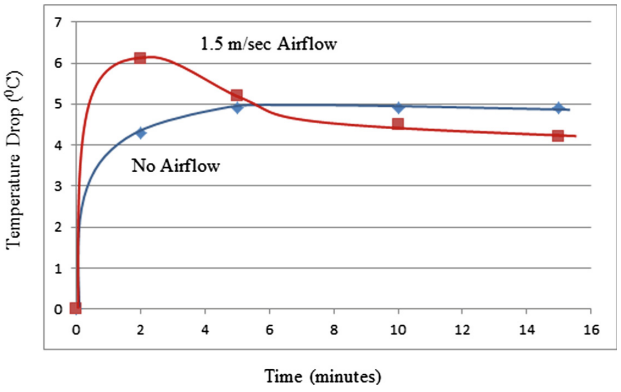


Fig. 3 Evaporative cooling observed for the "control" configuration with and without exposure to airflow

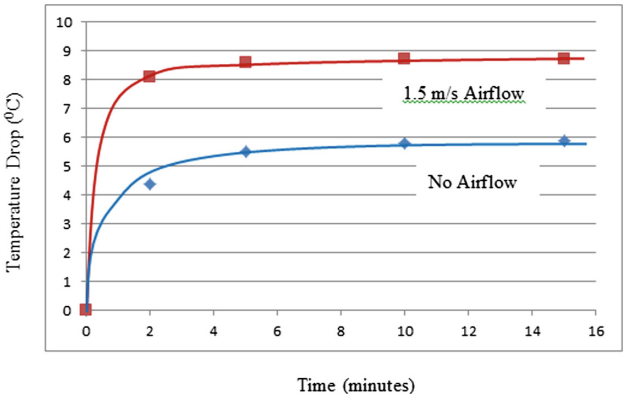
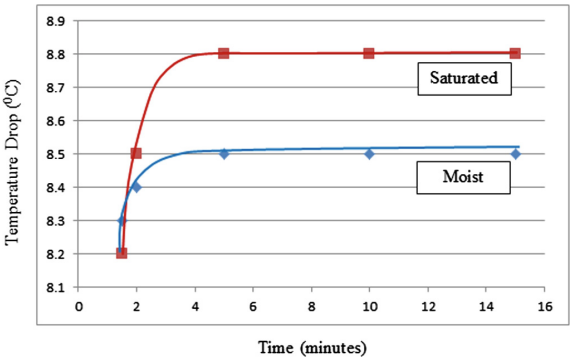


Fig. 4 Evaporative cooling observed for the 1-layer cotton fabric sample with and without exposure to airflow

Fig. 5 Evaporative cooling observed for the 1-layer cotton fabric sample under saturated and moist conditions during exposure to airflow



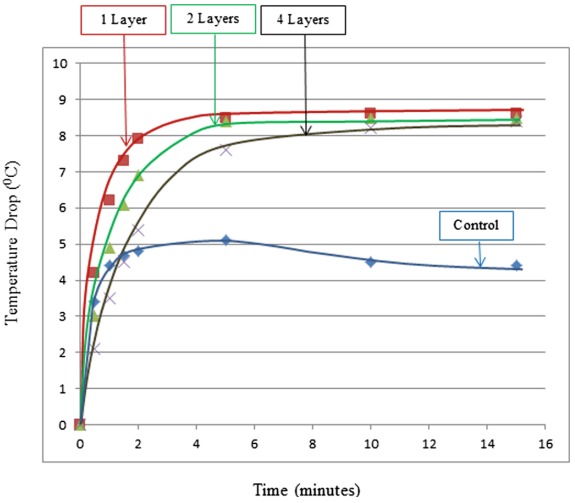


Fig. 6 Evaporative cooling for single-layer, double-layer, four-layer and control configurations exposed to airflow

Table 3, the "moist" sample performed much better than the "saturated" sample during the first 1.5 min of exposure to air flow while the saturated sample performed better afterwards. These findings suggest that the maximum cooling from fabric samples occurs when the amount of water available for evaporation is at an "optimal" level. The evaporation dynamics of multiple layers of fabric are illustrated in Fig. 6. It can be seen that the temperature drop exhibited by all of the fabric combinations was greater than the temperature drop observed for the "Control". It is interesting to note that the initial cooling response varied among the fabric combinations. The 1-layer configuration exhibited greater initial cooling than the 2-layer configuration and the 2-layer configuration exhibited greater initial cooling than the 4-layer configuration.

While the "Control" exhibited a decrease in evaporative cooling over time due to a loss of available water, all fabric combinations increased their cooling capacity over time. The different cooling response rates observed for the three fabric layer combinations can be attributed to the total amount of water retained by the various fabric combinations. Table 3 and Fig. 5, show that the "moist" sample initially created a greater cooling effect than the "saturated" sample. This suggests that maximum evaporative cooling is achieved when the amount of water in the fabric is available for vaporization.

5 Conclusions

The following conclusions can be reached based on the results of this study:

- Wet fabrics create cooling effects that are significantly greater than cooling generated by evaporation directly from the skin.

- The cooling response of fabrics is maximized when the amount of water contained in the fabric material is minimal, i.e., "moist".
- Multiple layers of fabric delay the cooling response until excessive water content in the fabric is lost.
- Multiple layers of fabric will not impact the total cooling capacity of a garment during the long term, although the cooling benefits are initially delayed.

Also, the results of this study help explain why many persons report feeling cooler in hot and humid environments when wearing single-layer clothing than when not wearing any clothing over the skin. Fabrics absorb (wick) "excess" sweat from the skin that creates lower humidity conditions which then can optimize sweat evaporation and subsequent skin cooling.

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Mechanical Property and Function of Bamboo Charcoal Paperboard

Takanori Kitamura, Kanta Ito, Suguru Teramura, Hiroki Nishimura, Noriaki Kuwahara, Zhang Zhiyuan and Hamada Hiroyuki

Abstract In this research, the bamboo charcoal paperboards (BCPs) were manufactured by paper making method. The paperboards constitute of many layers and each layer could be produced by different fibers materials. Bamboo charcoal was used and combined with recycled paper such as magazine, newspaper and corrugated paper box and so on. The mechanical properties included tension, compression, and pealing were tested to evaluate its potential applications. The scanning electron microscope observation was also conducted on the bamboo charcoal particle. At the same time, the benefit of bamboo charcoal paperboards on promoting attention for study was also evaluated. For attention effects on study, questionnaire survey was conducted from student to evaluate the effects of BCPs environment on studying. The brain wave data could be obtained during this process and investigated. The results indicated bamboo charcoal walls have good effect on concentrate attention to study.

Keywords Bamboo charcoal · Recycled paperboards · Mechanical property · Brain wave

1 Introduction

Bamboo charcoal is come from bamboo which carbonized under high temperature [1]. There are innumerable holes crosswise in its structure. It is said that the inner surface of bamboo charcoal reaches 250–300 m^2/g. In such large space, microbe can easy absorb on it, and the volatile bamboo charcoal contained rich nutriment for microbe, so bamboo charcoal possessed great absorption effect and the microbe it absorbed can decompose the absorbed ingredients clearly [2].

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Bamboo charcoal also possesses the ability to absorb and emit far infrared rays of 4–14 μm, an amount upon which all living creatures on Earth are dependent. Far infrared rays have even been deemed to be as vital as light and are easily absorbed by the human body, assisting with heat preservation and peripheral blood circulation [3]. Bamboo charcoal is also used in the biomedical field. Hamada et al. studied the effects of far infrared rays on Hela cells and WI-38 cells, and proved that far infrared ray emission at around body temperature effectively inhibited the growth of tumor cells in vivo [4]. Bamboo charcoal also releases anions, which have a stabilizing effect on mental health when administered in doses of 700 anions/cc. Anions improve sleep cycles and digestion, as well as preserve a youthful appearance; they even have air purifying properties [4].

The recycle and reuse of waste paper has increased around the word due to its advantage in saving energy, low cost, low wood consumption and environmental protection in the past decades. The trend will continue. The recycling paper are widely used in many aspects, such as making art works, packing products, housing products and so on. Paper and paperboards are fibrous materials made from pulp such as wood and plant straw. At present research, bamboo charcoal paperboards (BCPs) were made of recycled paper and bamboo charcoal. The paperboards constitute of many layers and each layer could be produced by different fibers materials. Bamboo charcoal could be used in each layers of paperboards. The mechanical properties included tension, compression, and shearing were tested and the fracture characteristics was evaluated to evaluate its potential applications. The scanning electron microscope observation was also conducted on the bamboo charcoal particle. At the same time, the benefit of bamboo charcoal paperboards on promoting attention for study was also evaluated. The brain wave data could be obtained during this process and investigated.

2 Materials and Experiment

2.1 Bamboo Charcoal Paperboards

BCPs were fabricated by Daiwa Itagami Co., Ltd with a density of 618 g/m^2. The designed thickness of the paperboard is 0.8 mm. Paperboard is in general composed of several pulp fiber sheets bonded by starch or adhesive material and is usually a multi-layered structure. The paperboard structure used in this research is illustrated in Fig. 1.

The paperboard was constitute of 8-layer structure. From the scanning electron microscope (SEM) observation, the fiber can be found random distributed in the paperboard plane. The fibers in the paperboard was random distributed. In this research, the paperboard was made from recycled newspaper, magazine and so on. The SEM observation shows the porosity structure of bamboo charcoal particle.

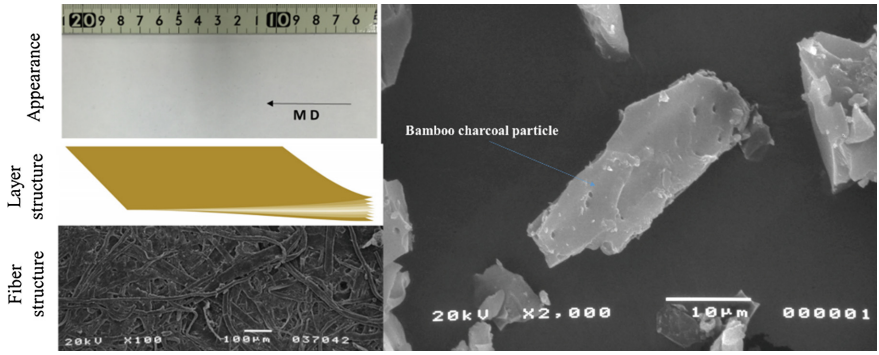

Fig. 1 Structure characteristic of paperboard and SEM observation of bamboo charcoal particle

2.2 *Mechanical Properties Test*

In order to investigate the tensile property of paperboard materials, tensile test was conducted on both direction, included machine direction (MD) and transverse direction (TD). The paperboard was cut into 200 mm in length and 20 mm in with. The span was 100 mm. The test was performed on universal testing machine with a speed of 1 mm/min.

In the compression test, the paperboard was cut into 152.4 mm in length and 12.7 mm in height. The universal testing machine was used here with a compressing speed of 12.7 mm/min (JIS P8113).

A peeling test of the paperboard was conducted. The paper was cut into 25 mm in length and 25 mm in width. Double-stick tape was employed to hold the paper specimens. The peeling speed was controlled at 50 mm/min on the same universal testing machine (JAPAN TAPPI T 506 su-68).

2.3 *Effects of Paperboard Wall on Study Efficiency*

Semantic differential (SD) method is a type of a rating scale designed to measure the connotative meaning of objects, events, and concepts. The connotations are used to derive the attitude towards the given object, event or concept. Impression evaluation of white bamboo charcoal paperboards and black bamboo charcoal paperboard was investigated by SD method. 10 key words were selected to evaluate the impression of bamboo charcoal paperboard included brightness,relieving,capaciousness,calm, concentration, noisy, difficulty for study, good smelling and relaxation. 33 students were asked about the effects of bamboo charcoal paperboards on study. And then, 57 students were asked after study in white and black bamboo charcoal paperboard wall room to investigate the color effects.

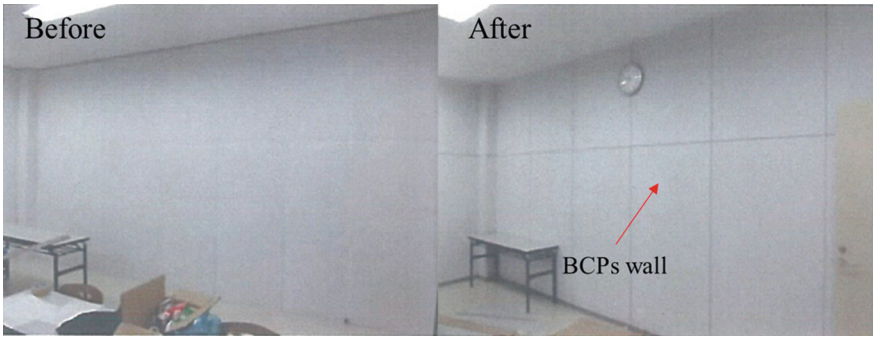

Fig. 2 Preparation for BCPs room

2.4 *Improvement to the Indoor Air*

Volatile organic compounds (VOCs) are chemical byproducts found in many building supplies and products. Treated wood, insulation, carpeting, paints and cabinets all contain VOCs that will evaporate or off-gas into the air. New homes have higher levels of VOCs. The same goes for renovations. VOCs levels will decrease over time due to off-gassing. But how long they off-gas depends on the material. Usually these kinds of gas are usually harmful to health and could cause sickness. Many method to get rid of these kinds of gas has been develop by now. One of the methods is to use bamboo charcoal. Bamboo charcoal can be used to absorb moisture and odor from the air in your home. In this research the bamboo charcoal paperboards were attached on a new room wall with space of 3 m × 5 m × 2.5 m for 1 week. The content of volatile gas were measured and compared by a Gas Chromatography at Technology Research Institute of Osaka Prefecture. The thermal desorption temperature is 280 °C. Figure 2 shows the preparation of BCPs walls.

2.5 *Measurement and Investigation of Brain Wave*

Electroencephalography (EEG) is an electrophysiological monitoring method to record electrical activity of the brain. It is typically noninvasive, with the electrodes placed along the scalp, although invasive electrodes are sometimes used in specific applications. EEG measures voltage fluctuations resulting from ionic current within the neurons of the brain [5]. To measure the brain wave, the Polymate II device of TEAC Corporation was used. The heartbeat and alpha waves were recorded and compared between study in a room with BCPs walls and a room without BCPs. The schematic of test is shown in Fig. 3. During the test, Sudoku was selected as home work to test to simulate the study state.

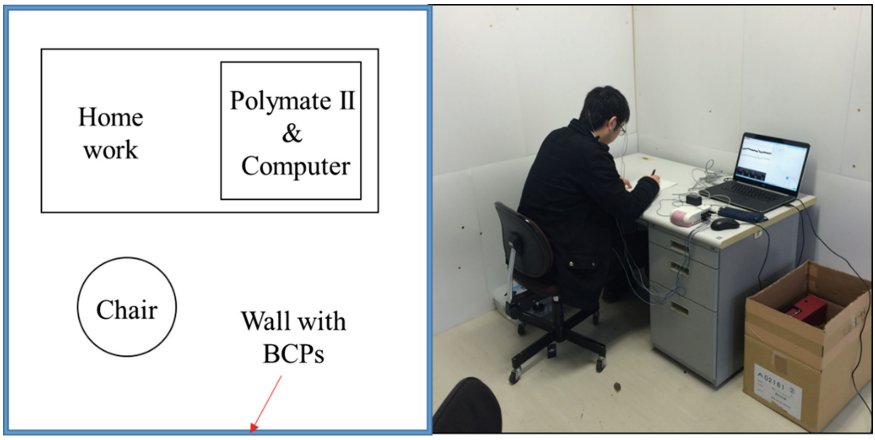

Fig. 3 Schematic and photo during brain wave measurement

3 Results and Discussion

3.1 Mechanical Properties

In order to investigate the basic property of BCPs materials, tensile test was conducted on MD and TD. It is obviously to know that the BCPs have anisotropic property. The strength and modulus in MD were 25.6 MPa and 4.5 GPa and in TD were 16.1 MPa and 1.9 GPa respectively. Both of the strength and modulus of TD were around half of MD [6]. This mainly caused by fabrication process of paperboard in which most of the fibers were distributed in MD.

In order to investigate the effect on mechanical property of paperboards after put the bamboo charcoal into paperboard, three kinds of test were conducted on both bamboo charcoal paperboard and normal paperboard. The results is shown in Table 1. From the results it was found the influence of bamboo charcoal on paperboard is little.

Table 1 Mechanical property of paperboards

	Tension (Mpa)		Compression (Mpa)		Peeling (Mpa)
	MD	TD	MD	TD	/
Bamboo charcoal paperboard	25.6	16.1	8.82	7.10	0.298
Normal paperboard	28.8	12.4	7.89	5.70	0.415

3.2 *Effects of BCPs Wall on Study Efficiency*

From the impression survey of 33 students, 31 student expressed that they like the bamboo charcoal paperboard room and had high frequency with the words of relieving and concentration. The results are shown in Fig. 4. Each key word has 5 levels to evaluate the impression to BCPs room. From the results, it was found that the high levels key words are relieving, concentration and easy to study. This result indicated that the BCPs have a good effect on study.

To investigate the effects of color, 57 students were asked. 32 students expressed that they likes BCPs room with black color and 25 students expressed that they like white ones. The detailed results are shown in Fig. 5. From the results, it was found that the students has high evaluation on relieving, concentration and easy to study attitudes in black BCPs room. BCPs room with black color has higher evaluation compared with white paperboard room.

3.3 *Improvement to the Indoor Air*

In order to get rid of VOCs, the effects of BCPs were investigated. Due to the porous characteristic of charcoal, it has function to absorb the VOCs from the air. It is considered that BCPs have this kind of function. The absorption test was conducted to verify this function of BCPs. The results of VOCs contents before and after using of BCPs are shown in Table 2. From the results, it was found that the contents of VOCs was decrease after using BCPs wall.

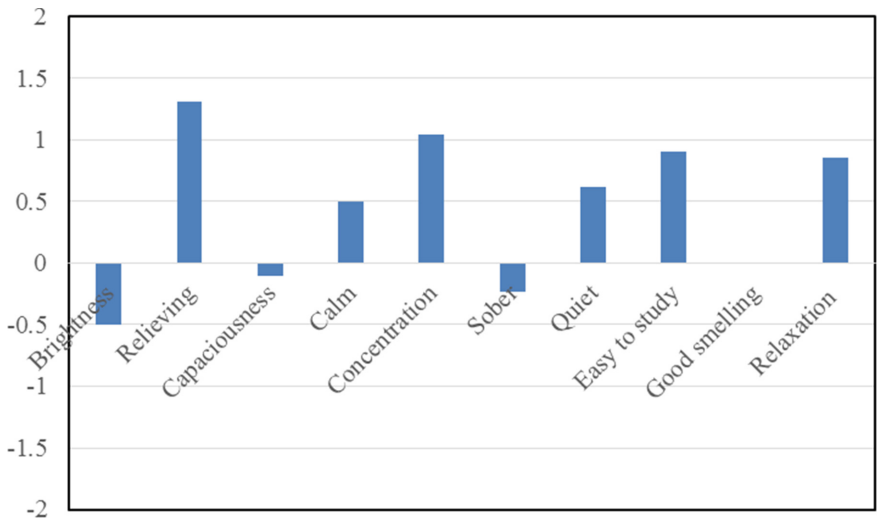

Fig. 4 Impression survey of bamboo charcoal paperboard by SD method

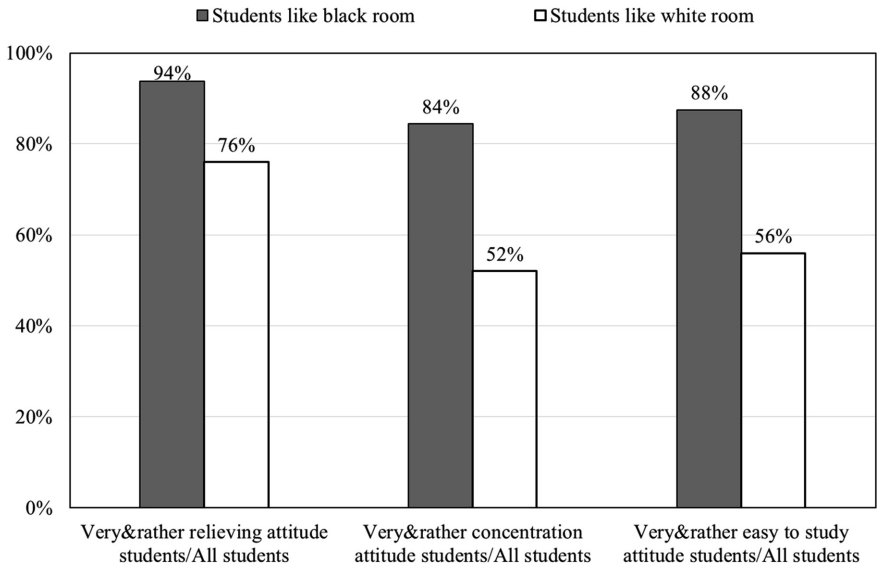

Fig. 5 Evaluation comparison between white paperboard room and black paperboard room

Table 2 Volatile gas content comparison before and after using BCPs

Sample	Content (peak area)
Before using BCPs	6.6×10^7
After using BCPs	2.1×10^7

3.4 Measurement and Investigation of Brain Wave

Brain wave measurement was conducted in both BCPs room and normal room when student was studying. In each room, 30 min was taken for studying. The results of 10 s from the 10 min were dealt with and are shown in Fig. 6. The pulse can indicated anxiety and nervous state of people. On other hand when people is in exciting and concentrated state. But this state make people easier to tire. For study, calm state is better. Therefore slow and stable state is more appropriate. Compared with normal room, the student in BCPs room expressed more calm state. From the average comparison, the pulse in BCPs room is 4.05 % lower compared with normal room. For the coefficient of variation, the values are 2.35 and 6.93 % for BCPs room and normal room which means stability of pulse is better in BCPs room.

Alpha waves are generated when people keep awaking and the frequency is from 8 to 13 Hz. It is considered to be an important brain wave to connect consciousness and subconsciousness. This brain wave could accelerate information gathering, enhance memory, it is the best brainwave promote learning and thinking. From the results it was found that the alpha waves are stronger in BCPs room case which means it is better to study in BCPs room.

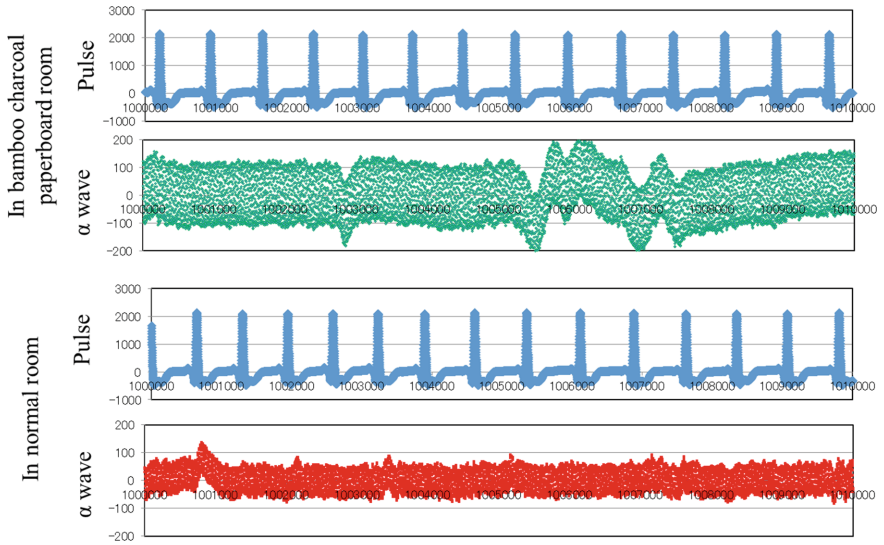

Fig. 6 Brain wave comparison between studying in BCPs room and normal room

4 Conclusion

In this research, the paperboard made of recycled paper and bamboo charcoal was developed. The paperboards constitute of many layers and each layer could be produced by different fibers materials. Bamboo charcoal could be used in each layers of paperboards. The mechanical properties included tension, compression, and pealing were tested and the fracture characteristics was evaluated to evaluate its potential applications. Impression questionnaire survey, volatile gas absorbing function and brain wave experiments were also conducted and following conclusion were obtained.

1. After combined with bamboo charcoal, the mechanical properties were tested included tension, compression and peeling and compared with normal paperboard. It was found the influence of bamboo charcoal on paperboard is little.
2. From the impression survey on BCPs, it was found that the BCPs room is helpful to study. Compared with white BCPs room, students tend to liking studying in black BCPs room and survey results shows good respond especially in relieving, concentration and easy to study aspects.
3. BCPs has obvious effect to absorb VOCs from the results of volatile gas measurement.
4. Measurement and investigation of brain wave results indicate when students in BCPs room, the pulse become slow and stabile. At the same time, the alpha waves also show active state. It is considered that the BCPs room is better for studying compared with normal room.

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Measuring the Influences of Footwear Shape and Area on the Coefficient of Friction by English XL

Ching-Chung Chen, Zhi-Xuan Chen, Chih-Lin Chang, Fang-Ling Lin and Liwen Liu

Abstract This study explores the influences of different footwear shapes and areas on COF by conducting a four factors experiment including five footwear areas, two footwear shapes, two floors with different roughness, and three floor contaminating conditions and the COFs were measured by English XL. The results demonstrate that the footwear area, footwear shape, floor roughness, and floor contamination condition all affect COF significantly. The COFs of square footwear treads are significantly higher than the cofs of round footwear treads. The relationships between shoe sole area and COF were affected by floor roughness dramatically. The relationships between different shoe sole area and COFs did not show any rules. The lower the floor roughness the lower the COFs with the larger shoe sole area under water and detergent contamination conditions.

Keywords Coefficient of friction · Shoe sole area · Shoe sole shape · English XL · Slip and fall

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1 Introduction

Slipping, falling and tripping are not only the major occupational injuries, but also the common incidents during daily life. National Safety Council [1] indicated there are more than 27,000 people died due to falling incidents. Slipping causes a lot of labor injuries, there are more than two third of falls and slips are caused by slipping [2]. Chen et all. [3] also point out the cases of slipping, falling and tripping account for 33, 50 and 7 % of all incidents.

Slipping/falling causes dramatic losses not only to individuals, families and firms but also the society. Liberty Mutual Workplace Safety Index [4] demonstrated that the total costs of companies from most ten serious disable injuries is 59.58 billion dollars which account for 83.8 % of all disable injures that is a billion each week in 2012. Among all the occupational incidents, falling is ranked as second large one which is more than 15.4 % of all occupational incidents and causes 9.19 billion losses to the industries. In UK, almost one third of occupational incidents are falling which causes more than 5 million ponds losses directly or indirectly to employer and more than 8 million ponds social losses [5]. The data collected by Federal Institute for Occupational Safety and Health (BAuA) showed 20 % of occupational incidents are falling which caused 300 million € dollars insurance compensations and 8 billion € dollar production losses [6].

The factors such as floors, shoes, contaminations, the way of walking, the status of walkways and environment affect the chances of falling [7]. Lacking friction between shoes and floor is considered as the major factor causes falling. The friction between shoes and floor can be measured by the coefficient of friction (COF) [8]. The floor is slipperier as the COF is lower. According to the researches of Chang and Matz [9], Chang [10], Li et al. [11] and Liu et al. [12], the factors affecting COF include the material of floors, the roughness of floors, the liquid or solid contaminations, shoe groove design and the equipment used to measure COF.

The augment about the COF will be lower due to water or liquid contaminated floor is well proved by many researchers [12–16]. While floor is contaminated by water, detergents, oil or other liquid, the liquid reduces the time of connecting shoe sole and floor. The friction could not be produced before the liquid is squeezed out of the surface between shoe sole and floor; therefore, the effects of slip resistance could not be performed and the opportunities of slipping/falling are increased. The squeeze film equation is used to describe the situation while a shoe step on the liquid contaminated floor show as followed.

$$t = \frac{K\mu A^2}{F_N}\left(\frac{1}{h^2} - \frac{1}{h_0^2}\right) \tag{1}$$

where t is the time to reduce the liquid thickness from the original h_0 to h; F_N is the vertical force; K is the function decided by the shape of surface pressing down; μ is liquid viscosity; and A is the area of surface pressing down.

Moore [13] proposed the squeeze film theory and indicated that the thicker the liquid is, the longer time to reduce the liquid thickness will need and the slipperier the floor will be. According to the squeeze film equation, the time to reduce the liquid thickness has positive relationship to the liquid viscosity (μ). That is, the higher the viscosity the larger the 't' is and the higher the danger of falling/slipping. On the other hand, the time 't' also has positive relationship to the square of contacting area. Therefore, the time 't' increased as the contacting area is larger. The shoe sloe area could be designed. K is the function decided by shape of pressing down which also could be designed. However, most of the studies discussed the impacts of shoe sloe shape to COF depended on the shoe sole material sample (test pieces) adopted according to the device adopted to measure COF. Li et al. [17] compared three different COF measurement devices including Brungraber Mark II (BMII), British Portable Skid Tester (BPST) and Horizontal Pull Slipmeter (HPS). The results showed that the contacting areas of BMII material (57.76 cm^2) are larger than those of BOST (3.05 cm^2) and HPS (3.8 cm^2). The large contacting area is more sensitive to the roughness of floor surface. And, the larger the shoe sole area, the higher the squeeze film effect while the floor contaminated by liquid.

Leclercq et al. [18], Grönqvist [19] and Kim and Smith [20] pointed out the patterns of shoe sole and the type of shoes had significant influences on COF under dry or contaminated floor conditions. And the combinations of the shoe sole pattern and floor could avoid squeeze film effect forming. Wilson [21] indicated the area of shoe sole contacting to floor should be considered besides shoe sole grooves and patterns to reduce fall/slip incidents. That is, the shoe sloe groove design not only influences the contact area between shoes and floor, but also the COF. Therefore, this study measured COF under different shoe sole shape and area by English XL to discuss the influences of shoe sole shape and area on COF.

2 The Methods

The study sets up a four factors experiment. The experiment factors including five different kind of shoe sole areas, two different kind of shoe sole shapes, two floors with different roughness, and three different floor contamination conditions. The experiment has 5 * 2 * 2 * 3 = 60 combinations in total. The COF measurement process repeated four times under each combination, therefore, there are 240 COFs obtained. All the experiments were performed in a lab with average temperature of 19.8 °C and relative humidity of 58.0 %.

2.1 Friction Measurement Device: English XL

English XL was developed by William English during 90 s also called Variable Incidence Tribometer (VIT). It is an articulated pillar metrology. While measuring,

a radius of 1.58 cm circular shoe sole sample was attached at the bottom of a metal rod. A cylinder with the pressure adjusted to 172 kPa to generate a push force on the shoe sole sample. The shoe sole sample hit the floor upon pushing by the rod and may slip or not on the floor. The scale of English XL was ranged from 0 to 1.0. Operation of the English XL followed the requirements in the ASTM F1679-04 [22].

2.2 Shoe Sole Area

English XL adopts a regular circular Neolite (hardness is 91 ± 1.73) shoe sole sample (radius is 1.58 cm). The circular shoe soles were designed based on the original shoe sole sample and further design different size with different radius. As the square shoe sole was designed base on the side length of the original shoe sole sample. Table 1 shows the different ratios of shoe sole area.

2.3 Floors

Procter [23] indicated that to improve the anti-slip function of floor the particular floor roughness will be needed. Chang et al. [24] and William [25] pointed out that by using floors with particular roughness could reduce the slipping problems caused by liquid effectively. When the floor surfaces are contaminated by liquid such as water or oil, the floor roughness could improve the squeeze film effects caused by liquid. Grönqvit et al. [26] indicated that the appropriate slip resistance will produced with Ra (arithmetical average of surface heights) between 7 and 9 μm. Therefore, this study adopted Ceramic A (Ra = 3.01 μm) and Ceramic B

Table 1 Five different shoe sole areas

Shoe sole	Size	Area	Ratio of area (%)
Circular	(2.8/2)2 × π	6.1575 cm^2	−22
	(3/2)2 × π	7.0708 cm^2	−10
	(3.175/2) 2 × π	7.9173 cm^2	0
	(3.4/2)2 × π	9.0792 cm^2	+14
	(3.6/2)2 × π	10.1788 cm^2	+28
Square	2.8 × 2.8	7.84 cm^2	−22
	3 × 3	9 cm^2	−10
	3.175 × 3.175	10.08 cm^2	0
	3.4 × 3.4	11.56 cm^2	+14
	3.6 × 3.6	12.96 cm^2	+28

(Ra = 17.05 μm) to measure COF. The Ra values were measured using a Mitutoyo® SJ301 profilometer.

2.4 Floor Surface Condition

This study used water (viscosity = 1 cP), 10 % detergent solution (viscosity = 1.39 cP) and +98 % glycerol (viscosity = 785.8 cP) contaminated floor surface all with the temperature of 25 °C. Referring the experiments of Li et al. [27, 28], during each hit, 10 ml liquid was added into the hitting area to simulate the floor surface conditions and the liquid was scraped to well coating on the floor surface before each measurement.

2.5 Data Analysis

SAS 8.0 was used to analyze the data collected. The influences of shoe sole area, shoe sole shape, floor roughness and floor surface conditions on COF were analyzed by ANOVA. The Duncan Multiple Range was used to perform multi comparison to discuss the differences between different levels of significant factors.

3 Results and Discussion

The results of ANOVA analysis demonstrated that the factors and their interaction between shoe sole area, shoe sole shape, floor roughness and the floor surface conditions are all significant ($p < 0.001$). The floor surface condition, floor roughness, the interaction between floor roughness and floor surface conditions had stronger impacts on COF. The influences of shoe sole shape and area on COF was also significant ($p < 0.001$), however, the influences were limited.

Table 2 showed the results of Duncan Multiple comparison of floor roughness, floor surface conditions, shoe sole shape and area. The COFs of Ceramic A with higher roughness was significantly ($p < 0.05$) higher than those of Ceramic B with lower roughness. The COFs will be the highest while the floor contaminated by water and the COF under 10 % detergent solution contamination will be the second. When the floor was contaminated by glycerol, the COF closed to zero which was the lowest one. The COFs of square shoe sole shape were higher than the circular ones. When the shoe sole area was 28 % larger than the regular one, it's COFs were significantly ($p < 0.05$) lower than COFs of other shoe sole areas. When the shoe sole area was 10 % smaller than the regular one, it's COFs were significantly ($p < 0.05$) lower than COFs of other shoe sole areas. However, when the shoe sole

Table 2 The results of Duncan test

Factor	Level	Mean	Duncan group
Floor roughness	Ceramic A	0.153	A
	Ceramic B	0.332	B
Floor surface condition	Glycerol	0.003	A
	10 % detergent	0.251	B
	Water	0.473	C
Shoe sole shape	Circular	0.238	A
	Square	0.246	B
Shoe sole area	+28 %	0.230	A
	+14 %	0.243	B
	−22 %	0.243	B
	0 %	0.244	B
	−10 %	0.251	C

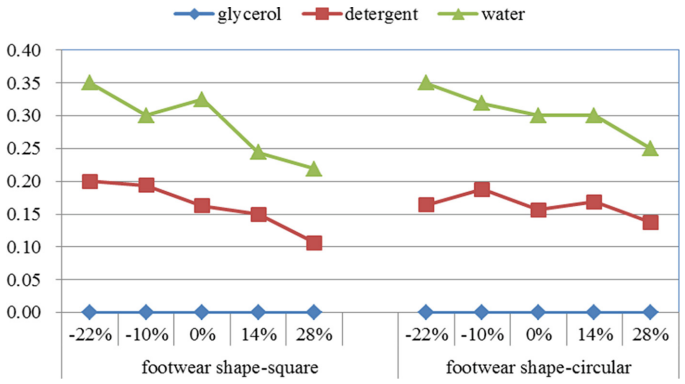

Fig. 1 COF on Ceramic A floor

area was 14 % larger or 22 % smaller than the regular one, the differences of COFs were not significant.

Figure 1 showed the COF of Ceramic A under different experiment conditions. When the floor contaminated by water, the larger the shoe sole the lower the COF for both shoe sole shape. The COFs of regular shoe sole area were larger than those of −10 % shoe sole area. The larger the square shoe sole, the smaller the COFs. The smallest COF happened when the circular shoe sole was the largest one. The relationships between COFs and shoe sole area did not show any rules. When the floor contaminated by glycerol, the COFs of five different shoe sole area and two different shoe sole shape were all close to zero.

Figure 2 showed the COF of Ceramic B under different experiment conditions. When the floor contaminated by water, the COFs of square shoe sole under five

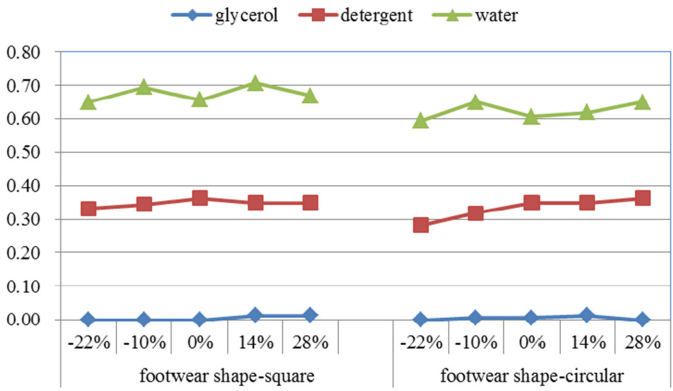

Fig. 2 COF on Ceramic B floor

different shoe sole area did not have rules. The COFs of −22 % shoe sole area (smallest) were the lowest. Under detergent contamination condition, the larger the shoe sole area, the bigger the COFs for both the square and circular shoe sole shape. When the floor contaminated by glycerol, the COFs of five different shoe sole area and two different shoe sole shape were all close to zero.

From Figs. 1 and 2, when the floor roughness was lower (Ceramic A), the COFs will be smaller as the shoe sole area getting bigger under water and detergent contamination conditions. This results were consistent with Li et al. [17]. The larger the shoe sole area are, the lower the COF will be due to squeeze film effects. However, when the floor roughness was higher (Ceramic B), the results were opposite. The larger the shoe sole area, the higher the COFs. Therefore, the floor roughness had stronger impact than shoe sole area on COFs. This is consistent to the results of Li et al. [11] and Liu et al. [12]. The floor roughness could reduce slip/fall. On the other hand, the different liquid contaminations have dramatic impacts on COFs which is consistence with Squeeze film effect [12]. Squeeze film effect indicated that viscosity affects COFs. The time of shoe sole trod on floor changes with the liquid viscosity. The larger the viscosity, the longer time to connect shoe sole with floor and the lower the COF will be. In this study, the COFs under water contamination condition were higher than the COFs of other two liquids with higher viscosity. With highest viscosity, the COFs were closed to zero under glycerol condition.

4 Results

This study adopting English XL to discuss the influences of shoe sole shape and area under different floor roughness and contaminated conditions by using single equipment. The results demonstrated that shoe sole area, shoe sole shape, floor

roughness and floor surface condition are all significant factors to COFs. The floor contamination conditions were the most important factors, followed by floor roughness and shoe sole shape. The influences of shoe sole area on COFs were last important. The relationships between shoe sole area and COF were affected by floor roughness dramatically. The relationships between different shoe sole area and COFs did not show any rules. The lower the floor roughness the lower the COFs with the larger shoe sole area under water and detergent contamination conditions. Therefore, when the floor roughness was low, the COFs of different shoe sole area was strongly affected by squeeze film effect, vise versa.

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Effects of Body Armor Fit on Marksmanship Performance

Hyeg Joo Choi, K. Blake Mitchell, Todd Garlie, Jay McNamara, Edward Hennessy and Jeremy Carson

Abstract This study examines the effect of body armor fit on marksmanship performance. Specifically, (1) does wearing body armor affect marksmanship performance, and (2) does the fit of the armor affect marksmanship performance. Fifteen male Soldiers participated in a marksmanship performance task using a weapon simulator in four different body armor configurations (no armor, initial fit, increased and decreased size). Accuracy (closeness to target center), precision (shot group tightness), and speed (transition time) were measured. Accuracy and precision were not significantly different regardless of body armor fit. However, speed was degraded in the initial fit body armor size and the increased size configurations relative to the baseline and decreased size configurations. In other words, in the decreased size, Soldiers engaged targets as quickly as when not wearing body armor, indicating body armor fit may impede Soldier's ability to transition between targets, thereby impacting mission performance.

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Keywords Body armor · Fit · Anthropometry · Marksmanship performance · Weapon simulator · Personal protective equipment (PPE) · Human factors · Military

1 Introduction

For all U.S. military personnel, body armor is essential personal protective equipment (PPE). The primary purpose of body armor is to "provide the Soldier with enhanced protection from small arms threats and fragmentation and munitions during ballistic and blast events, while maintaining comfort and maneuverability" [1]. Since body armor is not custom made, but a sized item with a limited number of sizes, it is not always possible to issue an optimal fitting system that guarantees maximal comfort and maneuverability to all Soldiers. Accordingly, potential performance degradation, due to body armor, is frequently anticipated and observed [2]. Thus, it is easy to assume that if an optimal body armor size is worn, any concerns regarding performance, comfort and maneuverability can be minimized.

To date, there has been no quantitative investigation of the effects of body armor fit quality on mission performance that can be used for body armor design. A systematic understanding of the relationship between mission performance and body armor fit may allow armor designers to create an improved product that allows users to complete their mission more efficiently and safely. The current study is a part of larger project that investigates the relationship among anthropometric variability, body armor fit, area of coverage (AoC), mobility, and performance, with a goal of improving body armor design. This study examines the effect of body armor fit on marksmanship as one aspect of mission performance.

Marksmanship, the skill of using a firearm, is an important basic combat and counterinsurgency (COIN)-related skill in the U.S. Army [3]. For this study, a rifle marksmanship task was selected as a component of mission performance to investigate the effect of body armor fit. Marksmanship performance was measured in two ways, skill level (how accurately and precisely a shooter can perform the marksmanship task), and transition mobility (how fast a shooter can transition from one target to another, horizontally, vertically and diagonally). Accuracy (closeness to target) and precision (shot group tightness) were used to evaluate the level of shooting skill. Speed (transition time) quantified the transition mobility while wearing body armor. The research questions of this study were: (1) how does wearing body armor affect marksmanship performance, and (2) does the fit of the body armor affect marksmanship performance?

2 Methods

2.1 Subjects

Fifteen male, active duty Soldiers volunteered for this study and completed all test conditions. Test participants' (TPs) ranged in age from 18 to 28 years (M = 21.13, SD = 3.48). The average body weight, height and body mass index (BMI) of the TPs were 82.0 kg (SD = 10.6 kg), 1734.2 mm (SD = 65.4 mm) and 27.3 (SD = 3.1), respectively. Relative to the current U.S. Army population [4], TPs' size distribution is represented in Fig. 1.

2.2 Test Configurations

All test configurations were counterbalanced to control for order effect.

Body Armor. The U.S. Army, standard issue Improved Outer Tactical Vest (IOTV) Generation III body armor system was used for the current study (Fig. 2). Four different configurations were tested: no body armor, duty uniform only (baseline); initial fit body armor size (initial size); one size smaller than initial fit size (decreased size); and one size larger than initial fit size (increased size). In all configurations, TPs also wore an Advanced Combat Helmet.

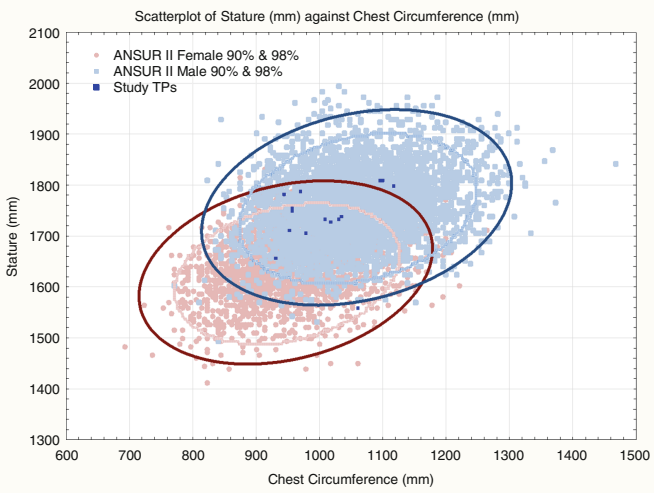

Fig. 1 Distribution of stature by chest circumference for 15 TPs (*dark blue dots*) relative to ANSUR II 2012 (*light blue* and *red dots*) [4]

Fig. 2 Improved outer tactical vest (IOTV) Gen III

Table 1 Distribution of predicted fit versus initial fit IOTV size

	Initial fit size						
	Chest Circ. (in.)	XS	SM	MED	LRG	XL	Total
Predicted by legacy size (chest circumference)	XS (29-33)	–					–
	SM (33-37)		1				1
	MED (37-41)		4	6			10
	LRG (41-45)				4		4
	XL (45-49)					–	–
	Total		5	6	4		15

Initial fit body armor size is the body armor size for an individual, as determined by a fit expert, via visual inspection, to be the best fitting size of available IOTV sizes. The fit expert started with the predicted size (see the sizing chart in Table 1) based on the TP's chest circumference, assessed that fit, and tried smaller and larger sizes, as needed. Then, the fit expert determined the initial fit size that provided required coverage/protection on the chest with the best apparent mobility of all tested sizes.

Ten of the 15 TPs predicted into size Medium; however, four of those TPs were assigned the size Small as their initial fit by the fit expert (Table 1). One TP predicted into a size Small and the other four predicted into size Large; all of these TPs were assigned their predicted sizes as initial fit size. No individuals predicted into size Extra Small or Extra Large.

Shooting Postures. A total of three different shooting postures were employed. These included: standing unsupported (Standing), kneeling unsupported (Kneeling), and prone unsupported (Prone). Appropriate shooting postures were employed based upon the task scenario (refer to Sect. 2.4). Prone posture was not evaluated in the multiple target task because transitioning between targets at that great of an arc (≥50°) was not operationally realistic.

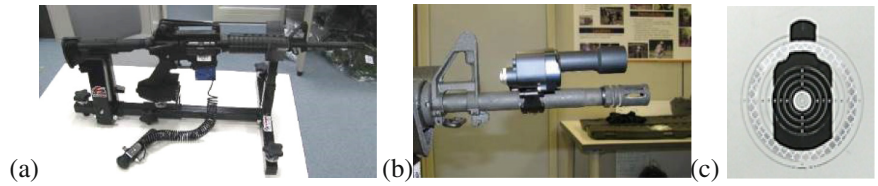

Fig. 3 Image on the *far left* **a** shows the de-militarized M4 weapon with integrated CO_2 recoil simulator. Image in *center* **b** shows the FN MilTrainer optical unit mounted to the barrel of the weapon. Image on the *far right* **c** shows the paper targets [5]

2.3 Marksmanship Weapon Simulator

A Fabrique Nationale (FN) (formerly Noptel) MilTrainer weapon simulator system was used to collect marksmanship performance data. The FN MilTrainer optical unit was mounted on the barrel of a de-militarized M4 carbine with an integrated carbon dioxide (CO_2) recoil simulation system (the mock weapon and CO_2 system were manufactured by LaserShot, Inc.).

As shown in Fig. 3, the targets were paper ring targets scaled to represent a full-size E-Type Silhouette target at 75 m when placed 5 m away from the shooter. TPs used the standard "iron sights" common to M4/M16 style rifles. The sights were kept adjusted to Battle-sight Zero, and the MilTrainer optical unit was adjusted to ensure the hit position recorded by the simulator was aligned with the settings of the weapon sights [5].

2.4 Test Scenario

TPs performed two marksmanship tasks, a single target task and a multiple target task. The target setup was identical for both tasks (Fig. 4). TPs used all five targets

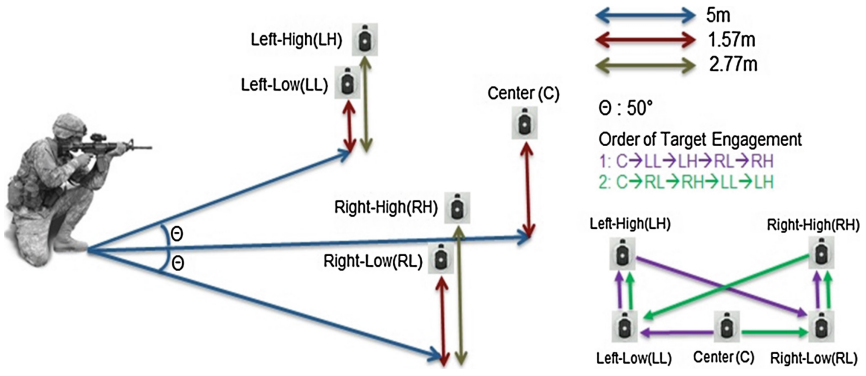

Fig. 4 Marksmanship test layout

in the multiple target task, but used only the center target in the single target task (Fig. 4).

Practice Session. Prior to data collection, TPs had a practice session followed by a qualification test. TPs qualified if 70 % of 10-standing position shots, 80 % of 10-kneeling position shots and 90 % of 10-prone position shots were within the "6" ring of the target. Once qualified, TPs initiated the experiment. The entire test scenario in each body armor configuration was completed during one 3–4 h test session.

Single Target Task. In the single target task, TPs aimed at the center target, positioned 5 m away from the center of the body, and took 25 shots (five groups of five shots) in each test configuration. The single target task evaluated the success of each shot group for accuracy and precision. A shot group is defined as a series of shots fired at the same point of aim (POA) from the same position and weapon barrel. In each test configuration, there was no time limit on obtaining an optimized body position, prior to firing. Once TPs started, the simulator system captured the information.

Multiple Target Task. There were five different stationary targets positioned at five different locations, including the center target also used in the single target task. TPs fired one shot per target, following the order of target engagement. They repeated firing in sequence until five series of five shots were completed. The order of target engagement was either: "center → left low → left high → right low → right high" and then "center → right low → right high → left low → left high" or vice versa (Fig. 4). For all test configurations, TPs fired a total of 50 shots, 25 shots following each order of target engagement.

The main purpose of the multiple target task was to evaluate the transition mobility or how quickly TPs moved from one target to the next. TPs were allowed as much time for their first shot as needed and therefore, shot accuracy for the center target was not compared to that of other targets. TPs were instructed to move from one target to the next as quickly as possible without sacrificing accuracy. Since each series of five shots were fired from five different POA to five different targets, those five shots were not considered as a shot group. Thus, precision was not an applicable measure to evaluate, however accuracy was measured to ensure there was consistency in a TPs' efforts.

2.5 Measures of Marksmanship Performance

Precision. Precision refers to the closeness of shots to each other within a shot group, regardless of closeness to the center of the target. The popular term for marksmanship precision is often "shot group tightness." The smaller the dispersion within the shot group, the better the precision. The primary measure of marksmanship precision, "variable error," was computed and indexed by the "mean radius (MR)" [6, 7].

Accuracy. Accuracy refers to how close to the target center a shot in the shot group is. It measures a TP's ability to hit the target center accurately. As computed in this study, accuracy refers to shooting errors based on the average of the distances from the center of mass (DCM) [6]. Theoretically, if a shot hits exactly at the target center, the distance between the target center and the shot is 0 and the accuracy is perfect.

Speed. Speed refers to the movement time between targets. In the multiple target task, TPs were required to transition their aim between each target (e.g., from center target to left low target) prior to firing; the time it took the TP to execute those two shots was the movement time. Transitions could be in three directions: horizontal, vertical or diagonal. Movement time was derived from the time stamp produced in the FN MilTrainer software.

2.6 Data Editing

All 15 TPs performed a total of 28 marksmanship trials across the different body armor configurations and shooting postures: 12 trials for the single target task and 16 trials for the multiple target task. The FN MilTrainer software produced 28 XML files, one file per trial. Manually editing data from each file (approximately 2700 lines of data) was a time—and labor-intensive process, prone to user error and suboptimal data throughput.

A custom data editing process tool developed in-house (NOPTEL_PARSE, Version 1.2) was used to assist in the post processing of the data to prepare it for analysis. NOPTEL_PARSE provided a robust, command-line interface for automatically parsing NOPTEL XML data and calculating TP measurements (MR, DCM, and movement time). Data and errors from these files were exported as comma delimited spreadsheets which were imported into a database and statistical software for analysis.

2.7 Data Analysis

For all measures of marksmanship performance, repeated measures ANOVAs were performed to investigate the statistical significance. For the single target task, body armor configuration and shooting posture were the two factors used to measure precision and accuracy. For the multiple target task, there were two additional factors, target location and order of engagement. Target location identified each target (left low, left high, right low and right high targets) to investigate the accuracy as the third factor along with body armor configuration and shooting posture. Similarly, order of target engagement was the third factor for speed with the other two factors, body armor configuration and shooting posture. Order of target engagement is the path the TP followed to engage each target: horizontal

(center to left low, center to right low), vertical (left low to left high, right low to right high), and diagonal (left high to right low, right high to left low) directions. For the three-way repeated measures ANOVAs, the model was reduced with all three main effects with two-way interaction terms associated with the body armor fit configuration.

For all repeated measures ANOVA tests, the concept of sphericity was examined by Mauchly's test [8]. If the concept of sphericity was violated, one of the alternative statistics was used, either the Greenhouse-Geisser correction, when the epsilon was smaller than 0.75, or the Huynh-Feldt correction, when the epsilon was greater than 0.75 [9]. When there were significant main effects or interaction effects, Bonferroni tests with adjustments were used to analyze pairwise comparisons ($\alpha < 0.05$). IBM's Statistical Package for the Social Sciences (SPSS 21), Statistica V12 and Microsoft Excel 2013 were used to perform data analyses and to create tables and graphs.

3 Results

3.1 Body Armors' Effect on Marksmanship Performance

To determine the effect of body armor on marksmanship performance, the baseline and initial size configurations were compared for precision, accuracy, and speed.

Precision. Precision was assessed only for the single target task, since the shots fired to each target in the multiple target task were not from the same POA. A two way repeated measures ANOVA was performed to investigate the main effects of configuration and shooting posture and their interaction effect. The smaller the MR, the tighter the shot group, and the better the precision. No statistically significant difference was detected between the baseline (M = 80.3 mm, SD = 20 mm) and the initial size (M = 80.0 mm, SD = 15 mm) configurations for precision, $F(1, 14) = 0.01$, $p = 0.69$. Precision was significantly different by shooting posture, however, $F(2, 28) = 18.07$, $p = 0.00$, Bonferroni adjustments revealed that TPs were the most precise in the prone posture (M = 63 mm, SD = 18 mm), followed by kneeling (M = 81 mm, SD = 19 mm), with standing resulting in the worst precision (M = 97 mm, SD = 26 mm), $p < 0.05$. The interaction effect of configuration and posture was not significant, $F(2, 28) = 0.57$, $p = 0.57$. For both baseline and initial size configurations, prone posture resulted in the most precision, followed by keeling, while the standing posture had the least precision.

Accuracy. Accuracy was assessed in both the single target and the multiple target tasks. For the one target task, a two way repeated measures ANOVA was performed to investigate the effects of configuration and posture, and a one way interaction with configuration. There were no significant effects for accuracy (configuration, $F(1, 14) = 0.07$, $p = 0.80$; posture, $F(2, 28) = 1.08$, $p = 0.35$; or interaction, $F(2, 36) = 1.63$, $p = 0.21$).

For the multiple target task, a three way repeated measures ANOVA was performed to investigate the main effects of configuration, shooting posture, and target location, along with the two way interaction effects with configuration. All targets except for the center target were compared to one another for accuracy. Accuracy between the baseline (M = 231 mm, SD = 68 mm) and initial size (M = 228 mm, SD = 70 mm) configurations was not statistically different, $F(1, 14) = 0.067$ $p = 0.80$. However, shooting posture had an effect on accuracy, $F(1, 14) = 12.74$, $p = 0.00$; accuracy was better when standing (M = 219 mm, SD = 66 mm) than when kneeling (M = 240 mm, SD = 65 mm). There was no statistical difference for accuracy based on target location, which confirmed that there was consistency in a TPs' efforts, $F(3, 42) = 1.14$, $p = 0.34$. Furthermore, there was no interaction effect between configuration and posture or target location, $F(1, 14) = 0.24$, $p = 0.63$ and $F(3, 42) = 0.66$, $p = 0.58$, respectively.

Speed. Movement time, the time to transition between targets, was assessed in the multiple target task. A three way repeated measures ANOVA was performed to investigate the main effects of configuration, shooting posture, and the direction (order of target engagement), in addition to the two interaction effects with configuration.

The movement times for the baseline and initial configurations were statistically different, $F(1, 14) = 5.05$, $p = 0.04$. TPs moved faster from one target to the next when they wore the baseline (M = 1.69 s, SD = 0.53 s) than in the initial size configuration (M = 1.90 s, SD = 0.78 s), $p < 0.05$. The movement time was also statistically different depending on the shooting posture, $F(1, 14) = 7.79$, $p = 0.01$. TPs' movement time was shorter when they performed in the standing posture (M = 1.57 s, SD = 0.39 s) than in the kneeling posture (M = 2.01 s, SD = 0.93 s).

Movement time also differed depending on the engagement direction, $\mathcal{E} = 0.32$, $F(1.59, 22.25) = 23.3$, $p = 0.00$. Within the two symmetrical orders of engagement, there were six different routes to transit from one target to the next (e.g., center target to left low target). Those six routes consisted of three different types of directions for both left and right transitions. These included horizontal (center to left low target and center to right low target), vertical (left low to left high target and right low to right high target), and diagonal transitions (left high to right low target and right high to left low target). On average, the movement time was shortest for vertical movements, followed by horizontal movements, with diagonal movements taking the longest, $p < 0.05$. This seems obvious because the distance traveled for the vertical movement (1.2 m) was the shortest, followed by horizontal movement (5.24 m) and the diagonal movement (7.7 m) was the longest.

Within the same direction (i.e., vertical, horizontal or diagonal), two symmetrical movements (e.g., left to right or right to left) were not different from each other, $p > 0.05$. It took a similar amount of time to move vertically from the left low target to the left high target (M = 1.32 s, SD = 0.36 s), and from the right low target to the right high target (M = 1.25 s, SD = 0.36 s), $p > 0.05$. A similar trend was found for the horizontal and diagonal movements, $p > 0.05$ (center target to left low target, M = 1.85 s, SD = 0.71 s; center target to right low target, M = 1.84 s,

SD = 0.80 s; and left high target to right low target, *M* = 2.26 s, *SD* = 0.99 s; right high target to right low target, *M* = 2.25 s, *SD* = 0.84 s, respectively).

There was no significant interaction for configuration by posture, $F(1, 14) = 1.11$, $p = 0.31$. Within the same shooting posture, TPs moved faster in the baseline configuration than in the initial size configuration. The interaction between configuration and order of target engagement was approaching significance, $\mathcal{E} = 0.57$, $F(2.85, 39.85) = 2.29$, $p = 0.09$. There was no difference in movement time between baseline and initial size configurations for the vertical movements, $p > 0.05$. However, TPs moved significantly faster in the baseline compared to their initial size for the horizontal movements, by 0.24 s and for the diagonal movements, by 0.29 s, $p < 0.05$. Given the distance for each movement, it is highly likely that as the travel distance gets longer, so does the delay in movement time for the initial size relative to the baseline configuration.

3.2 Impact of Body Armor Fit on Marksmanship Performance

Given that there does appear to be an impact on marksmanship performance due to the addition of body armor, primarily for the objective measure of speed, the impact of body armor fit on marksmanship performance (precision, accuracy, and speed) was also investigated. The delta values between performance in each body armor configuration and performance in the baseline configuration were calculated and used to analyze the impact of fit on performance. Those deltas were converted to percent differences to represent the improved (greater than 100 %) and degraded (less than 100 %) performance relative to the baseline. The baseline (duty uniform) represents a TP's performance without any effect from the body armor.

Precision. There was no statistical differences in delta values due to either body armor fit configuration, $F(2, 28) = 0.08$, $p = 0.93$, or shooting postures, $F(2, 28) = 0.44$, $p = 0.65$, nor was there any interaction effect between the body armor fit configuration and posture, $F(4, 56) = 0.95$, $p = 0.44$.

Accuracy. For the single target task, there was no significant difference in delta values due to either body armor fit configuration, $F(2, 28) = 0.65$, $p = 0.53$, or shooting posture, $F(2, 28) = 0.39$, $p = 0.68$, nor was there any interaction effect between the body armor fit configuration and posture, $F(4, 56) = 0.23$, $p = 0.92$.

The results were the same for the multiple target task. There was no significant difference in delta values due to body armor fit configuration, $F(2, 28) = 0.53$, $p = 0.60$, shooting posture, $F(1, 14) = 0.09$, $p = 0.77$, or target location, $F(3, 42) = 0.81$, $p = 0.50$. There was also no significant interaction effect between shooting posture and body armor fit configuration, $F(2, 28) = 0.47$, $p = 0.63$ or between target location and body armor fit configuration, $F(6, 84) = 0.71$, $p = 0.64$.

Speed. For the multiple target task, there was no significant difference due to shooting posture, $F(1, 14) = 0.00$, $p = 0.98$, or direction, $\mathcal{E} = 0.65$, $F(3.25,$

45.51) = 1.75, $p = 0.13$, nor were there any interactions between body armor fit configuration and shooting posture or direction, $F(2, 28) = 2.03$, $p = 0.15$ and $\mathcal{E} = 0.24$, $F(2.42, 33.81) = 1.55$, $p = 0.13$, respectively. However, the delta values of movement time were statistically different depending on the fit of the body armor, $\mathcal{E} = 0.83$, $F(1.67, 23.31) = 4.91$, $p = 0.02$. Regardless of the engagement direction, TPs moved faster from one target to the next when they performed in their decreased size configuration ($M = -0.02$ s or 101.05 % of baseline configuration) compared to speeds in their initial fit and increased size configurations, $p < 0.05$. The difference in movement time between initial fit size (M = 0.20 s, or 87.90 % of baseline configuration) and increased size (M = 0.20 s or 88.01 % of baseline configuration) was almost identical, $p > 0.05$.

4 Discussion

This study started with two research questions, (1) how does wearing body armor affect marksmanship performance, and specifically, (2) does the fit of the body armor affect marksmanship performance? In order to investigate both questions, marksmanship performance using a weapon simulator was evaluated in terms of skill level and transition mobility. Accuracy and precision evaluated the level of shooting skill; speed (movement time to transition between targets) quantified the transition mobility in various body armor configurations.

4.1 Skill Level

Shooting posture was the only factor that had a statistically significant effect on precision, and no other factors, either body armor fit configuration or the interaction between shooting posture and configuration were statistically significant for precision.

During the single target task, no statistically significant differences in accuracy were observed for configuration, shooting posture, or interaction effect. During the multiple target task, no statistically significant differences were found due to configuration, target location or the interaction between them. However, unlike in the single target task, when TPs were required to move the weapon and transition between targets, their accuracy was more degraded while kneeling than while standing.

In all, body armor fit neither further degraded nor improved marksmanship performance (precision and accuracy) relative to the baseline configuration without body armor.

4.2 Transition Mobility

For speed, all main effects were statistically significant and the interaction effect between configuration and the direction (order of target engagement) was also approaching significance when comparing baseline and initial fit configurations. TPs moved faster when they performed in a standing posture relative to kneeling, and in baseline relative to initial size. Interestingly, the further the distance between each target was, the more apparent the performance difference between baseline and initial size configurations became. Thus, the effect of body armor relative to the baseline configuration, was that it caused TPs to be slower in their transitions between targets, and the greater the transition distance required, the slower they performed.

Interestingly, body armor's effect on speed was different depending on the fit of the body armor. When all configurations are compared to each other, the transition time between two targets for baseline, decreased, initial fit, and increased size configurations are 1.69, 1.67, 1.90 and 1.89 s, respectively (Fig. 5a). If the total movement time for all five target engagements are compared, the mean speed was

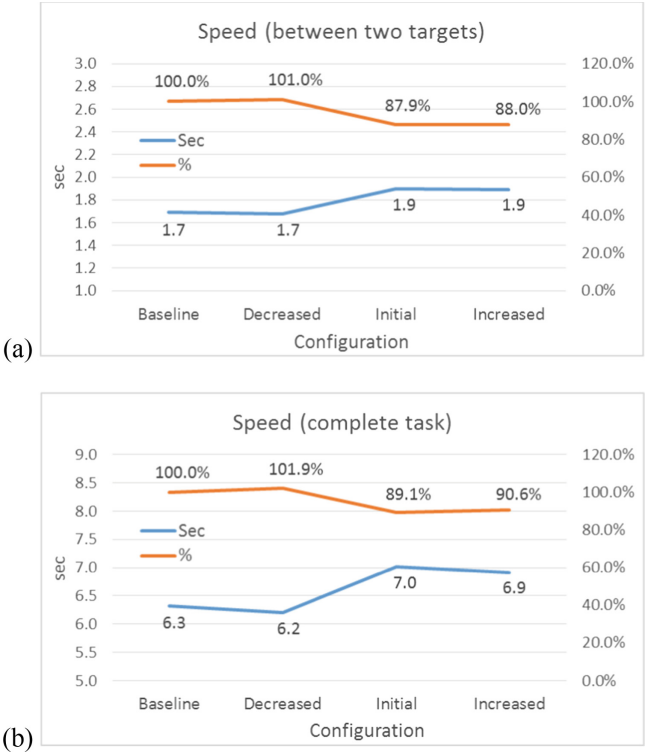

Fig. 5 Results of transition speed between **a** two targets and **b** all targets speed

maintained in the decreased size (M = 6.2 s, 101.95 %) relative to baseline (M = 6.32 s), but was degraded in the initial and increased sizes by 0.69 s (10.93 %) and by 0.60 s (9.42 %), respectively (Fig. 5b). Therefore, TPs' speed was statistically faster in the decreased size than it was in the initial or increased size. Remarkably, the speed in the decreased size was almost identical to that in the baseline, meaning that Soldiers' performance in the decreased size body armor was similar to their performance when not wearing any body armor.

4.3 Performance Coverage Trade off in Body Armor Design

Although the current results are from a limited number of Soldiers utilizing a controlled, laboratory based scenario, these results indicate two facts. One, regardless of fit, wearing body armor did not degrade or improve the skill level of marksmanship performance relative to the baseline configuration in this experimental setting with a simulator. Two, depending on the fit of the body armor, transition mobility during marksmanship performance can be maintained or degraded relative to the baseline configuration.

Thus, from a performance perspective, it is debatable whether body armor design specifications should aim to fit the Soldier in a size decreased from the size that currently would be predicted and issued. However, because the primary concern in body armor design is to protect the body from blast/ballistic threat(s), it is critical to further investigate the risk inherent (e.g., increased potential for injury) in selecting smaller sizes over initial fit sizes in order to improve performance. Currently, there are only two known factors that characterize the differences between two consecutive sizes of body armor: weight and area of coverage (AoC). When body armor is configured with soft armor, collar, yoke, and plates (front, back with two side plates), Soldiers would wear approximately 1 kg less by wearing an IOTV one size smaller on average (across the sizes from size Extra-Small to Extra-Large). For example, a size Small IOTV weighs 10.47 kg in comparison to a size Medium's 11.49 kg. Similarly, AoC is also reduced by wearing a smaller size, by 3.9 % between size Small and Medium as measured for those TPs in this study with an initial fit of Medium.

It is questionable whether the performance degradation/improvement is due to the difference in weight, AoC, or both. While we know that a reduction of weight is beneficial, the more critical question that should be addressed is the consequences of reduced coverage on Warfighter protection, and whether the performance improvement is worth sacrificing that additional protection. Currently, investigations on changes in protection relative to coverage reduction are being planned. These results will feed into recommendations on future body armor design.

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Study on the Operation of Liquid-Filled Anti-G Suit Based on Finite Element Method

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Abstract High-performance military pilot's blood shifts from upper extremities to the legs and feet and causes impaired vision and loss of consciousness. To avoid the effect of acceleration forces, a kind of liquid-filled protective garment has been proposed instead of pneumatic anti-G suits. In this paper, the finite element model of upper extremities and lower extremities of the body consisting of liquid-filled anti-G suit and human aircraft can generate extremely high gravitational acceleration which can shift pi tissue was developed to study the influence of liquid-filled anti-G suit on the body of pilot under different overload acceleration. The results show that: (1) the surface pressure gradually increases along with the increase of overload acceleration and liquid-filled level; (2) the maximum deformation of human mesh tissue increases along with the increase of overload acceleration and liquid-filled level; (3) the maximum stress and deformation of the clothes are similar with the pattern of human mesh tissue.

Keywords Liquid-filled protective garment · Overload acceleration · The maximum stress · The maximum deformation

1 Introduction

High-performance military aircraft can generate extremely high gravitational acceleration, which can shift pilot's blood from upper extremities to the legs and feet and cause impaired vision and loss of consciousness. Traditionally, pneumatic anti-G suit and anti-G straining maneuver were used to prevent the on-rush of blood

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to the lower part of the body, however the pneumatic suit is complex and the straining maneuvers can cause physiological fatigue in pilots. To avoid the effect of acceleration forces, a kind of liquid-filled protective garment has been proposed instead of pneumatic anti-G suits. Based on the theory of huge deformation in elasticity, Avula [1, 2] studied the deformation of liquid-filled membrane in the liquid. Human body blood vessels was simplified liquid-filled membrane and the effects of liquid-filled anti-G on human body blood vessels were explained by using the deformation of liquid-filed membrane in the liquid. These established a theoretical foundation for the applications of the liquid-filled anti-G suit. The mathematical formulas were used to calculate the deformation of the liquid-filled membrane that was immersed in water in varying degrees. The results showed that with the depth of degree, the shape of liquid-filled membrane changed from ellipsoid to sphere, when fully immersed in water, the shape of the membrane was spherical, and no matter what the depth was, only fully immersed in water, the shape of membrane remain the same. These offered the theoretical foundation for the study of the liquid-filled anti-G suit. In this paper, the finite element model of upper extremities and lower extremities of the body consisting of liquid-filled anti-G suit and human tissue was developed to study the influence of liquid-filled anti-G suit on the body of pilot under different overload acceleration. First of all, make sure the calculation model; Secondly, The geometry models were meshed separately in Hypermesh; Finally, study the changes of mechanical parameters of liquid-filled structure under different overload and get the clothing extension, muscle tissue deformation and change characteristics of body pressure under different overload.

2 Model Construction of Liquid-Filled Anti-G Suit

Due to the structure of human body is very complicated, in this paper, the human body model is simplified, the general model includes the upper limb and lower limb model system, separately containing bone, muscle layer, clothing and liquid-filled tube layer.

2.1 Model Construction of Upper Limb

The bones of upper extremity are simplified as the shape shown in Fig. 1. The total length of skeleton model is 454 mm, and the upper and middle parts are bulged, respectively simulating consolidation greater trochanter and the thick part of elbow joint bones. The upper limb links the forearm and upper arm together to model, and

the model is established on basis of the 50 percentile upper limb size in GJB 4856-2003 fighter (strong) plane, length 454 mm, arm circumference 290 mm, forearm around 266 m. The clothing layer of upper limb completely fit the muscle layer, established through the muscle layer shell, thickness of 1 mm.

According to the structure chart of the liquid-filled anti-G suit filling, substitute 50 percentile pilot relevant size in GJB 4856-2003 fighter (strong) plane, then you can calculate the total length of liquid-filled tube L = (shoulder height—back of foot height + full arm length).

2.2 *Model Construction of Lower Limb*

The bones of lower extremity are similar to the shape shown in Fig. 1. The model is established on basis of the 50 percentile lower limb size in GJB 4856-2003 fighter (strong) plane, leg length 363 mm, thigh length 492.5 mm, The clothing layer of lower limb completely fit the muscle layer, established through the muscle layer shell, thickness of 1 mm. The way of liquid-filled tube construction is identical with 2.1, along the lower limb, diameter 4 cm, thickness 1 mm.

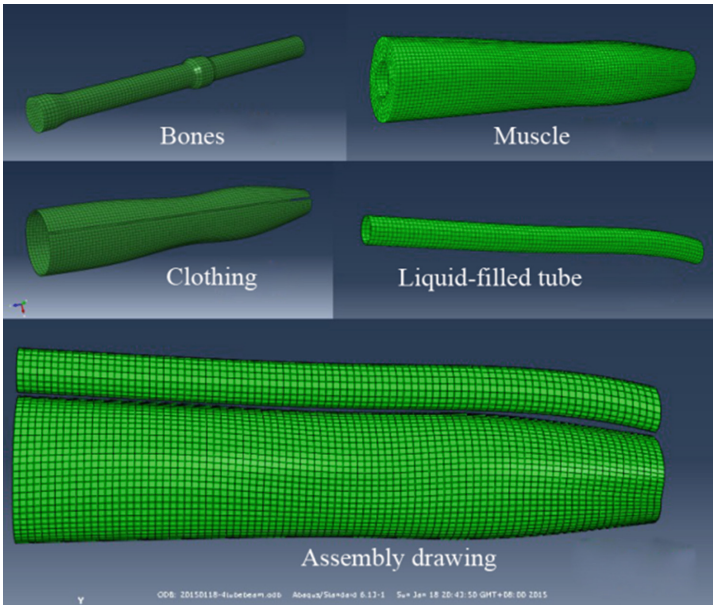

Fig. 1 Finite element model of upper limb

2.3 Finite Element Mesh Generation

This paper adopts Hypermesh software to proceed finite element mesh generation for upper and lower limbs and liquid-filled tube model. All adopt hexahedral mesh to divide so as to fully guarantee the quality of the divided mesh. The divided finite element model of lower limb is shown in Fig. 2.

2.4 Material Attribute

Refer to the references at home and abroad, the material attribute in this paper is shown in Table 1.

Due to large differences in different parts of the bone material, in order to simplify the model, this study adopts cortical bone elastic modulus and Poisson's ratio. The muscle layer is based on the data of literature [3], adopting super-elastic material. This model can simulate the large deformation behavior of elasticity and the deformation characteristics of muscle tissue.

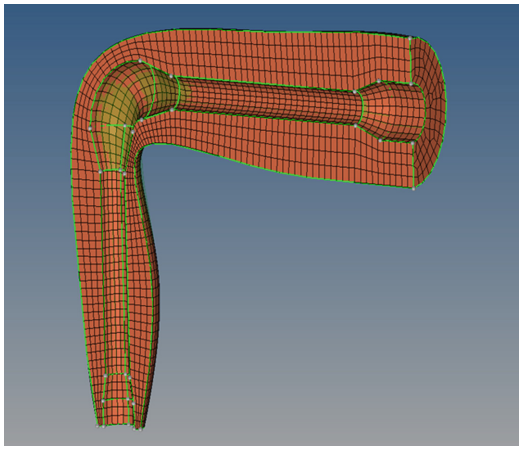

Fig. 2 Finite element mesh of lower limb muscles

Table 1 Material attribute in model

Name	Material attribute
Skeleton	Isotropic elastic material E = 42 MPa, = 0.3
Muscle	Hyperelastic—Mooney-Rivlin superelasticity material C10 = 1.65 kPa, C01 = 3.35 kPa, = 0.49
Clothing	Anisotropic elastic material elastic—engineering constants =220.69, ==13.79, ==0.2, = 0.25, ==8.97, = 4.83 unit: GPa
Liquid-filled tube	Isotropic elastic material E = 7.84E6 Pa, = 0.495

2.5 *Verification of Finite Element Model*

To verify the accuracy of the simulation result, we compare the simulation result and experimental data of inflatable anti-G suit to verify the feasibility of the simulation calculation. The data of simulation result in thigh midpoint and calf midpoint is compared with the experimental data. Figure 3 shows the selected position of thigh midpoint and calf midpoint in simulation results. Figure 4 shows the comparison chart between the surface pressure of thigh midpoint, calf midpoint and simulation result when the gas-filled anti-G suit is in inflating pressure 90, 465, 825, 1200 mmHg. From the result, under pressure 90, 465, 825 mmHg, the curve

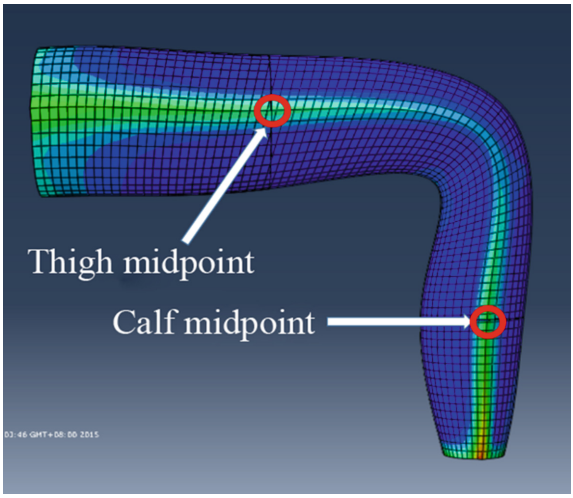

Fig. 3 Schematic diagram of thigh midpoint and calf midpoint

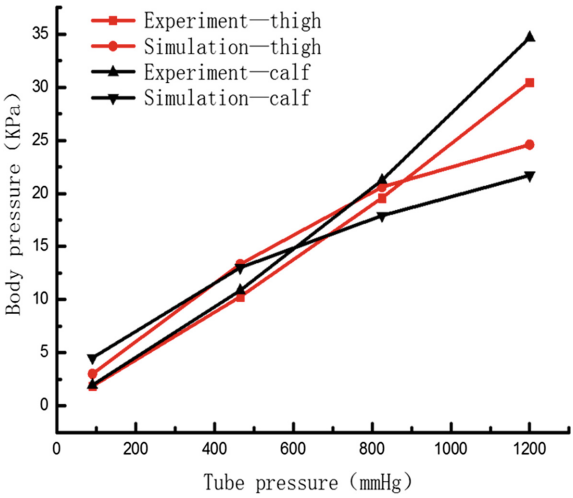

Fig. 4 The comparison between simulation and experiment

between the simulation result and the experimental data matches well; under pressure 1200 mmHg, the simulation result deviates far from the experimental data; but considering the maximum pressure of around 1000 mmHg in the simulation result, the simulation result can better reflect the real data.

3 Analyses of the Results of Calculation

3.1 Analyses of the Results of Calculation of Upper Limb

The Stress and Displacement Nephogram. This paper gets the mechanical parameter variation of upper limb clothing by analyzing the simulation calculation result of upper limb under 14G overload (maximum tube pressure approximately equal to 465 mmHg).

Figure 5 shows the stress and displacement nephogram of the cross section in the middle of the upper arm. The underneath of the figure is the location of liquid-filled tube. In the figure, the underneath represents one side of liquid-filled tube with maximum surface pressure. The surface pressure gradually decreases with increasing distance from liquid-filled tube. The pressure gradually reduces from outside to inside. The muscle deformation and the stress variation tendency basically stay the same, while the greater the force, the greater the deformation.

Muscle Maximum Deformation of Upper Limb under Different Liquid-Filled Levels. Figure 6 shows the relation between muscle maximum deformation and overload under different liquid-filled levels. The muscle deformation enlarges with the increasing of overload acceleration and liquid-filled levels, but increase amplitude gradually decreases.

Clothing Maximum Deformation of Upper Limb Muscles under Different Liquid-Filled Levels. Figure 7 shows relation between the clothing maximum deformation and overload under different liquid-filled levels. The variation tendency of clothing deformation and the variation tendency of muscle tissue deformation basically stay consistent, enlarging with the increasing of overload acceleration and liquid-filled levels, but increase amplitude gradually decreases.

3.2 Analyses of the Results of Calculation of Upper Limb

The Stress and Displacement Nephogram. This paper gets the mechanical parameter variation of lower limb clothing by analyzing the simulation calculation result of lower limb under 14G overload (maximum tube pressure approximately equal to 465 mmHg).

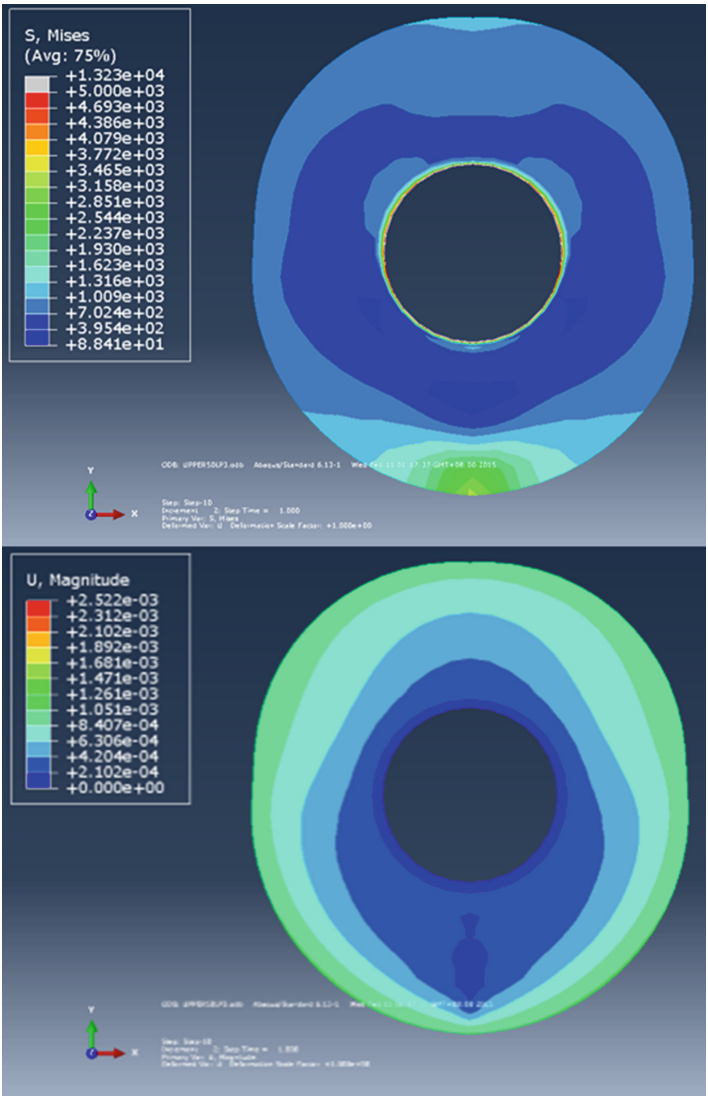

Fig. 5 Stress (*top*) and displacement nephogram (*bottom*) of the cross section in the middle of the upper limb

Figure 8 shows the stress and displacement nephogram of the cross section in the middle of the thigh. In one side of liquid-filled tube, the stress is relatively concentrated; this side acts as the center, the stress gradually reduces to all around. In the position of liquid-filled tube, the muscle deformation also reaches the

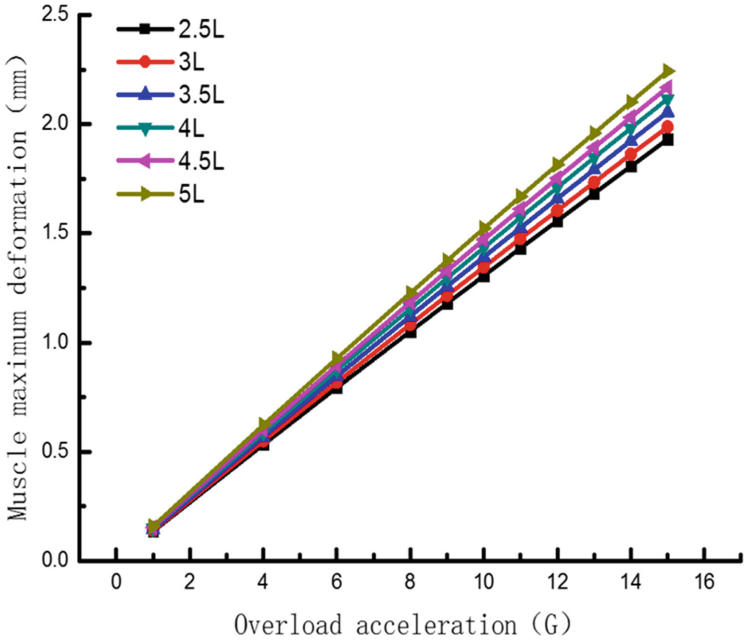

Fig. 6 Relation between muscle maximum deformation and overload under different liquid-filled levels

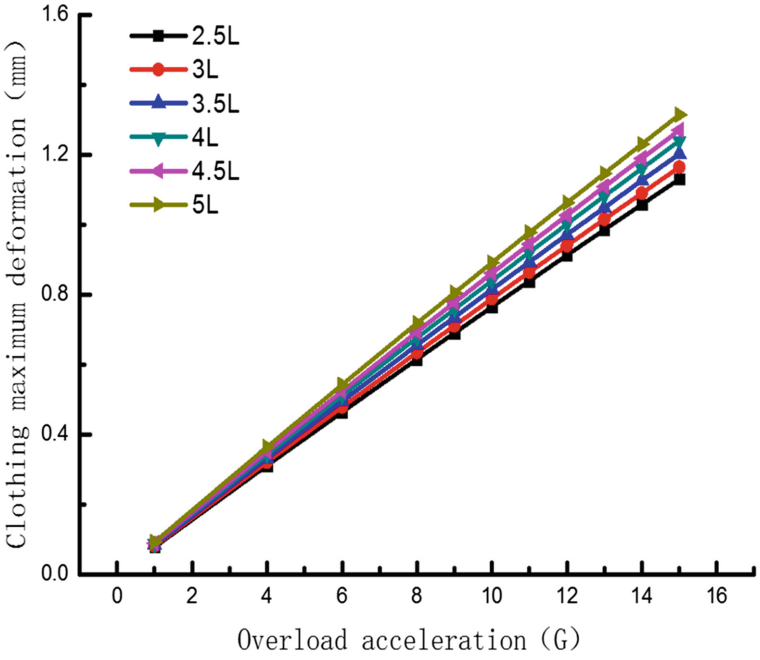

Fig. 7 Relation between the clothing maximum deformation and overload under different liquid-filled levels

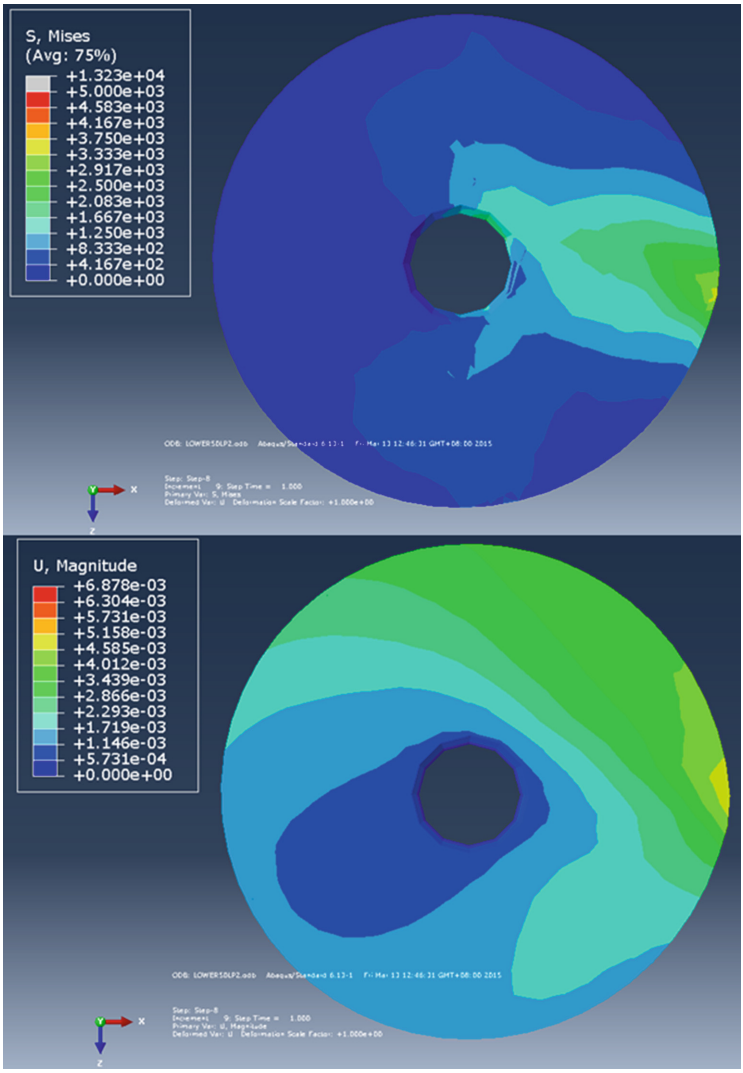

Fig. 8 Stress (*top*) and displacement nephogram (*bottom*) of the cross section in the middle of the thigh

maximum; this position acts as the center, the deformation gradually reduces to all around, the deformation of the upper part is relatively larger than the lower part.

Figure 9 shows the stress and displacement nephogram of the cross section in the middle of crus. The right side is the position of the liquid-filled tube, while the bottom is calf. Its stress and displacement change is consistent with the thigh; the stress is concentrated in one side of the liquid-filled tube, with maximum deformation.

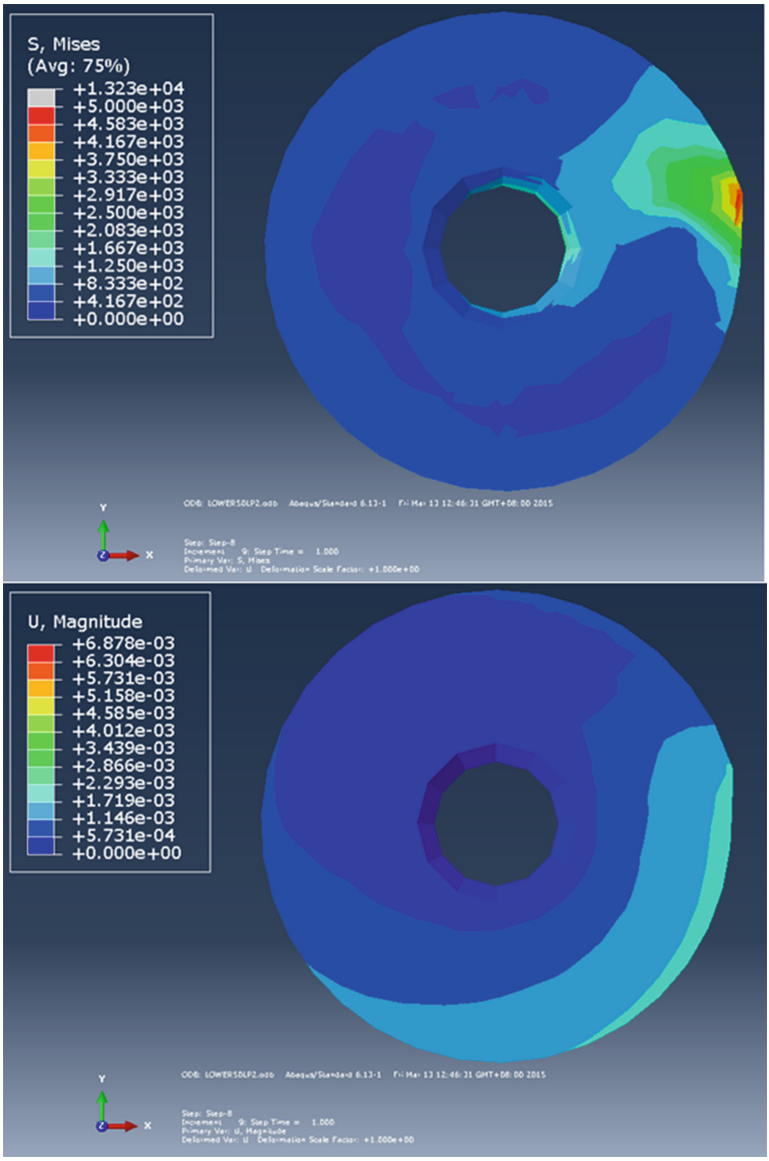

Fig. 9 Stress (*top*) and displacement nephogram (*bottom*) of the cross section in the middle of calf

Muscle Maximum Deformation of Lower Limb under Different Liquid-Filled Levels. As can be seen from Fig. 10, the maximum deformation of lower limbs muscle enlarges with the increasing of overload acceleration and

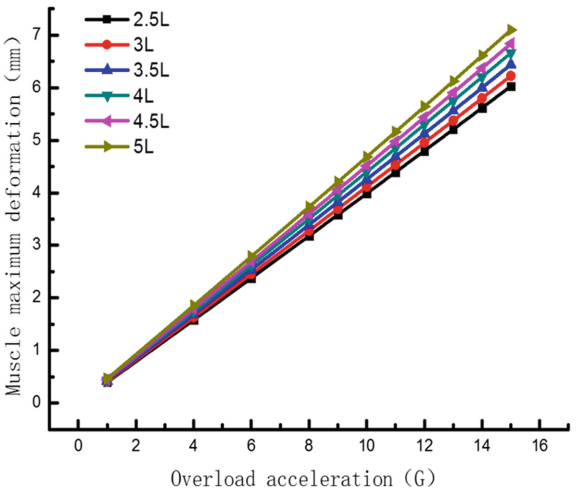

Fig. 10 Relation between muscle maximum deformation and overload under different liquid-filled levels

liquid-filled level, the difference from upper limb is that the increase amplitude does not significantly reduce, which may be related to the thick muscle layer of lower limb.

Clothing Maximum Deformation of Lower Limb Muscles under Different Liquid-Filled Levels. The tendency of the maximum deformation of lower limbs clothing is basically in line with the maximum deformation of lower limbs muscles (Fig. 11).

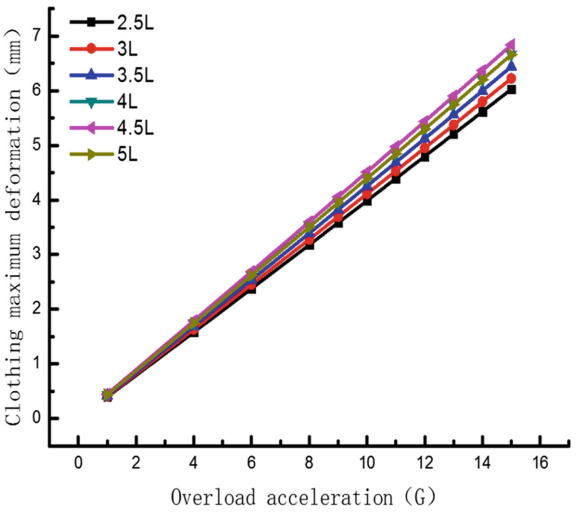

Fig. 11 Relation between the clothing maximum deformation and overload under different liquid-filled levels

4 Conclusion

In this paper, we study on simulation of liquid-filled anti-G suit under different liquid-filled levels and overload. We can draw a conclusion:

1. The surface pressure of tubular anti-G suit muscle tissue enlarges with the increasing of liquid-filled volume.
2. The maximum stress and maximum deformation of clothing enlarges with the increasing of overload (intraductal pressure), this is due to the increasing pressure inside the pipe, then the deformation of liquid-filled tube increases. To limit the deformation of liquid-filled tube, the clothing needs to make greater force;
3. The maximum stress and maximum deformation of clothing enlarges with the increasing of liquid-filled level. When the liquid-filled level increases, the corresponding liquid-filled tube will become coarse or thick, thereby generating greater stress on the clothing.

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Effectiveness of Personal Protective Equipment for Farm Workers Who Grow Pineapples

Maria Cristina Gonzaga, Roberto Funes Abrahão and Mauro José Andrade Tereso

Abstract One of the most challenging agricultural crops from the perspective of worker protection is the pineapple growing. Previous studies reveals the ineffectiveness of personal protective equipment (PPE) usually used by workers to protect themselves against accidents with poisonous animals and punctures by pointed leaves, particularly on the tasks of planting seedlings and harvesting. In view of these results, this study aims to experimentally evaluate the effectiveness of a commercial set of PPE in protecting workers against real venomous snake attacks. Four sets of PPE were tested, including shoes and protective gloves, leggings and over sleeves, each set with three different models. Only 5 models were approved in the tests, including one model of a shoe, two models of leggings and two models of gloves. The equipment that pass the real attack tests will then be evaluated by a group of workers in real use situations, according to qualitative criteria, including comfort and usability. It is expected that the results allow the selection of a set of PPE which effectively protect the workers and that facilitate, or do not interfere adversely during task execution.

Keywords Personal protective equipment · Snake attack · Pineapple

1 Introduction

Agriculture is considered one of the most hazardous productive sectors regarding human labor. Several epidemiological studies have shown consistently the occurrence of a great number of accidents and work related diseases among agricultural workers [1, 2]. The most common injuries are musculoskeletal disorders, due mainly to manual handling of loads, the permanence in extreme postures and repetitive hand movements [3].

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Due to the characteristics of the agricultural work and the synergy that occurs between the risk factors, work accidents that occur in rural areas are potentially more damaging than those in urban areas. This finding fully justifies the research effort directed to the analysis of risk factors and protective equipment selection or design that is effective and minimally intrusive and uncomfortable.

One of the most challenging agricultural crops from the point of view of labor risk factors is the pineapple. Its production, from the socio-economic point of view, is important for Brazil. United Nations data show Thailand as the world's largest producer of pineapple in 2011, with a production of 2,593,210 tons, followed by Brazil, with a production of 2,318,120 tons. The production process is divided into 4 phases: land preparation, planting, cultivation and harvesting [4]. These phases are divided into various agricultural operations that make up the production cycle of the crop, which can last from 18 to 24 months.

Pineapple production involves a series of manually executed steps: cutting the seedlings; loading the seedlings to the truck or the tractor trailer; unloading the seedlings into the soil; planting; coverage of the fruits with paper; weeding; fertilization; pesticide chemical preparation and application; harvesting; the quality control of the harvested and planted seedlings; the quality control of fruits to be harvested; and fruit organizing on the ground and in the truck. These operations expose workers to a great number of risk factors.

A study was conducted in order to identify the risk factors associated with the pineapple production [5]. The researchers used the technique of collective work analysis with the actors involved in the production of pineapple in the state of Paraiba, Brazil. They also used semi-structured questionnaires and conducted direct observations of real work situations. The study found risk factors at all stages of the production process, especially in the preparation and application of pesticides, and points out various problems of social and economic order, in particular the role of public and private social agents in maintaining unfavorable conditions for the workers.

Another group of researchers [6] conducted a comprehensive analysis of the working conditions in pineapple production process in the municipality of Guaraçaí, São Paulo. The study was motivated by a demand from the rural workers union directed to the analysis of the protective gloves commonly used by the workers. It was found, however, that the safety and ergonomic problems were much broader, and the researchers opted for a study that covered all the stages of the production process. They used the technique of ergonomic work analysis [7], including general and systematic observations of real work situations. The results highlighted the accidents with poisonous animals and the occurrence of perforations by spiky leaves in several body segments, especially in the stages of seedling harvesting and planting and fruit harvesting. The study pointed out the general inefficiency of the PPE used by the workers, a typical set consisting of protection trousers and sleeves, rubber boots and cotton gloves. The PPE not only failed in protecting the workers against the pineapple leaves and snake attacks, but also made it difficult to accomplish the tasks. In its conclusion, the study showed an inventory of identified risk factors and pointed out the suffering of workers and the

precariousness of the physical and social conditions associated with the work in the pineapple crop. It also highlighted the lack of appropriate technology to the alleviation of the workload and to the worker's protection.

Among the risk factors identified and reported by farmers stand out accidents with poisonous snakes. Globally, the World Health Organization [8] considers the resulting poisoning a public health problem in rural areas of tropical and subtropical countries in Africa, Asia, Oceania and Latin America. A recent study estimates that, each year, at least 421,000 poisonings and 20,000 deaths occur worldwide from snake bites, but cautions that these numbers may be underestimated. In South and Southeast Asia and sub-Saharan Africa is where the greatest number of attacks occurs.

Epidemiology of snakebites points to a profile that remains unchanged over the past 100 years in Brazil: occurs more frequently at the beginning and end of the year, in males, in rural workers in the productive age group of 15–49 years; reach, especially the lower limbs; and most of these accidents are attributed to the genus Bothrops [8].

In Brazil, between 2007 and 2013, a total of 750,303 cases of accidents with poisonous animals have been notified by the Notifiable Diseases Information System (SINAN), distributed as follows between the Brazilian states: Minas Gerais, 16.70 % (125,273 records); São Paulo, 12.16 % (91,236 records); Paraná, 11.44 % (85,805 records) and Bahia 10.18 % (76,378 records). This reporting system identified during this period 67 accidents in Guaraçaí, suffered by rural workers growing pineapples, mostly caused by Bothrops snakes Viperidae, commonly called species of pit vipers, *cotiaras* and *urutus*.

This study aims to evaluate a set of personal protective equipment (PPE) available on the Brazilian market for use in the pineapple production process according to their effectiveness in protecting workers against the attack of venomous snakes. The project is part of a broader effort that seeks to propose a commercial set of PPE suitable for work in pineapple cultivation in accordance with the identified risk factors and according to usability criteria. In addition, it seeks to define a set of parameters and alternatives to guide the design of a new set of PPE specifically conceived to the work in pineapple production.

2 Methods

The snake attack tests were performed at the Foundation Ezequiel Dias—FUNED of Belo Horizonte (MG), in September 2015, with the following PPE: 4 models of protective footwear (B1 to B4—manufactured according to ISO 20345); 3 models of protective gloves (P1 to P3—manufactured according to the EN388 2003); 3 models of leggings (L1 to L3—manufactured according to ISO 11611) and one model of a protective shirt sleeve (M—manufactured according to AT 388). The PPE set, donated by ANIMASEG (National Industry Association of PPE

manufactures), was identified by codes to preserve the identity of their manufactures.

The snakes used in the experiments running the attacks were 4 female healthy adult individuals, belonging to the following species: *Bothrops jararacussu* (Jaracuçu) and *Crotalus durissus terrificus* (Rattlesnake). The biometric data of the snakes used in the test (size, weight and the size of the fang) were recorded, as well as the height of the attacks.

The experiment was done in a room at a temperature of 25 °C and humidity equal to 60 %. To highlight the result of the attack—to verify if the PPE were perforated or not—two experimental sets were used: the PPE were adjusted in anatomical parts of mannequins (set 1) and filled with air-filled bladders (set 2). With the aid of a suitable hook, each assembly was approximated at about 30 cm from the snakes in order to stimulate the attacks. Each type of PPE was subjected to three attacks of each species of snake (rattlesnake and *jaracuçu*) for each experimental arrangement, so that each PPE underwent a total of 12 attacks.

3 Results and Discussion

Table 1 shows the biometric data of the snakes used in the tests; Fig. 1 shows a snake attack from the experimental arrangement with anatomical parts of mannequins:

Table 2 summarizes the test results on the basis of the experimental arrangement and snake species.

Table 2 shows that only 5 models of the PPE set evaluated resisted all of the snake attacks: the protective footwear B3, leggings P2 and P3 and protective gloves L2 and L3.

The main characteristics of PPE that resisted the snake attacks are presented below. These descriptions are taken from the PPE approval certificates issued by the Secretary of Labor Inspection of the Brazilian Ministry of Labor and Employment.

Table 1 Snake's biometric data

Species/chip number	Length (cm)	Weight (kg)	Fang size (cm)	Mouth aperture (cm)	Attack height (cm)
Bothrops jararacussu (900164000725985)	148	1.900	2.0	7.0	Between 20 and 25
Bothrops jararacussu (900164000325987)	138	1.025	2.0	9.0	
Crotalus durissus terrificus (900164000726123)	86	0.550	1.0	4.5	Between 10 and 14
Crotalus durissus terrificus (900164000726007)	110	1.025	1.5	5.0	

Fig. 1 Snake attack on a protective footwear

Table 2 Test results showing the effectiveness of the snake attacks

PPE	*Bothrops jararacussu* (Mannequim)		*Bothrops jararacussu* (air bladder)		*Crotalus terrificus* (Mannequim)		*Crotalus terrificus* (Air Bladder)	
	Perf. (yes)	Perf. (no)	Perf. (yes)	Perf. (no)	Perf. (yes)	Perf. (no)	Perf. (yes)	Perf. (no)
B1	X		X			X		X
B2	X		X			X		X
B3		X		X		X		X
B4	X		X			X		X
P1	X		X		X		X	
P2		X		X		X		X
P3		X		X		X		X
M	X		X		X		X	
L1	X		X			X		X
L2		X		X		X		X
L3		X		X		X		X

Protective Footwear B3. Protective boot manufactured in Brazil, according to the standard ISO 20347: 2008. A side zipper closes the boot, made of microfiber (microfilaments polyaramide, polyester and viscose, with heat bonded wires and finished in polyurethane) in black, lining upper in non-woven in gray, insole made of synthetic material in white, outsole polyurethane bidensidade in black, injected directly into the leather, without steel toe cap, resistant to fuel oil, for use in places where there is the presence of electricity. It was approved for protection of the

user's feet against risks of lightweight nature, against abrasive and scuffing agents and against electrical shock.

Legging P2. Made of waterproofed leather, finishing in fatty, front closure in elastic and velcro, nylon collar, internal lining with polyester filament, hydrophilic treatment of rapid moisture dispersion lining weft knitted fibers in long molecular chains produced from poly-terephthalamide paraphenlene, highly resistant to cut (manufacturer information—EPI has no certificate of approval).

Legging P3. Made of two layers of synthetic material, three batters in front PVC fixed by soldering, closing the edges through bias with soldering. It was passed to protect the legs of users against abrasive and scuffing agents, and heat from welding and similar processes.

Protective Glove L2. Manufactured according to standards EN 388 (2003) and EN 420 (2003); made of leather scrapes, internal reinforcement in the palmar and dorsal regions, external reinforcement strip on the thumb, scrapes and velcro strip on the handle for adjustments, handle 15 cm, mitten model of two fingers; passed to protect hands against abrasive, scuffing and sharps agents.

Protective Glove L3. Manufactured according to standards EN 388 (2003) and EN 420 (2003); made of treated leather on the back, palm and wrist; reinforcement strip in the palm, thermal lining on the palm and back; lined handle and stitched with aramid yarn, is 41 cm long arm; lined with fabric.

The snakes from the specie *Bothrops jararacussu* were the most efficient, managing to perforate the PPE in 55.9 % of the attacks, against 17.6 % of *Crotalus terrificus* specie. The attacks were remarkably consistent between repetitions, always perforanting or not perforating the same PPE model.

4 Conclusions

Only a small part of the evaluated PPE supported the attack of the snakes: one model of protective footwear and two models of gloves and leggings. This fact highlights the need for protection of agricultural workers who work in places with incidence of snake attacks.

The results of this work should serve as a basis for the design of personal protective equipment that effectively protects workers from snake attacks. The technical and construction characteristics of PPE which withstood the attacks should be thoroughly analyzed. In addition to protection, the design of a new set of PPE for snake attack protection should take into account issues like comfort and minimal interference in the performance of work activities. Therefore, usability testing should be conducted in real working conditions.

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Part V
Product Design

Design of a Universal Mounting Fixture (UMF) for ROPS Using Finite Element Method

V.K. Tewari and A.K. Shrivastava

Abstract A finite element model of Universal Mounting Fixture (UMF) was developed in CATIA_V5. This model consisted of a number of beam elements and nodes connected to the tractor frame. For the simulation, fasteners between the ROPS and tractor axle housing were designed. The finite element model was developed parametrically to accommodate a range of tractors and ROPS sizes. The parametric design permits changes in the model dimensions without varying the number of nodes or elements. It was important to note that this research examined trends for various scenarios for one base-fixture finite element model. The final design of fixture was developed and tested in accordance with IS 11821 (Part 2): 1992 [1]. With due consideration of part geometry, OCTREE Tetrahedron mesh was selected and parabolic displacement interpolation was used between the nodes and elements. After getting the satisfactory result of UMF, the fixture was fabricated and validated through static testing of ROPS. The sequences for the loadings were as follows: rear longitudinal, vertical crush, transverse, and second longitudinal. Each testing except vertical loading, were carried out until the fulfillment of energy criterion. The vertical loading test required maintaining of the load for a specific period of time. The axle housing and mounting fixture combinations must pass the static testing criteria as per standard for acceptability. The fixture design has been patented and being used in testing different types of tractor ROPS.

Keywords ROPS · Universal mounting fixture · CATIA_V5 · Finite element method · Axle housing

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1 Introduction

Rollover Protective Structure (ROPS) is a reinforcement member installed on a tractor with the intention of protecting or limiting the degree of tractor rollover by 90° and preventing the operator from getting crushed under the weight of the tractors. In case of passive safety measures, ROPS is the only high engineering control arrangement which already exists to prevent almost all fatalities due to tractor overturn. However, safety through ROPS reduces if there is no seatbelt for operators.

In most countries, safety regulations are extended to older tractors also, but were not always mandatory [2]. The reductions of rollover fatalities were also dependent on the type of protection and level of usage of ROPS. Therefore, based on the results of aforesaid studies, one time effort in installing a ROPS protects operator for the life of the tractor and its use with seat belt estimated 99 % efficacy in preventing death or serious injury. Additional active safety measures including instructions, warnings and subsequent implementation by the manufacturer could help minimize the accidents. Several attempts for designing ROPS on agricultural tractors in India have been made since the last decade by Singhal [3], Kumar (2001), Poteker [4], Poojary et al. [5], and Poojary and Kalamkar [6]. However, ROPS are still not a standard piece of equipment on Indian tractors although several standardization and legislative implementation have taken place worldwide. With the Indian tractor manufacturers ROPS are only a canopy support or hood assembly frame. Such frames popularly termed as "safety frames" are intentionally provided for protection against tractor rollover although there is no certification of such safety frames. Additionally, such ROPS are available with higher horsepower models of tractors without the possibility of interchangeability among various tractor models. Therefore in such cases, the fixing of available ROPS is limited only to those tractors for which they are designed. There is no demand of ROPS in the Indian market due to lack of awareness and any government regulation enforcement for installation and retrofitting of ROPS on to the Indian tractors. ROPS fitment creates axle housing failure due to dynamic forces [7] caused by the field bumpiness, thus it is essential that ROPS must be 'approved' for fitment to a selected tractor model.

A mounting technique as invented previously [8] may be a solution for retrofitting ROPS on some but not all Indian tractors. The design considerations of such fixtures are mainly based on the reference mass of the tractors which significantly vary. In India, medium horsepower range (20–35 kW) 2WD agricultural tractors are more in the use and preferred. However, merely using a particular structure could result in either overdesigning or under designing, where as a proper design could minimize the failure chances of the axle housing. Therefore, the study and development was conducted for a mounting fixture to accommodate variations of axle housing as well as different tubing sizes of ROPS. Therefore, there is a need for a 'Universal Mounting Fixture (UMF)' as a fastener between axle housing and ROPS which could match the tractor size independent of its design of the axle housings to fit into every tractor model. The present work speaks of the design of UMF using FEM for its strength and capabilities.

2 Universal Mounting Fixture Design

ROPS retrofitting on Indian tractor models is a tedious task due to variety of shapes of axle housings and tubing sections of vertical post of ROPS. Therefore, a Universal Mounting Fixture (UMF) was designed to grip the axle housing as well as ROPS and to be suitable for a variety of tractor models. The design (Fig. 1a) has three specially designed plates namely top plate, middle plate and base plate. The base plate and middle plate are designed for gripping the axle housing while middle plate and top plate are fixed together in which top plate is responsible for fixing the vertical post of ROPS. Some designs of ROPS have a bottom plate attached to its vertical post while other designs are available without any base attachment. For such cases top plate may be replaced by another circular provision shown in Fig. 1b. This was designed to accommodate different cross sections of vertical posts of ROPS namely hollow square, hollow rectangular and hollow circular. Additionally the UMF has all the provisions to accommodate ROPS without changing or modifying its original design.

These plates have been arranged in such a way that both the plates can rotate 90° with respect to each other (if required) in horizontal plane. The schematic diagram of designed fixture is presented in Fig. 2.

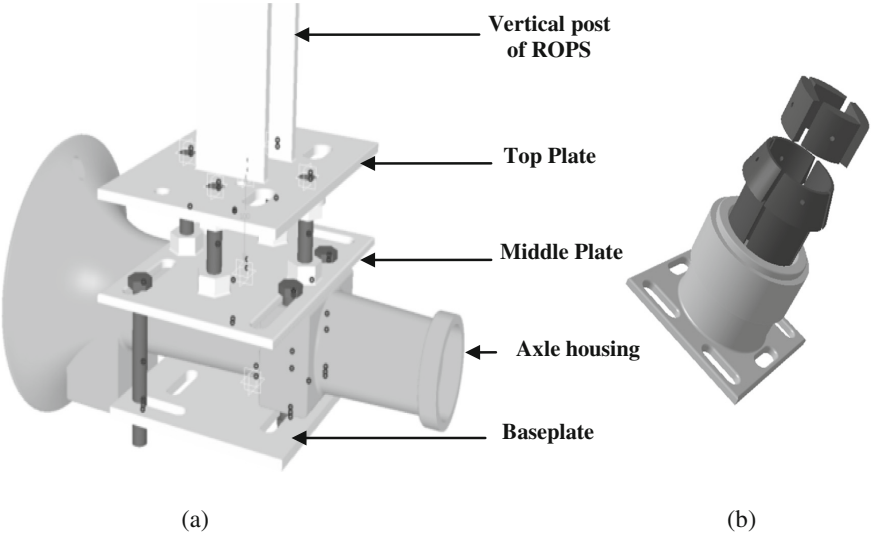

Fig. 1 Universal mounting fixtures

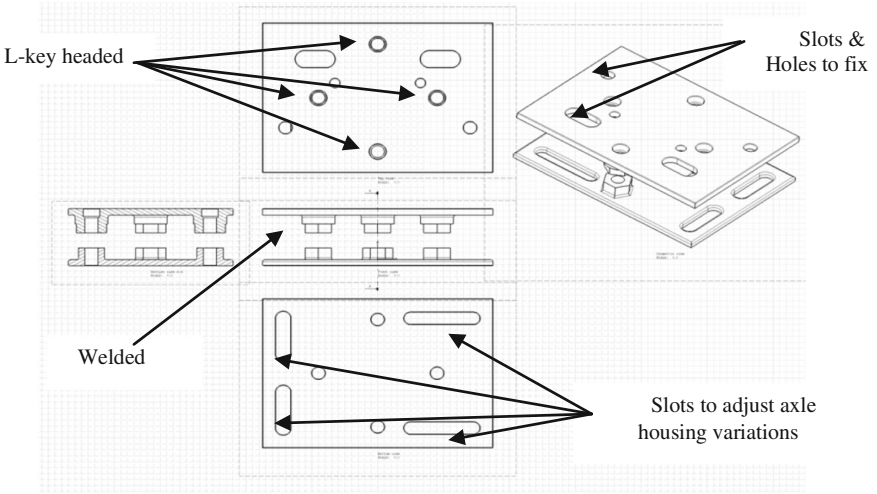

Fig. 2 A view of universal mounting fixture

2.1 Finite Element Analysis of UMF

Accuracy of FEM solution depends on mesh size. Before proceeding with complex FE model of UMF into CATIA, mesh size was obtained firstly. For the same, a hollow square section of size 40 mm × 40 mm × 5 mm of 1 m length was taken to compare the analytical and simulation results. The mesh size at which the analytical value matched with simulated value was considered accurate mesh size for further analysis of UMF.

The FE Model of UMF was analyzed at maximum load which was calculated from the IS 11821 (part 2) Standard [1]. These load acts as the cut off load that meets the Energy requirements. After applying load, the yield strength of material was compared with stress distribution color chart of CATIA in order to determine the yield point of the material.

3 Results and Discussion

A Finite Element Model of the selected axle housing was developed into CATIA based on the selected dimensions and material property. The analytical results of selected tractor axle housing were compared through Finite Element Analysis (FEA). Using this method, it was possible to estimate the axle housing strength until its actual failure point as well as critical failure sections of axle housing. A cantilever beam was also modeled and attached to the axle housing so as to simulate longitudinal static tests. OCTREE tetrahedron mesh was defined for model

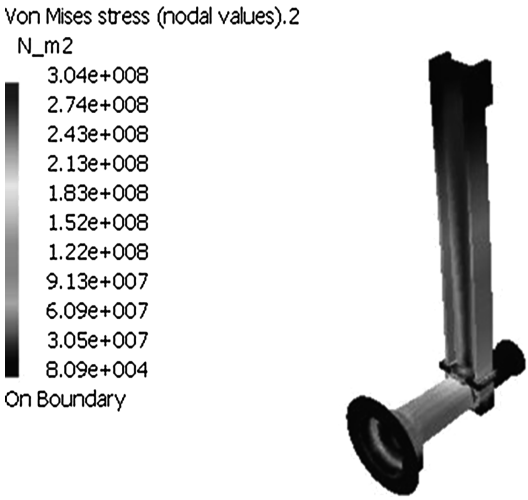

Fig. 3 Von-mises stress on axle housing

with mesh size and absolute sag of 30 and 10 mm respectively. The selected mesh size produced the total number of 21,451 nodes and 11,632 elements. The parabolic element type was chosen for accurate analysis and FEA identified the ROPS mounting point as the potential area of failure (Fig. 3).

Low stress levels were identified towards the main chassis end whereas higher level of stress was observed at critical area. At initial twisting moment of 2000 Nm, a stress of 26.5 MPa was produced. This procedure was continued till the twisting moment of 10,000 Nm where a maximum induced stress of 132 MPa was observed. Similarly, as the torque built up to 22,000 Nm, the stress level was found to be 291 MPa. For a 23,000 N force applied on top of the beam, maximum stress level was found to be about 304 MPa near the critical area of beam fitting, rest of the parts observed low stress levels. The critical location with higher stress level of beam point is the ultimate ROPS mounting point which suggested modification to be necessary to support axle housing. Possible rectification could increase the casting thickness or additional mounting fixture to attach the ROPS.

In addition, high stresses were experienced in housing bolts connected to the critical zone of ROPS mounting. It was also found that ROPS could not be mounted with just two mounting bolts using flange to present ROPS axle housing. Further, it was determined that simulation results are under 10 % prediction level from the calculated results, such results were also reported by Harris [9]. The predicted error could be due to difference in geometrical parameter and restraint conditions. Since FE modeling of axle housing involves filleting, chamfering and holes which reduce the stress concentration at corner points whereas such measures were ignored in analytical solution. Yield strength of axle housing was obtained at torque application of 23,000 Nm which was at par with the yield limit of axle housing material.

A relationship between twisting angle and torque of the axle housing was established by Li and Ayers [10], they concluded that axle housing had underwent elastic to plastic stage (or was partly plastic) with the twisting torque between 23,000 and 27,000 Nm. This meant that safe limit of torque application on single axle housing was about 13,500 Nm to avoid its plastic failure while testing on complete axle housing. It was concerning that material (grade) used for casting of axle housing in other countries differs due to thrust forces which varied according to mass of the tractors. But, a minimum standard criterion for material used in such case was FG 260 as per IS 3896 (Part 2): 1985 and this was highly comparable with grade of other countries [11]. Therefore minimum torsional yield strength was considered to be about 320 MPa due to supplementing ingredients which create difference in casting strength. Analytical solution of selected housing with known material suggested that the elastic limit exists at 20,000 Nm applied torque. Similarly, the modeling also suggested that axle housing underwent into elastic deformation stage after 23,000 Nm of applied torque. Since analytical and simulated values showed an elastic failure of housing in the range of 20,000–23,000 Nm. The torque application was limited to 18,000 Nm.

Experimental testing on the Test Rig has been presented in Fig. 4. A continuous loading force was applied up to 13,429 N with an arm length of about 1.5 m for maximum torque value of 20,144 Nm. The loading was stopped intentionally after reaching the set limit. The beginning of the curve showed some system adjustment of the system while application of the initial load. The torque returns to its initial loading condition after releasing the load, confirming the house in elastic limit. However, there was no sign of axle housing fractured up to 13,429 N which reflect that housing absorbed forces under elastic limit. The axle housing was expected to function appropriately in the elastic deformation stage, and the operator is safe as long as the axle housing does not go into the plastic deformation stage.

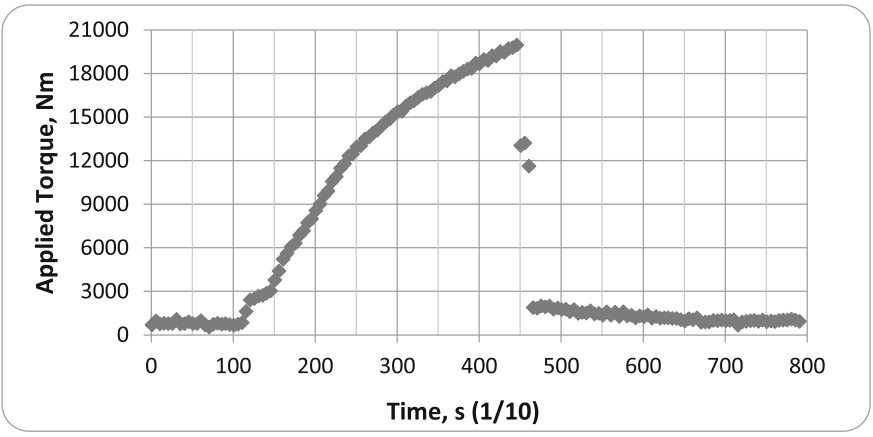

Fig. 4 Applied twisting force on selected axle housing

4 Conclusions

Analyzing the UMF design was complex in view of the chassis restraint conditions such as, fastening technique, material properties and loading conditions. However, theoretical analysis of the UMF was done by static analysis using Generative Structural Analysis workbench of CATIA_V5 (R19), both the provisions of the UMF were analyzed separately. In actual condition of ROPS retrofitting on rear tractor axle housing, two similar UMF are to be fitted. Both sides of the axle housing are expected to bear equal amount of load during rearward overturning [12]. Therefore, considering symmetry of the loading on the axle housing one side of tractor axle housing with UMF was analyzed. The results were first discussed for loading on each plate and then for the complete UMF assembly. The crucial factor during the software simulation was the mesh size and element type. Model with finer mesh densities resulted in more accurate results.

Acknowledgments The authors are grateful to ICAR, New Delhi for funding the project.

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Research on the Effect of Body Height on Zonal Spring Mattress Design

Yuding Zhu, Xiaochun Zhang, Liming Shen and Fei Fang

Abstract This study discussed the spinal alignment and lying comfort for the subjects within different height ranges when lying on zonal spring mattresses by indentation measurement and body pressure distribution measurement. Nine healthy female subjects were instructed to lay on three kinds of zonal spring mattresses. The height ranges of subjects were from 150 to 170 cm. The results indicated that the ratio of back to buttock sinkage of different height subjects laying on mattresses is in the range of 0.6 to 0.8, the distance of waist and back of different height subjects laying on mattresses is 20–30 mm. Height difference on mattress sinkage of three kinds of five zonal spring mattresses has no significant effect. Tall subjects got better pressure distribution on the mattress with more length in back zone and short subjects on the mattress with less length in buttock zone. It's a matter with height of subjects.

Keywords Height difference · Zonal spring mattress · Spinal curve · Body pressure distribution

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1 Introduction

The third part of the life we spend sleeping, sleeping is the important part of our human life, so a comfortable mattress is very necessary. Zonal spring mattress is that the elasticity of each zone is precisely calculated according to the weight of each body part, according with the dimension of every body part and biomechanical characteristics, making the mattress to match with body shape. Li-ming [1] we are all different sizes and shapes, and each zone of spring mattress corresponding to human body part are all different, so we think that it is necessary to research on the effect of body height on zonal spring mattress design.

As to sleep comfort, mattress firmness is very important to reduce or prevent pain and stress. Some experts think the spine support is the most important factor affecting sleep quality. Burman et al. [2] used interface pressure to determine relative differences in support surface performance between a patient's skin and the support surface. Frederick Shelton et al. defined pressure index (Pindex) derived from an analytical equation used to evaluate the average interface pressure, the peak pressure, the magnitude of the peak pressure, and the number of peak pressures on the entire body [3]. Peter Buckle and Avalino Fernandes used body contact pressure and subjective ratings of comfort to find no significant differences were found between mattress types. Analysis of body contact pressures (measured at the shoulder, elbow, buttock, knee and ankle) found few significant differences between experimental conditions. No significant associations were found between comfort ratings and peak body contact pressures [4]. Lahm and Iaizzo [5] conducted comfort research on three mattresses in different firmness and the results showed that the mattress firmness had no significant effect on subjects' EMG, heart rate and subjective comfort, but had a larger effect on spine alignment.

Haex et al. [6] developed the finite element model of a mattress to predict the curvature of an individual's vertebral column when lying on it. Measurements are made and compared to the predicted results to adjust and to refine the model. By considering body contact pressure and subjective ratings of comfort, Buck et al. analyzed body contact pressures (measured at the shoulder, elbow, buttock, knee and ankle) and found no significant differences between experimental conditions such as mattress types [7].

Based on the approximate anthropometric model, Inhyuk et al. presented an air-cell mattress which could prevent bedsore and control pressure. The air mattress had eighteen cylindrical air cells made of porous material. The body was divided into four sections such as head, trunk, buttock and leg. The pressure of each section was independently calculated from the weight of each part based on the individual body height and weight and the approximate anthropometric model. The experimental results showed that the proposed air-cell mattress was effective in preventing pressure ulcer [8].

Yosuke studied the relations buttock between sleep posture and sleep comfort. Pocket spring mattress can be divided into four regions: the head, chest, waist and legs. The results showed that The chest area soft (spring wire diameter 1.9 mm), the

waist area hard (spring wire diameter 2.1 mm), the spine form is posture S spinal form type, good sleep comfort; the chest area hard (spring wire diameter 2.1 mm), the waist area soft (spring wire diameter 1.9 mm), spinal shape with flat back standing or concave back spine form similar posture, bad sleeping comfort [9].

In this study, we studied the effect of height difference on sleeping comfort, through tested the methods of mattress sinkage measurement and body pressure distribution, and analyzed spine form and body pressure distribution index, to provide theoretical basis for the personalized design of zonal spring mattress.

2 Materials and Methods

The subjects consisted of a sample of healthy tall women (n = 3), medium women (n = 3) and short women (n = 3) who were all students from Nanjing Forestry University, aged from twenty to thirty. The mean body height of tall women subjects were 166.7 cm (SD = 0.6, the range of 166–170 cm), The mean body height of medium women subjects were 160.3 cm (SD = 2.3, the range of 156-165 cm), The mean body height of short women subjects were 154.7 cm (SD = 0.6, the range of 151–155 cm). The subjects wore the same clothes, with no belts, buttons and similar adornment.

Experimental mattresses were three kinds of five zonal spring mattresses. The five zonal spring mattress was subdivided into five zones such as head, back, waist, buttock and leg. The research shows the soft mattress had the lowest peak pressures in the buttocks zone. The medium mattress had the lowest peak pressure in the shoulder zone. Zhu et al. [10] Pocket spring module parameters [11] were ② (1.8 65 5), ③ (2.0 65 6), ④ (2.0 65 5), ⑤ (2.2 65 6) and ⑥ (2.2 65 5); Common sponge was thirty millimeter thick; its density was 20 kg/m3, and composite fabric. the height of everybody is different,the length of body regions is different, so the corresponding length of each zone of five zonal spring mattress is also different. Therefore, the length of each zone of five zonal spring mattresses are designed as shown in Table 1. The buttock zone length of mattressIis shorter than The buttock zone length of mattress II, and The buttock zone length of mattress III is longer than The buttock zone length of mattress II.

Table 1 The mattress size and elasticity of five zonal spring mattresses

	Mattress number	Head	Back	Waist	Buttock	Leg
Mattress size	Mattress I	390 mm	260 mm	195 mm	325 mm	780 mm
	Mattress II	390 mm	260 mm	195 mm	390 mm	715 mm
	Mattress III	390 mm	325 mm	195 mm	390 mm	650 mm
Mattress elasticity	Mattress I Mattress II Mattress III	④	③	⑥	②	⑤

Mattress sinkage measurement was done by use of spine alignment sinkage measurement system developed in our own laboratory. Taking the zonal spring mattress as the tested object, when subjects were lying on the mattress, with the spine alignment corresponding to the straight benchmark line, the extension of the benchmark on measurement points could be measured before and after subjects lying on the mattress. The sinkage of mattress measurement points was calculated and spine alignment was depicted when subjects were in lying position. According to the shoulder and back sinkages, waist and buttock sinkages and horizontal distance, the back and waist clearance was calculated to reflect spine alignment in lying position.

The back and waist clearance was the vertical distance from the higher point on the back and waist to the tangent line of the lower points on the shoulder, back and buttock. It could be calculated by the following equation

$$S = \frac{1\left(h' - \frac{h \times l'}{l + l'}\right)}{\sqrt{1^2 + \left(h - \frac{h \times l'}{l + l'}\right)^2}} \tag{1}$$

In the equation, h stands for the sinkage difference of the lowest points between shoulder, back and buttock; h′ stands for the sinkage difference between the highest points on the waist and the lowest point on the buttock; l stands for the horizontal distance between the lowest points on shoulder and back and the highest point on the waist; l′ stands for the horizontal distance between the highest points on waist and back and the lowest point on buttock; S stands for vertical distance from the higher points on the back and waist to the tangent line of the lower points on the shoulder, back and buttock, namely the back and waist clearance, as shown in Fig. 1.

To quantitatively classify mattress sinkage distribution in lying positions, by measurement of the largest back and buttock sinkages, the largest sinkage ratio was calculated by the equation X = b/h. B and h respectively stands for the largest back and buttock sinkage, as Fig. 2 showed.

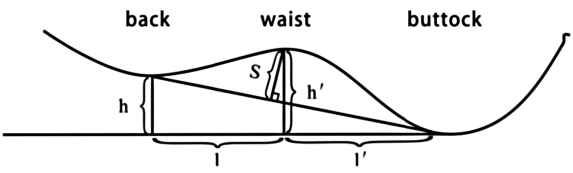

Fig. 1 The back and waist clearance

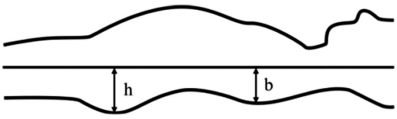

Fig. 2 The maximum back and buttock sinkage

The test employed the Body Pressure Measurement System made by Tekscan. When subjects were lying on the mattress, the pressure distribution on the head, shoulder and back, waist, buttock and legs and the total body were measured. The body pressure parameters included maximum pressure, mean pressure, contact area, pressure ratio and so on.

3 Results

When subjects were lying on a mattress, the test benchmark was corresponding to the human spine alignment. According to the mattress sinkage, the spinal curve was depicted, and that is the spine alignment in the supine position. It could be seen from Fig. 3 that, the sinkage of buttock is largest, and the the sinkage of waist is least. whether the subjects are tall, medium or short, the largest sinkages of back, the least sinkages of waist, and the largest sinkages of buttock of three kinds of five zonal spring mattresses are no significant different. The lying spinal curves of all height subjects laying on three kinds of five zonal spring mattresses are also no significant different. The results show that height difference on mattress sinkages of three kinds of five zonal spring mattresses has no significant effect.

The ratio of back to buttock sinkage reflected the spine alignment in lying position. When the ratio was bigger than 1, the spine alignment inclined to back area. The spine alignment inclined to buttock area when the ratio was smaller than 1. The ratio of back to buttock sinkage of all height subjects on the three kinds of spring mattresses is in the range of 0.6 to 0.8, which was consistent with the weight ratio of back and buttock. When standing, the gravity direction of the three parts is overlapped, and the distance of waist and back is 40–60 mm. But when in sleeping posture, the distance of waist and back is reduced to 20–30 mm, the direction is parallel [1]. It could be seen from Table 2 that, the distance of waist and back of all height subjects on the three kinds of spring mattresses is 20–30 mm, close to the natural state. The results show that the elasticity distribution of three kinds of five zonal spring mattresses are reasonable.

From the Table 3, we know that the interface area of tall subjects on mattress III is largest, and the interface area of tall subjects on mattress Ii s least. The peak pressure of tall subjects on mattress II is least, The peak pressure of tall subjects on mattress I is largest. The mean pressure of tall subjects on mattress III is least, the mean pressure of tall subjects on mattress I and mattress II are same. The interface area of medium subjects on mattress III is largest, the second is mattress II, the least is mattress I. the peak pressure of medium subjects is same to the interface of medium subjects, largest is mattress III, the second is mattress II, the least is mattress I. The mean pressure of medium subjects on mattress II is least, the mean pressure of tall subjects on mattress I and mattress III are same. The interface area of short subjects on mattress II is largest, and the interface area of short subjects on mattress I is least. The peak pressure of short subjects on mattress II is least, the peak pressure of short subjects on mattress III is largest. The mean pressure of short

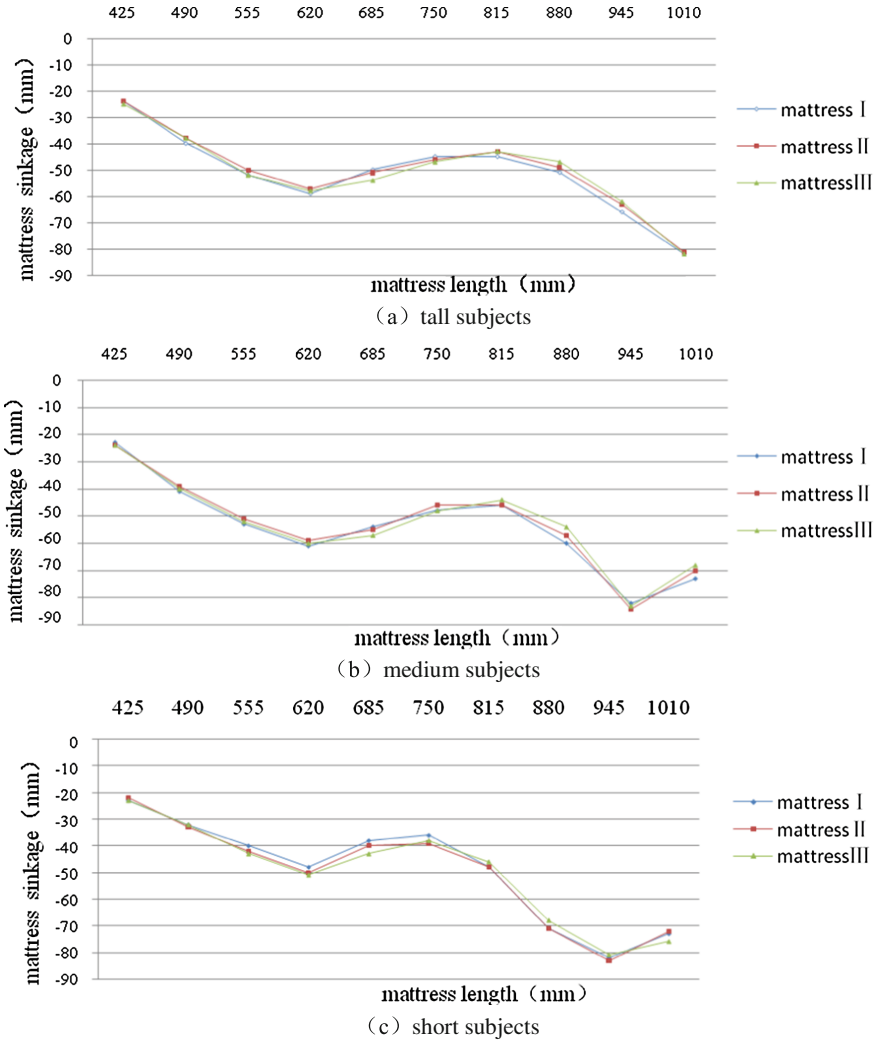

Fig. 3 Lying spinal curve of all height subjects **a** tall subjects, **b** medium subjects, **c** short subjects

subjects on mattress III is largest, the mean pressure of short subjects on mattress II is least.

Taking about the peak pressure, the mean pressure and the interface area, the mean pressure of tall subjects and medium subjects laying on three kinds of spring mattresses are no significant different, the mean pressure of short subjects laying on mattress II is least. The interface area of all height subjects laying on mattress I is least, and The peak pressure of all height subjects laying on mattress I is largest. Therefore, the body pressure distribution of tall subjects laying on mattress III and

Table 2 Sinkage ratio of back to buttock and distance of waist and back of all height subjects

Subjects	Mattress number	Ratio of back to buttock sinkage (%)		Distance of waist and back (mm)	
		Mean	SD(N = 3)	Mean	SD(N = 3)
Tall subjects	Mattress I	65.6	9.0	26.4	1.38
	Mattress II	63.2	10.1	27.9	0.05
	Mattress III	64.7	8.5	25.7	1.79
Medium subjects	Mattress I	71.1	4.6	23.5	1.43
	Mattress II	69.1	1.65	23.2	2.18
	Mattress III	70.4	0.71	22.5	1.41
Short subjects	Mattress I	65.3	9.63	24.7	1.06
	Mattress II	66.1	8.86	25.5	1.46
	Mattress III	67.3	6.25	24.4	0.75

Table 3 Whole body pressure distribution index of all height subjects

Subjects	Mattress number	Interface area (cm^2)		Peak pressure (Kpa)		Mean pressure (Kpa)	
		Mean	SD (N = 3)	Mean	SD (N = 3)	Mean	SD (N = 3)
Tall subjects	Mattress I	3592.0	329.6	8.66	0.70	1.32	0.18
	Mattress II	3593.9	379.5	7.99	0.52	1.32	0.09
	Mattress III	3600.3	359.5	8.20	0.20	1.31	0.07
Medium subjects	Mattress I	3788.4	286.0	10.82	5.53	1.25	0.04
	Mattress II	3922.0	393.1	10.83	4.22	1.24	0.02
	Mattress III	3982.3	209.7	11.17	4.81	1.25	0.01
Short subjects	Mattress I	3102.8	422.2	8.72	0.85	1.23	0.18
	Mattress II	3133.6	318.7	8.16	2.33	1.17	0.14
	Mattress III	3114.3	385.9	9.30	1.60	1.28	0.20

mattress III are more reasonable than the body pressure distribution mattress I. The body pressure distribution of medium subjects laying on mattress II are more reasonable than the body pressure distribution mattress I and mattress III. The body pressure distribution of tall subjects laying on mattress I and mattress II are more reasonable than the body pressure distribution mattress III.

4 Discussion

When different height subjects laying on mattress II, spinal curve from Fig. 4 and Table 2, the spine alignment of tall subjects laying on three kinds of five zonal spring mattresses are flat, and on the other subjects they are curve. The distance of the largest back sinking points and the least waist sinking points of tall subjects are

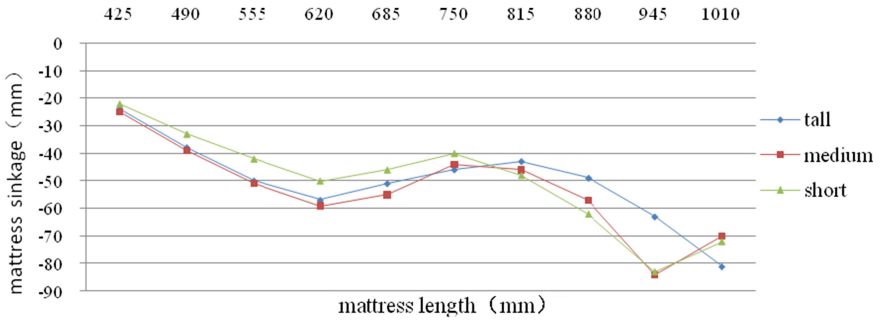

Fig. 4 Lying spinal curve on mattress II of all height subjects

larger than the distance of medium subjects and short subjects. The distance of the largest buttock sinking points and the least waist sinking points of tall subjects are larger than the distance of medium subjects and short subjects. The back sinkage of short subjects is least, the waist sinkage is also least, the buttock sinkage is largest. It's a matter with height of subjects. The ratio of back to buttock sinkage of medium subjects is largest, but the distance of waist and back is least. The ratio of back to buttock sinkage of tall subjects is least, but the distance of waist and back is largest. To some extent, the largest sinkages of back and buttock is large, the least sinkages of waist is also large, can lead the distance of waist and back to become less. the largest sinkages of back and buttock is little, the least sinkages of waist is also little, can lead the distance of waist and back to become larger. It's a matter with body shape of three kinds of height subjects (Fig. 5).

When subjects were lying in the supine position, the stress parts on the mattress were different and the pressure distribution of each body part was also different. It could be seen from Fig. 3 that, the mean pressure of back, waist and buttock of tall subjects laying on mattress III is least. The mean pressure of back and waist of

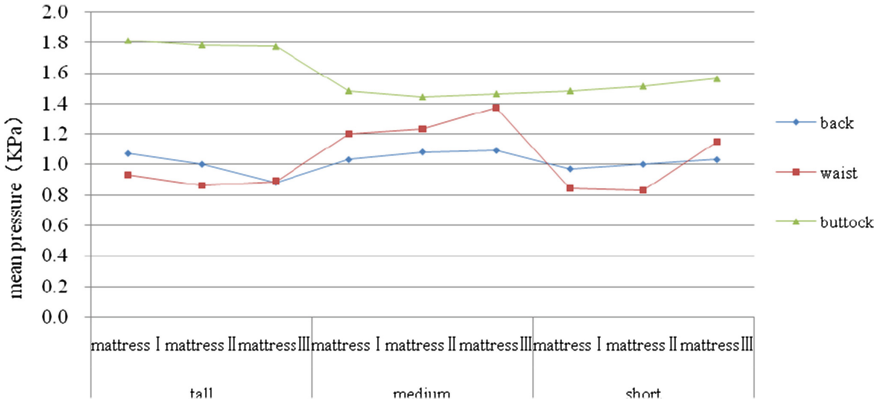

Fig. 5 Mean pressure of major body regions of all height subjects

medium subjects laying on mattress I is least, the mean pressure of buttock of medium subjects laying on mattress II is least. The mean pressure of back and buttock of short subjects laying on mattress I is least, the mean pressure of waist of short subjects laying on mattress II is least.

Taking about whole body pressure distribution index and partial body pressure distribution index, the body pressure distribution of tall subjects laying on mattress III is relatively reasonable, the body pressure distribution of medium subjects laying on mattress II is relatively reasonable, the body pressure distribution of short subjects laying on mattress I is relatively reasonable. This is because that the buttock length of mattress I is shorter, the buttock length of mattress III is longer, compared with mattress II. The elasticity of back zone and buttock zone are larger, leading to the interface area of mattress III is larger, the interface area of mattress I is less.

5 Conclusions

In this study, we studied the effect of height difference on sleeping comfort. Height difference on mattress sinkages of three kinds of five zonal spring mattresses has no significant effect. The distance of waist and back of all height subjects on the three kinds of spring mattresses is 20–30 mm, close to the natural state. These show that the elasticity distribution of three kinds of five zonal spring mattresses are relatively reasonable. The body pressure distribution of tall subjects laying on mattresses of the longer buttock region is relatively reasonable, the body pressure distribution of short subjects laying on mattresses of the short buttock region is relatively reasonable. It's a matter with height of subjects. Under the condition of certain zonal spring mattresses, if each zonal sizes of zonal spring mattress are different, the body pressure distribution index of subjects laying on these mattresses are different. Only when each zonal sizes of mattresses match with each part dimensions of human body,the body pressure distribution index on these mattresses are well, the comfort of these mattress are well.

Acknowledgments The authors are grateful to the subjects' participation in the study. This work was financially supported by Zhejiang agriculture forestry university talented person Initial project, "Research of Comfort and Design of Pocket Spring Mattresses" (2014FR040).

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Ergonomic Consideration for Wearable Device Design in Frozen Shoulder Rehabilitation

Huei-Huang Chen, Chien-Hsu Chen, Zheng-Yu Hoe and Zong-Xian Yin

Abstract This paper is regarding the wearable device design which is based on frozen shoulder game rehabilitation. At present some studies are focus on sensors and rehabilitation outcomes. However the sensors designed without a suitable wearable device and it will influence the sensed results and wear comfort. Thus, this article records the design process of the wearable device, particularly the worn ways and the fabric. The way in which wearable device are worn will be analyzed with the user experience to improve sensing accuracy and comfort. The material in which wearable device are used will be tested with making models. Then the models of the wearable devices are made and tested to find out the design factors which are suitable ergonomic.

Keywords Rehabilitation · Frozen shoulder · Wearable device

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1 Introduction

Frozen shoulder or adhesive capsulitis is a disease affecting patients mainly on people aged from 40 to 60 years old [1]. It is an extremely painful and debilitating condition leading to stiffness and disability due to the soft tissue in the joint of fibrosing and adhesions [2]. In general, the longer the stiffness stage lasts the longer is the recovery stage stays [3].

Currently, the treatment ways of the frozen shoulder have physical therapy, intra-articular, steroid injection, intra-articular sodium hyaluronate, oral steroid therapy, and acupuncture [2]. According to Bo J. Lundberg [1] research, adjuvant therapy consisting of intensive physiotherapy by promoting regeneration of the synovial tissue appears that the affected area return to normal state [1]. Hence the main treatment combined with rehabilitation exercise will get better and faster healing influences.

However the long time and single rehabilitation exercise makes patients feel boring, tedious and painful. That is why the frequency of motion will become less and less. At present, some research teams began to develop the game-based rehabilitation exercise. Recently, some literature studies the virtual reality game-based treatment system on the wall and made each training step adjustable based on the patient's physical condition [4]. Yeh, Lee and Fan did a similar experiment in 2014. They used virtual reality to combine with motion tracking to develop interactive shoulder joint rehabilitation system [5]. In 2010, some researchers combine hardware shoulder wheel with software game to made the game system for shoulder rehabilitation [6]. Other researchers designed a set of sensors which consists of wearable wireless sensor network (WSN), inertial sensor nodes, and sticky sensors on the arm to the measure the bodily motions and prove that the devices were feasible and that the proposed model was accurate [7].

The game rehabilitation is installed sensors in patient's arms and sense the arm range of activities. Patients only need to play the game that can achieve the rehabilitation influences. This way can encourage patients not only regular ongoing rehabilitation but also the activities ranges are increased than other patients who didn't use game rehabilitation [4].

However, game rehabilitation needs to fixed the sensors on the arm, conform the arm exercise, changing in muscle and sweat. Therefore it is necessary to design a wearable device which is comfortable and can be wearing for a long time for patients. But in related studies of game rehabilitation it showed that the sensors are only fixed on the arm by tape. The device needs to the alignment the arm position, so this fixation way is waste times, reduce measurement accuracy and user comfort. Therefore, this article would be to design the wearable device to improve the status of sensors placed. The way in which wearable device are worn is analyzed with user experience and the model is made with human factors.

2 Design and Implement

In this part, the wearable devices are analyzed three wearing ways on the arm according to the user experience. One is bunched like sphygmomanometer, another is encased like sleeves, and the other is combined wearing ways like sphygmomanometer and sleeves. In the refine part, the reproduction model has combined the advantage of first part models to outputs the wearable device to satisfy design requirements.

2.1 Material Selection

The clothes we wear every day are made of different property fabrics. It is because people are more able to accept the fabric. If the material wearable device is more skin-friendly and easy perspiration then the wearable device can be worn longer when doing rehabilitation. And good elasticity fabric makes wearable device suitable for most people's arm size. Hence the fabric is chosen for the main material of wearable device and focus on an elastic fabric which is easy to buy. Many kinds of fabrics have their own characteristic, according to the needs of the experiment to select four kinds of fabrics with different elasticity and thickness. They are space cloth, sandwich mesh, Lycra, and cotton viscose fabric, as shown in Fig. 1. Moreover, square up the wearable body will combine with the electronic parts, so

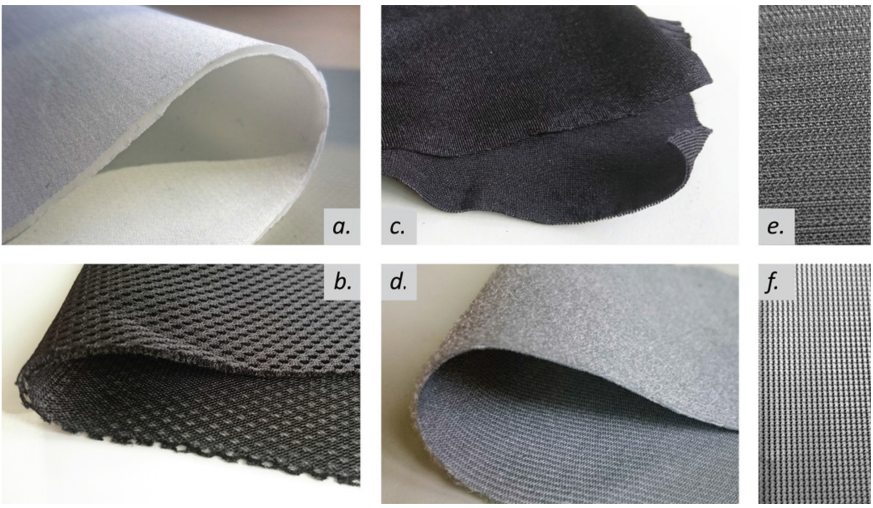

Fig. 1 **a** Space cloth, **b** Sandwich mesh, **c** Lycra, **d** Cotton viscose fabric, **e** General Velcro (*A side*) and f. meticulous Velcro (*A side*)

we use Velcro as a binding medium. The Velcro B side which is hairy will use flexible cotton viscose fabric on modeling and the already-made plastic buckles are used on the local details.

2.2 Design Constraints

The wearable device can divide into two parts which is bonded the two parts together by the Velcro. One is electronic components; the other is a main body of the wearable device. The electronic components are included the sensors installed in the upper arm and forearm, Bluetooth, battery and the main panel and wrapped by insulating fabrics and meticulous Velcro.

The main body of the wearable device can wear intuitively by aligning portion hollowed at elbow joint prominent place. And the fabric of the wearable device will be folded when the arm is bent, to solve this situation that the main body of the wearable device has a large area of hollowed out at the elbow bend. The hollowing out of the area is calculated by the arm and forearm contact with each other, as shown in Figs. (2) and 3.

2.3 Ideation

The models 1–1 to 1–3 are used the bunch operation like sphygmomanometer as a basis for model design, as shown in Fig. 4. The model 1–1 uses space cloth, 1–2 is used space cloth at the junction and the bunch places are wide elastic ropes, and 1–3 is sandwich mesh.

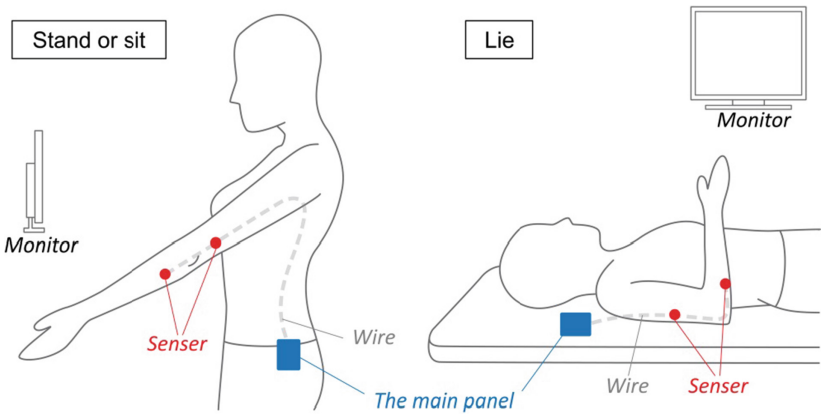

Fig. 2 The basic position of related electronic components when patients are lying, standing or sitting rehabilitation

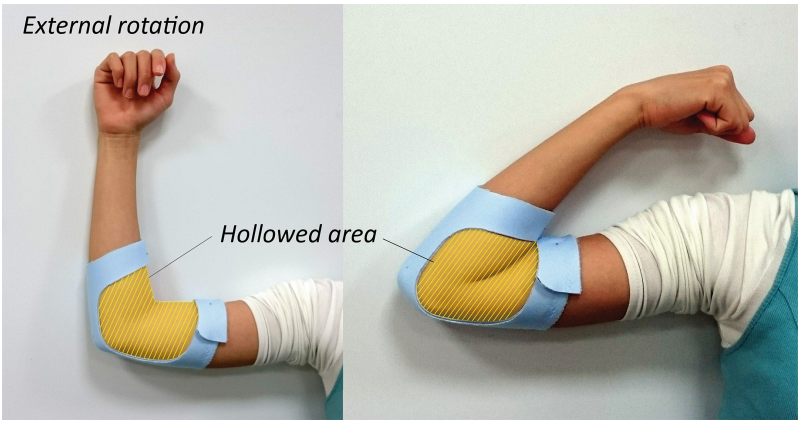

Fig. 3 The shaded area is hollowed area. The starting point for defining the area of hollowed is after contact with the arm that the intersection point

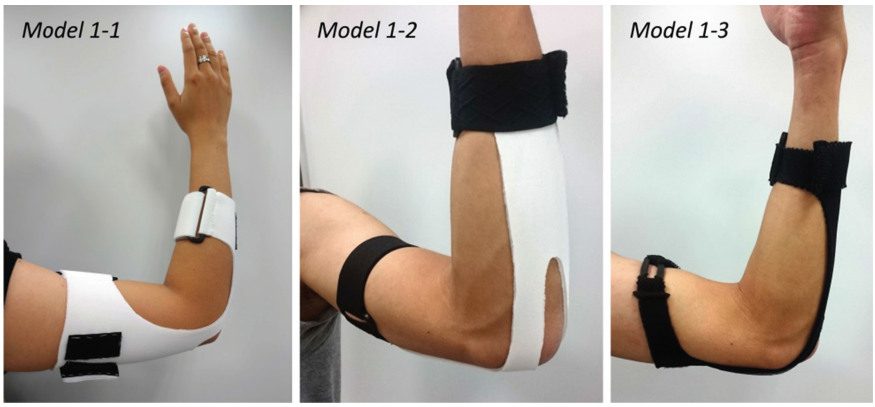

Fig. 4 Model 1–1 to 1–3 showed the wear way in which is bunch

The models 1–4 to 1–6 are used the sleeve encase operation as a basis for model design, as shown in Fig. 4. The models 1–4 and 1–5 both use space cloth and the upper arm are used Velcro. The model 1–4 is designed by referencing the styrofoam net structure. That the geometric holes can breakthrough existing elastic to suitable for more human arm size. The model 1–5 is opened two holes at wrist position of the radius and ulna and used Velcro tied the wrist tightly. The model 1–6 is the same as the model 1–5 but the difference is used double sandwich mesh. And the wrist didn't use Velcro (Figs. 5 and 6).

The models 1–7 to 1–9 are combined the action bunch with encasing as a basis for model design and try to combine different fabrics. In the fabric, the model 1–7 is space cloth, the model 1–8 is cotton viscose fabric and the model 1–9 is the inner uses space cloth and outer uses sandwich mesh.

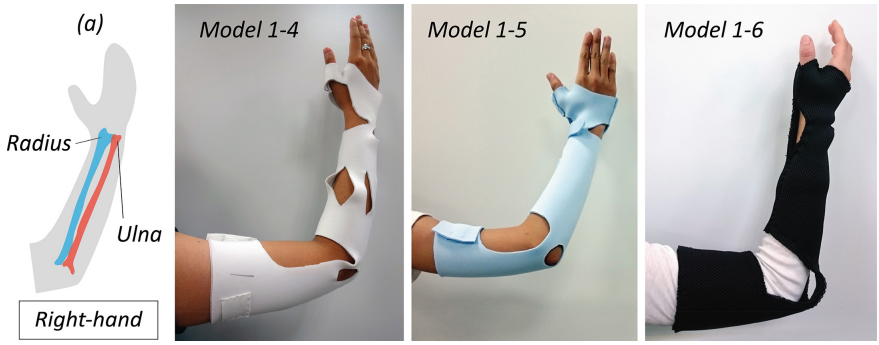

Fig. 5 Model 1–4 to 1–6 is wear by encasing. Fig **a** show the position of ulna and radius

Fig. 6 Models 1–7 to 1–9 have the similar appearance. But the different fabric characteristics can be observed clearly

2.4 Testing

Participants. After models were produced, the models were tested by 6 participants (3 female and male). The problems of models will be discussed with activity and feedback from the participants. And the discussion is the focus on subjective topics of comfort and intuitive. The Table 1 records the body information from participants and Fig. 7 show the measurement range.

The Wearing Results. In fabrics testing result, the space cotton has good elasticity and no directivity, the material is also skin-friendly. The sandwich mesh didn't have good elasticity than space cloth because the elasticity has one directivity. And the structure is fluffy, semi-translucent and larger pores so it could breathable wicking.

The thickness is recorded when the models combined with different fabrics, as show in Table 2. When the fabrics thickness is more than 3 mm then participants

Table 1 The body information is measure participants right-hand

Number	1	2	3	4	5	6
Gender	Female	Female	Female	Male	Male	Male
①Arm length	59.0	59.8	55.7	70.5	64.0	67.2
②Forearm length	32.7	33.5	28.7	36.0	33.5	34.5
③Upper arm diameter	23.0	25.0	19.2	31.1	30.8	28.5
④Forearm diameter	21.4	21.1	17.5	27.3	23.4	25.0
⑤Wrist diameter	14.7	14.8	13.8	16.4	16.4	17.4

Unit cm

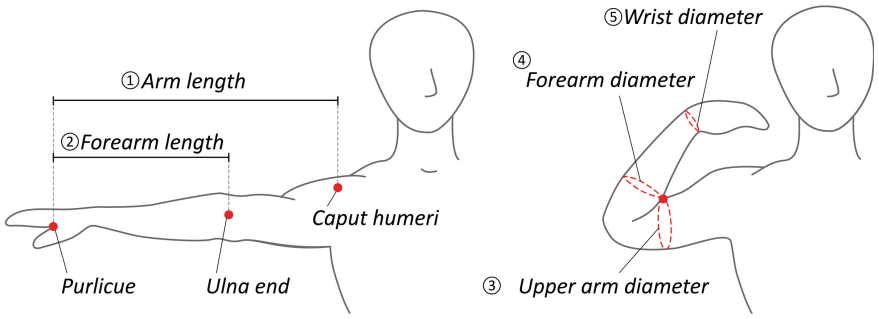

Fig. 7 Define of the measurement range

Table 2 This is used fabric thickness

Sequence	Fabric name	Thickness
1	Space cloth combine with sandwich mesh	5 mm up
2	Sandwich mesh combine with cotton viscose fabric	3 mm up
3	Sandwich mesh	3 mm
4	Space cloth	2 mm
5	Cotton viscose fabric	1 mm
6	Lycra	0.5 mm

will feel uncomfortable. Relatively, the participants have the less obvious feeling when the thin fabrics are piled up. In fabrics skin-friendly, according the participants feedback the degree of skin-friendly fabric that space cloth is best, Lycra is second and sandwich mesh and cotton viscose fabric are third.

In participant feedbacks, the buckle will be pulled to the wrong position and which is the same problem in models 1–1 to 1–3. Two reasons were found after observation and discussion, one is elastic strips, the other is tension strips of model can be made parallel. Because human arm is conical, not columnar then the model must be made radian, as show in Fig. 8.

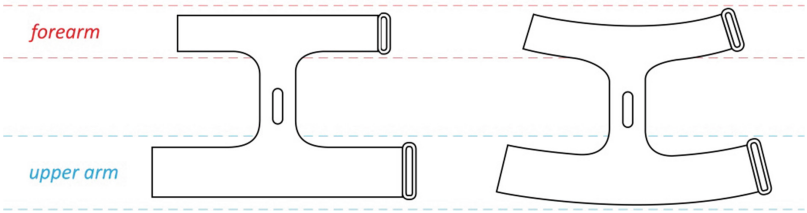

Fig. 8 Here are template models of tension strips and it needs to designs by arms radian and perimeter

The participant's wrong wearing is the biggest deficiency at model 1–1 to 1–3. Especially the users are middle-aged if the wearable device is wrong wearing, it will influence the sensor accuracy and wires. So the wearable device design must to be more intuitive to reduce wrong wearing.

The most intuitive and stability in this ideation is the model 1–7 but it has some defects that the finger easy wears the wrong hole. And the wear range of model is not enough for participant 3 who has thin arm.

3 Refine

The refine model is integrated the experience of previous models. The refine model used two layers of fabrics, the inner is space cloth and the outer is cotton viscose fabric. In the appearance, the way in which wearable device is worn combine the sleeves and the sphygmomanometer. And try to open a big hole at wrist near the ulna and fill up by Lycra which is thin and high-elasticity. The large area at the radius uses Lycra and try to fit different arm size. The model have comfortable and tight effect for patients. The tension strips use the less elastic cotton viscose fabric and use belt loop on the tension strips through the path. To make sure the path always is stable, the model as shown in Fig. 9.

Fig. 9 Model 2 the performance in a different situation

Fig. 10 **a** When the model is flat, the Lycra at the wrist is concave. **b** Elastic Lycra made hand through smoothly. **c** After through the Lycra, the model is restored and fit the wrist

The performance of the final model can find many details are modified from the part 1 models. The refine model forearm part can accept the arm size from participant 3 to participant 4. The Lycra at radius made the telescopic range raised to about 10 cm at the forearm circumference. Moreover to solve the situation of worn wrong, it only opens two holes for fingers. The initial holes both used Lycra to replace. The achievements display the Lycra is tensioned when sewing at the radius, it can create a concave space. This space only makes the model can fit the wrist but also let the fingers will not wear wrong, as shown in Fig. 10.

4 Discussion and Conclusions

This research analyzes the problems in hand wearable device design and studied the relationship between the wearable device of frozen shoulder rehabilitation and Ergonomic. The model accord with objectives of Ergonomic would be such things as increased convenience of use, reduced errors, and increase productivity. This paper also tested the fabrics and observed the changes when the wearable device mobile with implement and wear. After model testing, all models were amended to make the final result which can correspond the goal of human factors and usability. Let frozen shoulder patients can wear longer and move longer when they are playing the rehabilitation game.

Here has more discussion between result of research and goal of Ergonomic. On safety considerations, the model appearance has three difference kind of design. One is the bunch model, another is the sleeve model, the other is combine bunch and sleeve model and each model has advantages and disadvantages. The bunch models have simple appearance design and low production costs. But the simple appearance is not intuitive enough to wear, and easily wear in wrong way or upside down. The sleeve models have higher production costs since the large area covered. And the sleeve models are more intuitive than the bunch models. The intuitive wearable device will be chosen because it can reduce the chances of wear wrong. The models combine bunch and sleeve also have higher production costs, but fit effect is all the best.

On efficiency considerations, if the wearable device can fit to arm that the data will be sense accurately. In models testing, the bunch models and the models combine bunch and sleeve display the result in which can be suitable for patient's arm. Because of the movement "bunch", those models can be nestled up with the skin. "Bunch" this movement also spend less time when we want to tie tight something.

On comfort considerations, material selection is an important issue for comfort. In the result of fabric testing, first try to use a single fabric stitch with two or more fabrics. One thing should be noted that sandwich mesh and cotton viscose fabric both have rough surface and this causes of poor comfort. And the fabric construction and the wear manner will influence comfort [8]. Therefore designer must understand the structure and properties of the fabric which the wearable devices are made by the fabric, so that they can properly apply the material to the appropriate position. In the elasticity testing that Lycra is first, space cloth is second and sandwich mesh and cotton viscose fabric are third. In fabrics elasticity directional, Lycra and space cloth were sew together and have non-directional restriction. And there are single directivity restriction that sandwich mesh and cotton viscose fabric were sew together.

After fabric testing, we found that the whole model could not make with single fabric. Hence, refine model additional used Lycra at more elastic demand portion. In the two fabrics stitch, the elastic will limit by sandwich mesh in combination with the sandwich mesh and space cloth, and the fabric thickness are quite thick have protective effect. The elastic will limit by cotton viscose fabric in combination with the space cloth and cotton viscose fabric. Equal two of fabrics were sewn that can reference poor elastic one. So that the fabrics are combined need to consider the material of permeability, hardness and tension.

In appearance model design, some ideation were failed after testing. But fail result still can modify partial model for next design. For instance, the model 1–4 that the model of the forearm is similar with Styrofoam net had been opened some big holes. After model 1–4 tested, open smaller holes and increase more holes are suggested. Because the fabrics indeed can improve the flexibility after cut the holes. This direction is testable in the future design.

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Ergonomic Keyboard Layout Designed for the Filipino Language

Jose Miguel R. Salvo, Christian Jay B. Raagas, Maria Tatjana Claudeene M. Medina and Alyssa Jean A. Portus

Abstract The Philippines is a developing country and computers have become an essential component in everyday activities. However, prolonged exposure to keyboard typing may result to Repetitive Strain Injury. In this study, a keyboard layout was designed and generated specifically for the Filipino language using Carpalx. Applying its typing effort model, the model parameters were determined by acquiring language data from a Filipino corpus of 10 million words and by gathering finger strength. Quantitative comparative analyses were performed to assess the efficiency of the generated layouts in comparison with other existing keyboards. Results showed a decrease in total typing effort and suggest that a layout designed for the Filipino language may be developed that will be more fitting than the existing QWERTY. Usability testing may be performed to further justify the results of this study.

Keywords Carpalx · Ergonomics · Keyboard · Typing effort · Filipino

1 Introduction

1.1 Statement of the Problem

QWERTY is not an ergonomic keyboard layout [1]. Repetitive and sustained usage of such a keyboard may lead to pain, injury, or in the long run—disability [2]. Alternate keyboard layout ergonomically designed for the Filipino language has yet to be developed.

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1.2 Significance of the Study

Implementation of the developed ergonomic Filipino keyboard layout may reduce risk of Repetitive Strain Injury (RSI) and other ergonomic injuries [3]. This will benefit not only for those who work in the Filipino newspaper industry but as well as daily computer users.

1.3 Scope and Limitations

This study is limited only to rearranging the 26 letters of the alphabet. The study also assumes conventional typing technique and hand placement.

2 Methodology

2.1 Overview of the Methodology

This study designed an ergonomic keyboard layout for the Filipino language by gathering language data of around 10.7 million Filipino words and finger strength data of 124 Filipinos, measuring key distances on a Macbook Pro keyboard, and using these as inputs to Carpalx, an open sourced keyboard layout optimizer. A heuristic method for generating better keyboard layouts was also developed and used. The diagram below illustrates the interaction of the different components used in this study (Fig. 1).

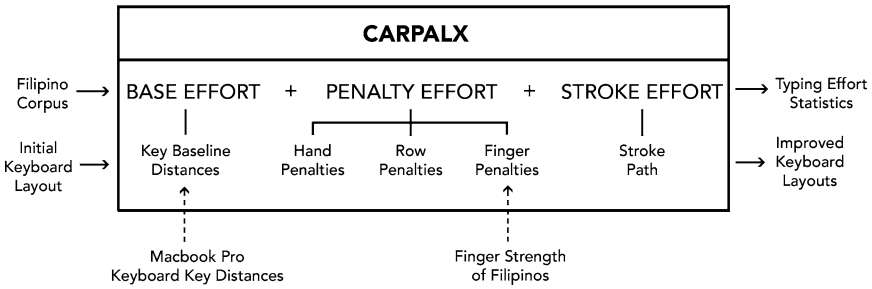

Fig. 1 System diagram of the methodology, including the subsystem of Carpalx and its typing effort model. The figure illustrates the necessary inputs for the different components of Carpalx and the corresponding outputs of the program

2.2 Finger Strength Data

Initial data gathering was conducted on 30 respondents with ages ranging from 16 to 36 years old. Respondents were asked to sit in upright position, with their wrists resting on a flat surface. A pinch gauge was placed within each finger's reach. The respondents were asked to exert maximum pressure on the device.

The following statistical formula was used to determine the total number of respondents to be surveyed.

$$n = \left(\frac{t_{\alpha/2,v} * s}{k\bar{x}}\right)^2. \quad (1)$$

where

t t-value, at alpha = 0.05,
s standard deviation,
k allowable error,
$\bar{x}$ mean (average) finger strength,
v initial sample *n-1*

A minimum number of 123 respondents was required to keep the allowable error within 8 %. A total of 124 samples were gathered. The following table summarizes the finger strength data gathered (Table 1):

2.3 Language Data

A Filipino corpus of approximately 10.7 million words was obtained [5]. The corpus was parsed into triads and a total of 12644 unique triads, groups of three consecutive letters, were tallied.

2.4 Carpalx

Carpalx is an open sourced keyboard layout optimizer which computes for the perceived typing effort of typing a corpus using a keyboard layout and optimizes the layout using simulated annealing [4]. Given certain parameters, a corpus, and an initial keyboard layout, the program computes for the typing effort associated to the layout and then generates a more ergonomic keyboard layout [4].

Table 1 Average finger strength of Filipinos measured in pounds (lbs)

	Left hand	Right hand
Pinky	3.77	4.27
Ring	4.54	5.08
Middle	5.65	6.37
Index	6.09	6.57
Thumb	–	–

2.5 Typing Effort Model

Carpalx works by parsing the corpus into triads, computing for each triad's effort using its typing effort model, and then computes for the typing effort of the keyboard as the average triad effort for all triads. The typing effort model is based on the attributes inherent in each key location on the keyboard. This means that each triad location on the keyboard (e.g. location of letters *qaz*) has a constant effort. The program then places letters in each location such that the effort is minimized. For example, if triad location *qaz* has a high effort, the program would assign less frequently used letters in those key locations so as to minimize the typing effort.

The typing effort model of Carpalx takes into account three main factors, namely: baseline effort, penalty effort, and stroke effort. The following paragraphs summarize the model. A more detailed explanation and the exact equations used may be found at the Carpalx website [4].

The base effort component takes into account the physical distance travelled by the fingers to reach the different keys. The base effort of a key is the physical distance travelled by a finger assigned to the key to reach that key from the finger's default position according to the conventional typing technique as seen in Appendix A. 1. The following figure illustrates the baseline distances for each key, measured from a Macbook Pro keyboard (Fig. 2):

The penalty effort component takes into account penalties incurred from using a particular hand, reaching for a particular row, and using a particular finger. The parameters of the program may be modified to assign appropriate penalties.

The finger strength data gathered was translated into penalties to favor the use of stronger fingers. The use of either hand was not penalized since the effect of difference in hand strength is already captured in the finger strength data. The default row penalties used in Carpalx were adopted, with a higher penalty for reaching for the bottom row of the keyboard.

Finally, the stroke path effort component considers that some triads are more difficult to type than other triads because of the stroke. It assigns effort for different types of strokes, considering different hand, row, and finger alternation patterns.

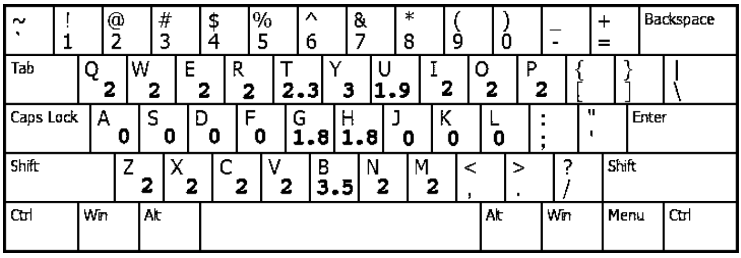

Fig. 2 Baseline distances (in cm) for each key, measured from a Macbook Pro keyboard. Distances are measured from the center to center of keys. Distances are between the default key location of the finger and the destination key

For hand alternation, the model favors the use of both hands as opposed to the use of a single hand. For row alternation, the model favors strokes with letters that are on the same row (e.g. typing *ert*) and assigns high effort for strokes which follow a non-monotonic progression (e.g. typing *abe*). Lastly, for finger alternation, the model favors strokes which use different fingers with a monotonic progression (e.g. typing *asd*) and assigns high effort for strokes which entail the use of the same finger for typing different keys (e.g. typing *tfb*). These stroke factors contribute to the total stroke path effort for each triad.

2.6 Heuristic Method

Since the Carpalx typing effort model works in such a way that each triad location on the keyboard has a constant effort, this study was able develop and use a heuristic method to generate better keyboard layouts.

The heuristic method assigns the most frequent triads to feasible triad locations with lowest efforts. A keyboard variant placing frequently used letters for shortcuts, *Z*, *X*, *C* and *V* fixed was also generated.

The most frequent triad in the Filipino corpus is *ang*. However, it could not be assigned to the location with the least typing effort *jjj* since the triad is a combination of three different letters and only one letter could be assigned per key location. This means that the triad *ang* can only be assigned to locations with the same pattern. Since the location *jfd* is the next feasible location to place the triad *ang*, each letter was assigned respectively. Correspondingly, the second most frequent triad *ala* was assigned to triad location *jgj*, which means that letter *l* was assigned to keyboard location *g*. The same algorithm was performed until all letters were assigned a location on the keyboard.

2.7 Carpalx Improvement

The QWERTY and all keyboard layouts generated from the heuristic method were used as input keyboards in Carpalx and were further improved.

3 Results and Discussion

Two keyboard layouts were developed using the heuristic method, one with the letters *Z, X, C,* and *V* fixed, and another with all the keys rearranged. Carpalx improvement yielded four more keyboard layouts. The layouts can be seen in Appendix B.1–6. Effort statistics for different keyboard layouts are summarized in the following figure (Fig. 3).

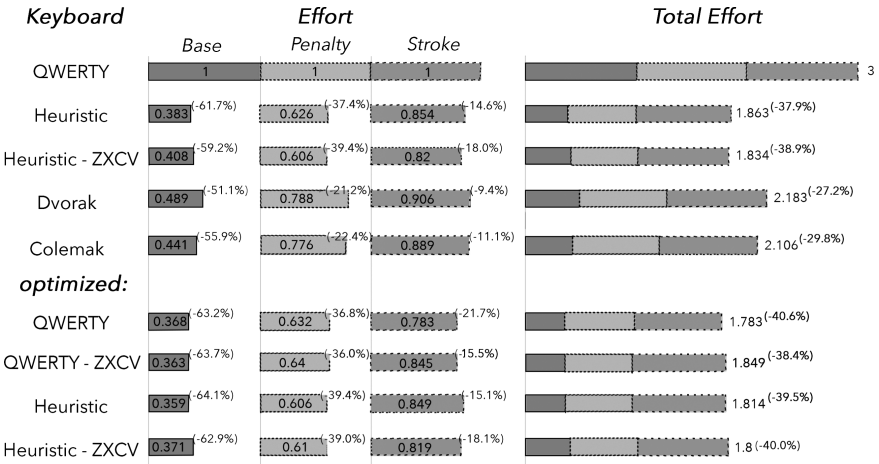

Fig. 3 Carpalx effort component analysis of each keyboard. The values for each effort component are shown. Percent decrease of total effort and for each effort component relative to the QWERTY keyboard are also displayed in parenthesis

Optimized QWERTY yielded the least effort. Row use for each keyboard is summarized in the following table, Table 2:

The developed keyboards yielded increased use of the home row and decreased use of the bottom row. Finger use for each layout is also summarized in the following (Table 3):

Finger use for the developed keyboards was mostly concentrated on the index and middle fingers, compared to the QWERTY layout which made frequent use of the left pinky. This reduces the strain for weaker fingers by allowing stronger fingers to shoulder most of the typing.

Table 2 Relative row use in percentages for each keyboard

Keyboard	Top row	Home row	Bottom row
QWERTY	31.7	48.2	20.1
Heuristic	22.1	73.8	4.1
Heuristic—ZXCV	24.8	73.8	1.3
Dvorak	22.0	67.5	10.6
Colemak	23.1	66.8	10.1
Optimized:			
QWERTY	21.5	74.7	3.8
QWERTY—ZXCV	25.4	72.4	2.1
Heuristic	25.1	73.6	1.3
Heuristic—ZXCV	24.6	74.1	1.3

Table 3 Relative finger use in percentages for each keyboard

	Left hand			Right hand				
Keyboard	Pinky	Ring	Middle	Index	Index	Middle	Ring	Pinky
QWERTY	23.1	5.9	4.8	18.2	24.7	11.8	8.4	3.1
Heuristic	5.9	5.3	11.1	25.8	29.7	11.2	8.9	2.2
Heuristic—ZXCV	5.9	5.2	11.7	22.9	31.1	11.2	8.9	3.0
Dvorak	23.0	4.3	2.3	20.8	18.5	6.2	15.8	9.1
Colemak	23.1	3.3	5.8	20.6	26.4	5.2	11.2	4.3
Optimized:								
QWERTY	8.9	7.4	15.7	15.4	15.1	25.1	10.6	1.8
QWERTY—ZXCV	8.9	15.5	12.4	13.5	12.5	27.1	7.7	2.3
Heuristic	4.9	10.5	11.1	16.2	32.6	16.1	6.5	2.1
Heuristic—ZXCV	7.0	6.4	16.3	17.1	18.0	25.7	6.5	3.0

4 Conclusion

Based on the effort calculations, it can be seen that QWERTY is not efficient for the Filipino language. All keyboard layouts developed in this study had lower total typing efforts as compared to it.

Although the optimized QWERTY had the lowest total effort, the optimized Heuristic ZXCV layout is still considered better, as the letters *Z, X, C,* and *V* remained fixed as in QWERTY, allowing for easy access to these shortcuts.

Also, both Dvorak and Colemak are better layouts for the Filipino language than QWERTY. Between the two, Colemak had a lower typing effort and it kept in place the letters Z, X, C and V as well. In line with this, Filipino typists may opt to use Colemak as it is still better than QWERTY for both English and Filipino.

5 Recommendations

To reduce the risk of repetitive strain injury, the following are recommended:

- The optimized Heuristic ZXCV layout as seen in Appendix B.6 may be adopted by Filipino typists.
- Colemak should be preferred over QWERTY when typing English or Filipino.

The following steps may be done in future studies to further improve and strengthen the results of this study:

- Usability tests may be performed to verify if the resulting keyboard was indeed perceived to require less typing effort than QWERTY.

- A keyboard layout efficient for both English and Filipino may be developed so that typing with language switch would still be efficient.
- More runs of simulated annealing in Carpalx may be performed in order to confirm global optimal keyboard layout.
- Characters other than the letters, such as punctation marks and numbers may be included in optimization.

Acknowledgments The authors would like to thank all the respondents in the finger strength data gathering and Dr. Rhandley Cajote of the Electronics and Electrical Engineering Institute—UP Diliman for the corpus used in this study. The authors would also like to thank Martin Krzywinski for creating Carpalx and providing his invaluable insights on this project.

Appendix A: Definition of Terminologies

A. 1 Conventional Typing Technique and Hand Placement

(see Fig. 4)

Appendix B: Keyboard Layouts

B.1
(see Fig. 5)

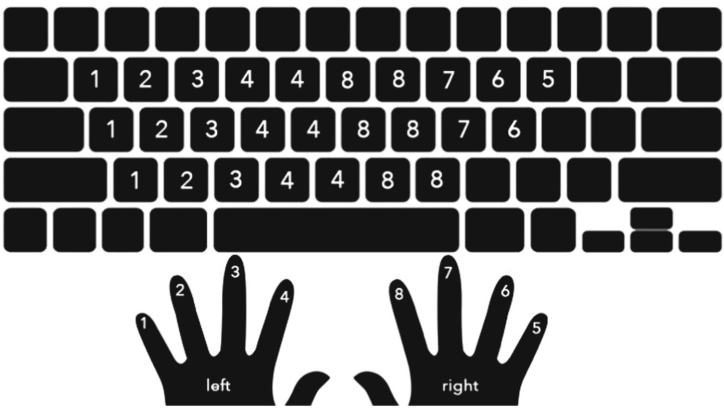

Fig. 4 The figure illustrates the conventional typing technique and hand placement

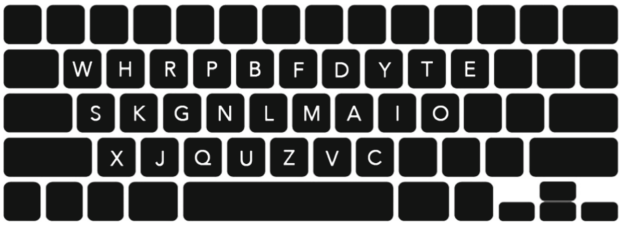

Fig. 5 Heuristic keyboard layout

B.2
(see Fig. 6)
B.3
(see Fig. 7)
B.4
(see Fig. 8)
B.5
(see Fig. 9)
B.6
(see Fig. 10).

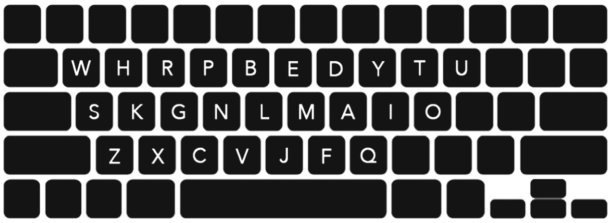

Fig. 6 Heuristic—ZXCV keyboard layout

Fig. 7 Optimized QWERTY keyboard layout

Fig. 8 Optimized QWERTY—ZXCV keyboard layout

Fig. 9 Optimized Heuristic keyboard layout

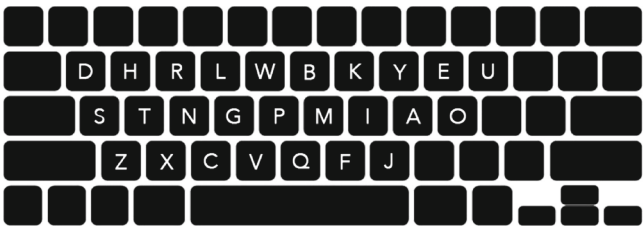

Fig. 10 Optimized Heuristic—ZXCV keyboard layout

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Redesign the Cleaning Tools from Analysis of Working Postures at a Cleaning Job Using the Task Analysis and OWAS Methods

Ming-Hsu Wang, Bi-Hui Chen and Wen-Ko Chiou

Abstract Work of physical labor is conducted in many parts of different workplace. The relationships between a poorly designed workplace, poor working posture and diseases of the musculoskeletal system have been demonstrated. A number of studies also have reported that cleaners have a high risk of developing health problems particularly musculoskeletal problems, especially affecting the back, neck, shoulders, elbows and hands. This study used task analysis to analyze the typical cleaning job and used OWAS to analyze the working postures of cleaning workers in the university environment. We collect the all daily routine cleaning tasks for task analysis. Thirty cleaning workers, with an average work experience of 8.5 years, participated in this study. For an overall distribution of trunk postures, OWAS identified that a bent and twisted trunk posture, which fell into action category 3, was the major poor posture for cleaning workers. Distribution of arm posture were also fell into action category 3. This study also identified that trash cleaning task, class washing task, and toilet cleaning task were the 3 principal tasks in which cleaners cleaning the school environment exhibited poor working posture. This study used the posture analysis of OWAS to redesign the assistant cleaning tools. We extend the length of tools by the heights of the cleaners and the angle of cleaning tool could be adjusted by the different tasks of cleaning job. The redesign tool would help the cleaners to work without the over extending postures. To help them work with the normal postures to reduce and evaluate poor posture in a dynamic cleaning job site.

Keywords Cleaning tools · Working posture · Task analysis · OWAS

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1 Introduction

Work of physical labor is conducted in many parts of different workplace. Musculoskeletal disorders (MSD) are a major cause of problem in the different working populations. The relationships between a poorly designed workplace, poor working posture and diseases of the musculoskeletal system have been demonstrated [1]. Cleaning occupation is important, physically demanding, labor-intensive work, conducted by millions worldwide. Currently, there are approximately half million people working as cleaners in Taiwan, most of them are middle age and aging women with relatively low income, knowledge status and mainly work in public buildings such as schools, offices, hospitals and retail stores. The cleaning workforce comprises a high proportion of ageing women with low social status, who are generally poorly educated with social support [2].

Many working and environmental factors can affect the working safety of cleaners. The National Institute for Occupational Safety and Health reported that awkward working posture had a strong relation to the causation of musculoskeletal disorders [3]. Previous studies indicated that cleaning tasks are characterized by static muscle and repetitive movements of backs, hands and legs delivering a high output of force and bad postures. A number of studies also have reported that cleaners have a high risk of developing health problems particularly musculoskeletal problems, especially affecting the back, neck, shoulders, elbows and hands [4, 5].

In many of the workplace where cleaners are found the conditions that promote various occupational diseases (e.g., musculoskeletal disorders) are readily manageable. Cleaning is considered a high physically demanding job, resulting in high cardiovascular load high frequency of awkward postures and, as such, it is rated as a highly strenuous job [6].

Cleaning tasks are characterized by vacuuming, carpet steam cleaning, detailing (for example, cleaning surfaces including tables, tiles, walls, mirrors, glass, and interiors of lifts), toilet cleaning, floor and hard surface polishing, waste paper, rubbish and recycling management, pest control, sanitary services and other general cleaning tasks [7]. Inappropriate and poor working postures, lack of task variation, poor ergonomic design of work places, poor design of cleaning tools and work organization are all areas where relatively simple interventions can significantly reduce the rate of exposure to occupational disease. The poor working resources make the high rate of related musculoskeletal disorders for the cleaners. The risk factors for work-related musculoskeletal disorders include physical risk factors, psychosocial risk factors and individual risk factors [8].

However, the protection devices provide the same solutions and suggestions for the cleaners and did not consider the height difference of the cleaners. The cleaners with different height may suffer the musculoskeletal disorders from the various working postures.

Therefore, the aims of this study was performed to evaluate the musculoskeletal disorders of the cleaners and to evaluate the effect of height on cleaners' working postures in a school environment. This may be helpful to improvement of cleaner

protection capable of reducing a potentiality of musculoskeletal disorder occurrence by repeated cleaning works. And redesign the cleaning tools from the working posture analysis.

2 Method and Subjects

A two-stage method was used in this study. First, we used task analysis to filter the typical cleaning tasks by the whole body changes. Secondly, we analyze the OWAS for the subjects who divide into three height categories. To compare the posture changes during the typical cleaning tasks.

This study used task analysis to analyze the typical cleaning job and used OWAS to analyze the working postures of cleaning workers in the university environment. We collect the all daily routine cleaning tasks for task analysis. Thirty cleaning workers, with an average work experience of 8.5 years, participated in this study. Three typical tasks of cleaning jobs were chosen to videotape at a university and analyzed later in the laboratory.

2.1 Task Analysis

This study filtered the typical tasks from the procedure of the cleaning jobs. According to the cleaning task analysis, the procedure of cleaning job in the schools was analyzed and divided into 12 elementary tasks (show as Fig. 1). This study

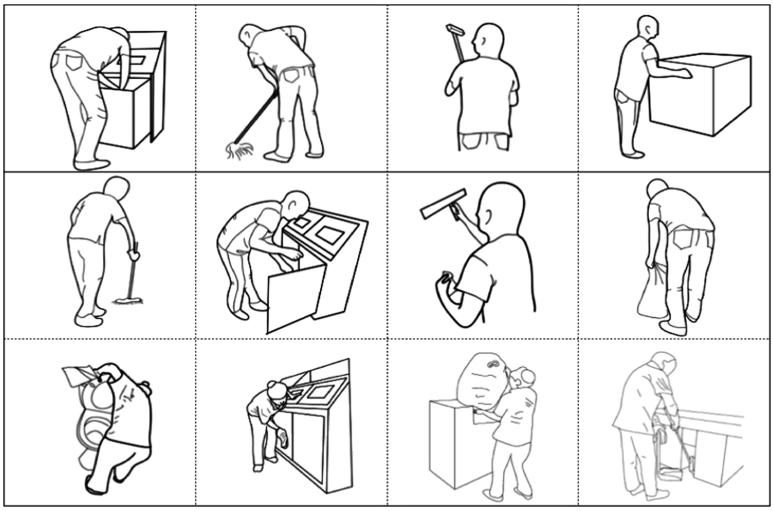

Fig. 1 The 12 elementary school-cleaning task

Fig. 2 The three typical school-cleaning tasks (polish the mirror, mop the floor, and clean the trash)

focused on tasks executed mainly by the changes of body posture. Tasks that involved mainly hand movement task without body posture change (table and armrest surface polishing) were disregarded. Figure 2 shows typical tasks (polish the mirror, mop the floor, and clean the trash). All 12 elementary tasks were videotaped at a school-cleaning workspace and analyzed later in the laboratory. For each job, only one cleaning worker was observed. The observation time was 30–60 min; during which 60 still videotape frames were sampled at intervals of 10s from the representative contents of the task for later analysis. During the time for videotaping, we record the complete elementary tasks for the routine job without any interference. The total number of videotape frames analyzed in this study was 180(3 tasks × 60 frames).

2.2 OWAS Analysis

This study used OWAS methods to analyze working postures of participants with different height during the school-cleaning job. For the OWAS observation, the subjects of this study were 30 male university students without musculoskeletal disorder in one year and category the subjects into three groups by the height (short/normal/tall). (show as Fig. 3) The subjects' age ranged between 21 and 25 years. Mean age was 22 ± 0.6 years, respectively. Complete explanation of the typical tasks operation should be mentioned before they start to test. Before the typical tasks operation in the cleaning workspace, the researcher also mentioned the participants to do the tasks by the free and relax response without any limits. Every task was being operated for five times and 60s for one time without rest during the

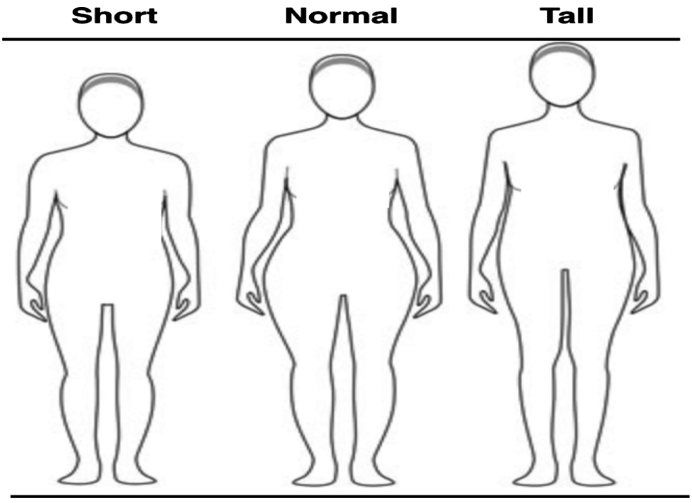

Fig. 3 Three subject groups by the height category (Short/Normal/Tall)

Table 1 Definition of Postural Codes and Action Code in OWAS [9]

Posture			OWAS Action code and action required
Arm	Trunk	Leg	
1 = Both arms below shoulder height	1 = Straight/upright	1 = Sitting	AC1 no action required
2 = One arm above shoulder height	2 = Bent forward	2 = Standing on both legs straight	AC2 action required in the near future
3 = Both arms above shoulder height	3 = Straight and twisted	3 = Standing on one straight leg	AC3 action required as soon as possible
	4 = Bent and twisted	4 = Standing on both legs bent	AC4 action required immediately
		5 = Standing on one bent leg	
		6 = Kneeling on one or both legs	
		7 = Walking	

operation interval. Table 1 shows the definition of postural codes(trunk, arms and legs) and four action code in OWAS (AC1, AC2, AC3 and AC4). We exclude the force measurement for OWAS with the typical cleaning tasks.

3 Working Postures and Action Categories

For an overall distribution of trunk postures, OWAS identified that a bent and twisted trunk posture, which fell into action category 3, was the major poor posture for cleaning workers. Distribution of arm posture was also fell into action category 3. Table 2 shows the overall percentage distribution of postures for trunk, arms and legs, for cleaning workers performing the three typical tasks. For the "short" category, the most frequent postures for the trunk, arms, and legs were straight and twisted (29 %), one arms above shoulder height (43 %), and walking (31 %). For the "normal" category, the most frequent postures for the trunk, arms, and legs were straight and twisted (29 %), one arms above shoulder height (46 %), and walking (32 %). And for the "tall" category, the most frequent postures for the trunk, arms, and legs were straight/upright (29 %), both arms below shoulder height (49 %), and walking (32 %).

The cleaning ratios of standard working postures were listed in Table 3. The short and tall categories showed the higher poor postures(AC3/AC4) than the normal category. The short category got the highest ratio in the code 333(13 %) and code 335(12 %) for the tall category.

Compare the results from three categories, it showed that the difference of critical posture for the categories.The related research focus on the physical, psychosocial, environmental and tools' effect for the musculoskeletal disorders, they provided better working guides and equipment for the workers. But the rate for the worker's musculoskeletal disorders is still very high [10]. And the difference of

Table 2 Definition of Postural Codes and Action Code in OWAS

		Short	Normal	Tall
Body area	Posture	Frames (%)	Frames (%)	Frames (%)
Trunk	Straight/upright	42(23)	56(31)	53(29)
	Bent forward	50(28)	46(26)	41(23)
	Straight and twisted	52(29)	52(29)	40(22)
	Bent and twisted	36(20)	26(14)	46(26)
Arms	Both arms below Shoulder height	65(36)	78(43)	89(49)
	One arm above shoulder height	77(43)	82(46)	61(34)
	Both arms above shoulder height	38(21)	20(11)	30(17)
Legs	Sitting	0(0)	0(0)	0(0)
	Standing on both legs straight	21(12)	41(23)	34(19)
	Standing on one straight leg	32(18)	25(14)	11(6)
	Standing on both legs bent	21(12)	30(17)	21(12)
	Standing on one bent leg	35(19)	16(9)	12(7)
	Kneeling on one or both legs	15(8)	10(6)	45(25)
	Walking	56(31)	58(32)	57(32)

Table 3 Definition of Postural Codes and Action Code in OWAS

Short				Normal			Tall		
	Posture	Frequency	%	Posture	Frequency	%	Posture	Frequency	%
	112	7	6	112	12	12	112	12	10
AC1	113	6	5	113	13	13	113	13	11
	114	16	14	114	6	6	114	10	8
	122	9	8	122	8	8	122	9	8
AC2	123	15	13	123	15	14	123	15	13
	124	8	7	124	12	12	124	8	7
	222	8	7	222	9	9	222	8	7
AC3	223	14	12	223	8	8	223	6	5
	224	9	8	224	7	7	224	12	10
	333	15	13	333	5	5	333	7	6
AC4	334	5	4	334	5	5	334	4	3
	335	4	3	335	4	4	335	14	12

personal characteristics could make the posture difference. Most researches showed the individual risk factors, including age, gender and related working experience for the musculoskeletal disorders [11].

Base on the related researches, little is known about the personal anthropometric difference for the musculoskeletal disorders, such as height difference.

From the finding of this study, the comparison of different height categories could be an important issue for the future study.

This study found out the difference of categories from the OWAS. We use the finding to redesign the cleaning tools. The working assistant device and safety recommendation provide the protection for musculoskeletal disorders during the working time [12]. During the last decade, new cleaning tools and better working techniques have entered the cleaning industry. Nevertheless, cleaners are the workers with the highest risk of developing work-related disorders and also have a high risk of leaving their job before their intended retirement [13].

4 Main Findings and Application for Redesign Cleaning Tool

The Fig. 4 showed that the poor posture(AC4) for the short and tall categories. The short category focus on the straight and twisted, both arms above shoulder height and standing on one straight leg (code: 333).

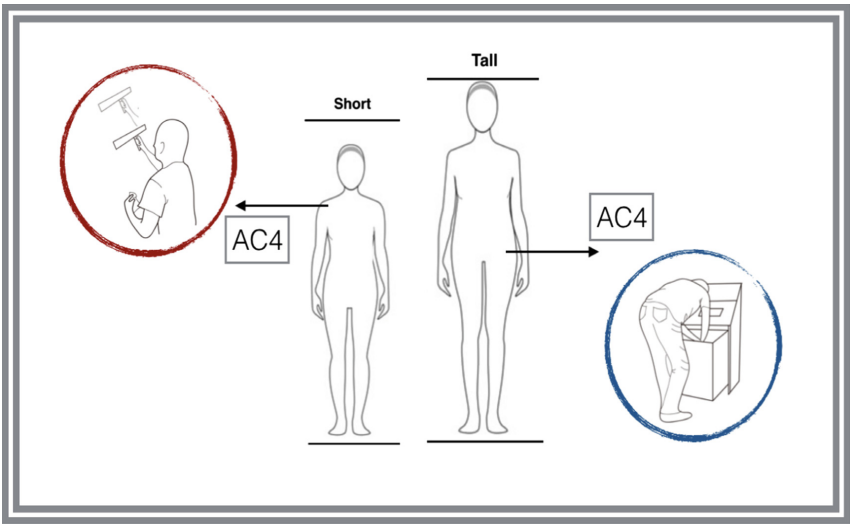

Fig. 4 Critical postures(AC4) from OWAS for short and tall category

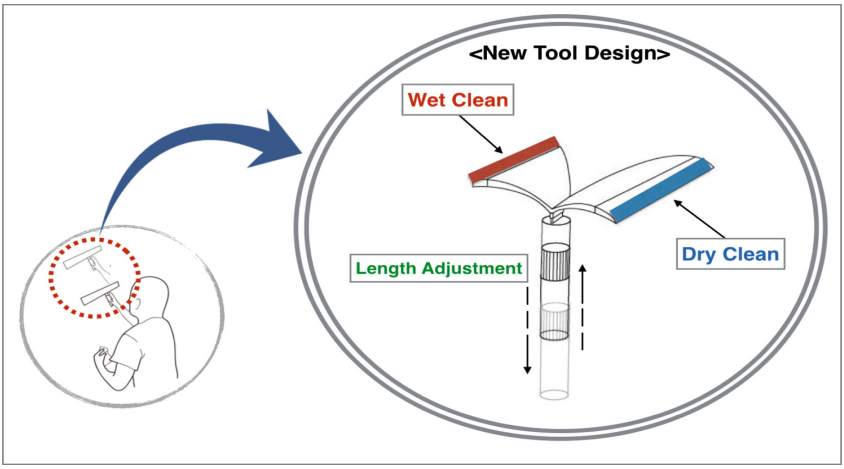

Fig. 5 Redesign mirror cleaning tool for the short category

We redesign the cleaning tool base on the poor posture for the short category.(as show in the Fig. 5). The new tool has combination of the wet and dry cleaning tools and length adjustment for the mirror cleaning. From the simulation of the redesign cleaning tool, the cleaning posture code change from AC4 to AC2. It reduced the risk for the mirror cleaning tasks.

This study used the posture analysis of OWAS to redesign the assistant cleaning tools. We extend the length of tools by the heights of the cleaners and the angle of cleaning tool could be adjusted by the different tasks of cleaning job. The redesign tool would help the cleaners to work without the over extending postures. To help them work with the normal postures to reduce and evaluate poor posture in a dynamic cleaning job site.

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Part VI
Anthropometry

Anthropometric Evaluation of the Design of the Classroom Desk for the Sixth and the Seventh Grades of Benghazi Schools

Ahamed Altaboli, Moatasem Elhinaid, Aisha Alasbali and Isra Egjam

Abstract This study is a part of an ongoing project aiming to evaluate the existing design of the classroom desk used in the basic education stage in Benghazi schools. This study represents the third phase of the project covering the sixth and the seventh grades. Anthropometric data was gathered for a total of 120 students (children of age 10–13 years old) from several schools in Benghazi. Selected body dimensions were measured for each student. The evaluation procedure involves the utilization of several equations relating body dimensions to desk dimensions. Each equation computes an acceptable range for each desk dimension based on the associated body dimension. Each desk dimension is compared to the range computed for the related body dimension for each student and percentages of matches/mismatches are determined accordingly. Results of the evaluation revealed considerable percentages of mismatches between the desk dimensions and students' anthropometry.

Keywords Schoolchildren · Anthropometrics · School furniture · Classroom furniture · Children anthropometry

1 Introduction

This article reports the outcomes of the third phase in a larger ongoing project study. The overall objective of the ongoing study is to evaluate the existing design of the school furniture that currently being used in the Libyan public schools in the basic education stage and to propose potential improvements in the design accordingly. The study involves gathering related anthropometric data for the students and utilizes it to evaluate the existing and potential proposed improved

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designs with the objective of developing the furniture design(s) that would best fit students' anthropometry. Results of the first two phases covering the first to the fifth grades are reported in [1, 2]. This article covers the results of the sixth and the seventh grades.

Anthropometric evaluation procedures of school furniture have been applied in many studies [1–11]. One widely applied procedure utilizes several equations relating body dimension(s) to the furniture dimension to be evaluated. Each equation is used to individually compare body dimension(s) of each student to the furniture dimension; the furniture dimension is considered suitable for the student if the results of the comparison showed that it was compatible with the body dimension. This procedure was developed and applied first by Parcells et al. [3] and was further developed and applied later by Gouvali and Boudolos [4] and Agha [5]. A similar procedure was used in the first two phases of this project study [2] and in this current study as well.

2 Method

2.1 Participants

The school system in Libya consists of two stages: basic education and middle education. The basic stage consists of nine grades (first to ninth). The purpose of the current study is to evaluate the classroom desk used in public schools for the sixth and the seventh grades of the basic education stage. Anthropometric data for students from these two grades was gathered and used to evaluate the current design of the classroom desk. Anthropometric data were measured for a sample of a total size of 120 students (half males) aged between 10–13 years old. The sample was randomly selected from two schools in the city of Benghazi during the school year 2015/2016. Measurements were taken after getting permission from the officials and principals in each school and all students voluntarily participated in the study.

Seven body dimensions plus body stature were measured for each student. Measurements were taken using measuring tapes in the classroom while students were sitting on the desks wearing their everyday normal cloths and shoes. The dimensions are shown and defined in Fig. 1 and Table 1.

2.2 Measures of Classroom Desk

Public schools in Libya use one design of classroom furniture (desk) with the same dimensions (one size) for all of the nine basic education grades. This desk consists of a fixed height bench seat connected to a fixed height desk, designed to accommodate two students sitting side by side.

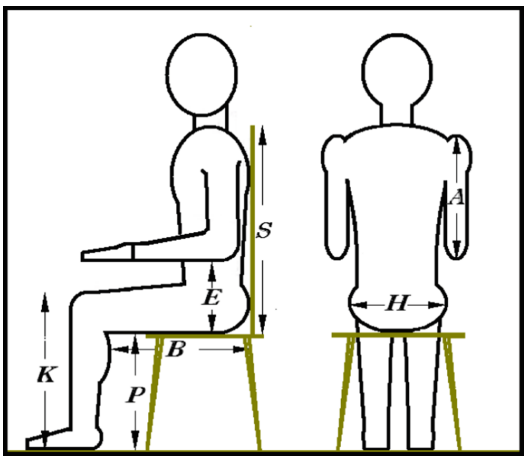

Fig. 1 The measured body dimensions

Table 1 Definitions of the measured body dimensions

Body Dimension	Definition
Popliteal height (P)	The vertical distance from the floor to the popliteal angle at the underside of the knee where knee flexion at 90°
Popliteal-buttock length (B)	The horizontal distance from the rear of the buttock to the back of the knee
Shoulder height sitting (S)	The vertical distance from the seat surface to the top of the shoulder
Knee height (K)	The vertical distance from the floor to the upper surface of the knee with knee flexed at 90°
Elbow–height sitting (E)	The vertical distance from the seat surface to the underside of the elbow while the elbow was flexed at 90° and shoulder was flexed at 0°
Shoulder to elbow length (A)	The vertical distance from the top of the shoulder to the underside of the elbow while the elbow was flexed at 90°
Hip breadth sitting (H)	Maximum horizontal distance across the hips in the sitting position

Six desk dimensions were evaluated in this study to see if they are compatible with related student's dimensions. These six desk dimensions are seat height, seat depth, seat width, backrest height, desk height, and under desk height. The dimensions of the desk are shown in Fig. 2 and Table 2.

2.3 Evaluation Criteria

The same evaluation criteria and procedure as the ones used in the first two phases of the study [1, 2] are used in this current study. They are similar to the procedure used in [3–5]. The procedure uses several equations relating body dimension(s) to

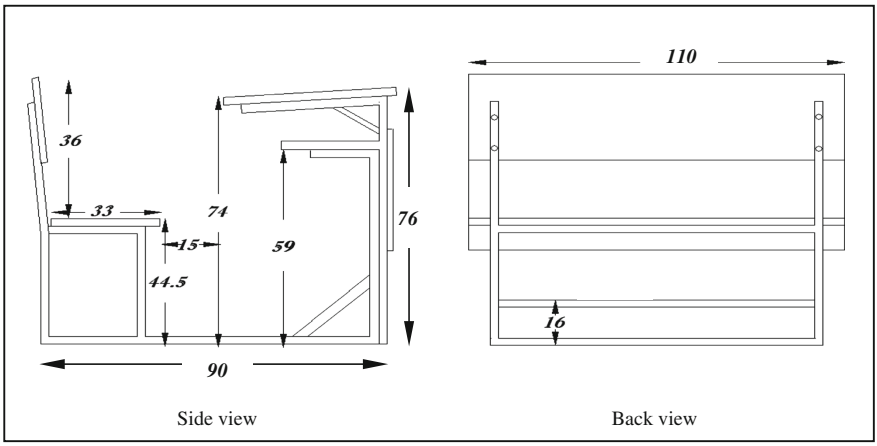

Fig. 2 Dimensions of the classroom desk (in cm)

Table 2 Dimensions of the classroom desk

Dimension	Measurement (in cm)
Seat height (SH)	44.5
Seat depth (SD)	33
Seat width (SW)	55 (= 110/2)*
Backrest height (BH)	36
Desk height (DH)	74
Under desk height (UH)	59

* The total width of the bench seat is divided by two to obtain the width available for one student

Table 3 Equations used for the evaluation

Disk Dimension	Equation	
Seat height (SH)	$(P+2)\cos 30^\circ \leq SH \leq (P+2)\cos 5^\circ$	(1)
Seat depth (SD)	$0.80\,B \leq SD \leq 0.95\,B$	(2)
Seat width (SW)	$H + A + 5 < SW$	(3)
Backrest height (BH)	$0.6\,S \leq BH \leq 0.8\,S$	(4)
Desk height (DH)	$E + (P+2)\cos 30^\circ \leq DH \leq (P+2)\cos 5^\circ + 0.8517\,E + 0.1483\,S)$	(5)
Under desk height (UD)	$(K+2) + 2 \leq UD \leq (P+2)\cos 5^\circ + 0.8517\,E + 0.1483\,S - 4$	(6)

furniture dimension to be evaluated. Each equation is used to individually compare body dimension(s) of each student to the desk dimension; the desk dimension in question is considered a match to the associated student dimension, if the results of the comparison showed that the desk dimension sets within the limits calculated by the related equation. Table 3 gives the equations used to compare each dimension

of the desks. All are the same as the ones used in the first two phases of the study [1, 2]. All were originally adopted from [3–5,] with very few adjustments to fit requirements of the current case.

3 Results

3.1 Results of Anthropometric Measurements

Table 4 summarizes the gathered anthropometric data after all the necessary corrections for cloths and shoes were made. Mean and standard deviation are summarized for each dimension, and are presented per gender for each grade.

3.2 Results of the Comparison

3.2.1 Calculations of the Acceptable Upper and Lower Limits

The students' anthropometric data gathered in this study were used to calculate the acceptable upper and lower limits for each desk dimension. The mean and standard deviation of the acceptable upper and lower limits for each desk dimension are given in Table 5.

Table 4 Summary of the measured dimensions (mean (standard deviation), in cm)

Body Dimension	Grade 6			Grade 7		
	Female (N = 30)	Male (N = 30)	Total (N = 60)	Female (N = 30)	Male (N = 30)	Total (N = 60)
Age (in years)	11.3 (0.5)	11.1 (0.4)	11.2 (0.5)	12.2 (0.4)	12 (0.3)	12.1 (0.4)
Stature	153.7 (8.3)	149.7 (7.5)	151.7 (8.1)	155.4 (6.6)	156.3 (8.8)	155.9 (7.7)
Popliteal height	40.4 (2.6)	39.1 (2.5)	39.8 (2.6)	40.4 (2.5)	40.4 (2.5)	40.4 (2.5)
Popliteal-buttock length	48.5 (5.6)	47.1 (4.5)	47.8 (5.0)	52.6 (6.5)	48.2 (3.8)	50.4 (5.7)
Shoulder height sitting	52.3 (5.0)	48.6 (3.8)	50.5 (4.8)	53.7 (3.9)	48.9 (4.1)	51.3 (4.6)
Knee height	50 (4)	49.1 (3.5)	49.5 (3.8)	50.4 (3.5)	51.8 (4.3)	51.1 (3.9)
Elbow height sitting	22.5 (3.3)	19.9 (2.5)	21.2 (3.2)	23.1 (2.0)	19.7 (2.7)	21.4 (2.9)
Shoulder to elbow length	32 (3.3)	31.1 (3.1)	31.5 (3.2)	33.2 (3.5)	31.8 (3.1)	32.5 (3.4)
Hip breadth	35.1 (6.0)	34.5 (5.0)	34.8 (5.5)	38.0 (5.2)	40.5(8.6)	39.3 (7.2)

Table 5 Mean and standard deviation of the upper and lower acceptable limits (mean (standard deviation), in cm)

Desk Dimension	Existing Measurement	Limit	Grade 6			Grade 7		
			Female	Male	Total	Female	Male	Total
Seat height	44.5	Upper	42.3 (2.6)	41.0 (2.5)	41.6 (2.6)	42.3 (2.4)	42.2 (2.5)	42.3 (2.5)
		Lower	36.7 (2.3)	35.6 (2.2)	36.2 (2.2)	36.7 (2.1)	36.7 (2.2)	36.7 (2.1)
Seat depth	33	Upper	46.1 (5.3)	44.8 (4.2)	45.4 (4.8)	50.0 (6.1)	45.8 (3.6)	47.9 (4.9)
		Lower	38.8 (4.5)	37.7 (3.6)	38.3 (4.0)	42.1 (5.2)	38.5 (3.1)	40.3 (4.1)
Seat width	55	Upper	–	–	–	–	–	–
		Lower	72.1 (8.1)	70.6 (7.0)	71.4 (7.5)	76.2 (6.9)	77.3 (10.6)	76.7 (8.8)
Backrest height	36	Upper	41.8 (4.0)	38.9 (3.0)	40.4 (3.5)	42.9 (3.1)	39.1 (3.3)	41.0 (3.2)
		Lower	31.4 (3.0)	29.2 (2.3)	30.3 (2.6)	32.2 (2.3)	29.3 (2.5)	30.8 (2.4)
Desk height	74	Upper	69.2 (5.2)	65.2 (4.2)	67.2 (4.7)	69.9 (3.6)	66.3 (4.0)	68.1 (3.8)
		Lower	59.2 (4.7)	55.6 (3.8)	57.4 (4.2)	59.8 (3.2)	56.4 (3.7)	58.1 (3.4)
Under desk height	59	Upper	65.2 (5.2)	61.2 (4.2)	63.2 (4.7)	65.9 (3.6)	62.3 (4.0)	64.1 (3.8)
		Lower	54.0 (4.0)	53.1 (3.5)	53.5 (3.8)	54.4 (3.5)	55.8 (4.3)	55.1 (3.9)

3.2.2 Percentages of Match/Mismatch

Using the procedure and equations described earlier, the desk dimensions were compared to the individual acceptable limits calculated for each student. The desk dimension in question is considered a match to the associated student dimension(s), if the results of the comparison showed that the desk dimension falls within the limits calculated by the related equation. If the desk dimension falls outside the limits, it is considered a mismatch; either above the upper limit or below the lower limit. A mismatch above the upper acceptable limit indicates a desk dimension larger than the related body dimension(s)/size; while, a mismatch below the lower acceptable limit indicates a desk dimension smaller than the related body dimension (s)/size. Table 6 gives the results of comparison of the desk dimensions to the related acceptable ranges. The results are summarized as percentages of match or mismatch.

Table 6 Percentages (%) of match/mismatch in each grade

Desk Dimension		Grade 6			Grade 7		
		Female	Male	Total	Female	Male	Total
Seat height	Match	23	10	17	17	17	17
	Mismatch	77	90	83	83	83	83
	Above	77	90	83	83	83	83
	Below	0	0	0	0	0	0
Seat depth	Match	10	0	5	3	3	3
	Mismatch	90	100	95	97	97	97
	Above	0	0	0	0	0	0
	Below	90	100	95	97	97	97
Seat width	Match	7	0	3	0	0	0
	Mismatch	93	100	97	100	100	100
	Above	–	–	–	–	–	–
	Below	–	–	–	–	–	–
Backrest height	Match	93	83	88	93	87	90
	Mismatch	7	17	12	7	13	10
	Above	7	17	12	0	13	7
	Below	0	0	0	7	0	3
Desk height	Match	20	3	12	10	0	5
	Mismatch	80	97	88	90	100	95
	Above	80	97	88	90	100	95
	Below	0	0	0	0	0	0
Under desk height	Match	80	63	72	87	60	73
	Mismatch	20	37	28	13	40	27
	Above	10	30	20	3	20	12
	Below	10	7	8	10	20	15

3.3 Analysis and Discussion

As shown in Table 6, high percentages of mismatch are found with several desk dimensions. High-above the upper acceptable limits mismatches are found with both seat height and desk height. This indicates that students are sitting on a desk with both seat and desk surface too high for them.

Seat depth and seat width are smaller for students' body sizes, as indicated by the high percentages of mismatches below the lower limits found with both dimensions.

Relatively high percentages of matching are found with both backrest height and under desk height. However, for both dimensions, mismatches are found both above and below the acceptable limits, with higher percentages of mismatches above the limits in the sixth grade and higher percentages of mismatches below the

limits in the seventh grade. This indicates that both dimensions change from being large to being small for students as they grow larger with age.

From these results it is clear that the existing desk size is incompatible with the anthropometrics of the students. The one size fits all is obviously not suitable for children in these two grades. Other design alternatives should be sought to eliminate or reduce this problem. These alternatives can range from designs of completely adjustable separated chairs and desks for use by single students to at least adjusting the dimensions of the existing desk design to reduce the percentages of mismatch as much as possible.

4 Conclusions

As with the first five grades [1, 2], with the sixth and seventh grades, the evaluation revealed substantial percentages of mismatches between desk dimensions and students' anthropometry, especially for seat height and desk height. Students are sitting on desks with seats and tables that are too high for them. This could force students to sit in awkward and constrained postures, and in the long run this may result in musculoskeletal discomfort for the children that might even continue to their adulthood.

The next phase in the ongoing project study is to finish gathering anthropometric data and evaluation for the remaining two grades in the basic education stage. After that, potential improved design alternatives are going to be proposed and evaluated.

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Develop a Circumference Measurement Device for Patient with Upper Limb Lymphedema

Tsai-Wei Chang, Chien-Hsu Chen and Zheng-Yu Hoe

Abstract The lymphedema often happens after breast cancer therapy and brings patients great discomfort in their daily life. Therefore, measuring, tracking, and recording becomes a serious clinical issue, but there are still no standard definition and measuring method for lymphedema. The water displacement and circumference tape measurement are mostly used to date. But there are some disadvantages of these methods and influence the difficulty and the accuracy. Thus, the device would be developed according to the conditions relative to disadvantages of these two existing methods. To achieve the conditions, the rotary encoder and grating has been rearranged and tested to develop a new measuring method. The multiple encoder data will be developed and computed as further study in the future.

Keywords Lymphedema · Circumference measurement · Upper limb · Mechanical mouse encoder · Linear grating

1 Introduction

Lymphedema usually comes after breast cancer surgery. Because during the breast cancer surgery patient's lymph nodes will be cut off, there is protein-rich lymph fluid accumulates and makes the patient swell and feel uncomfortable. The greatest

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differences between patients with and without lymphedema are for pain, stiffness, weakness, and numbness [1]. When the condition gets worse, it might be associated with some complications such as low joint flexibility, decline of skin resistance, high probability of getting chapped or scratched, or even tissue fibrosis. The lack of a standard approach to define and quantify the patients' condition would make their daily basis exacerbated [2].

There are many researchers have researched the lymphedema after treatment for breast cancer and the incidence of lymphedema to date, but most of researchers have their own way to measure and quantify lymphedema [3]. And there are a few measuring methods which are used mostly today, such as water displacement and circumference tape measurement. The indicative difference in circumference tape measurement vary from 1.0–3.0 cm, and in the arm volume is a 200 ml difference [4].

Nowadays, the water displacement method is still the gold standard of measuring lymphedema [5]. It is to hang patient's arm vertically in the tall bucket that full of water, and by measuring the water that is filled out of the bucket to get the data of the arm volume. The total volume and the volume variation can be measured and calculated, but there is no way to know how the shape of the arm changes or where the edema happens. It is inconvenient to prepare for the whole test and to make the measurement although the data is more precise by using this method.

The circumference tape measurement method is to measure the arm circumference by tape, and compare the two circumference of two arms at the same section to determine the edema level. It is much easier to operate, and patients can do it at home. But the edema is not usually happened at the same section or not around the section that used to be measured. This method only measures 3–5 spots on one arm, so it is less precise compares to water displacement method and too less to compute the arm volume. The spots where the researcher measured might be slightly different every time and they might not be the spots where lymphedema happened since it depends on the patient's constitution.

Therefore, the device is designed for overcoming the limitations of these existing methods. It should be portable, light, easy to operate, cheap and receiving the data which is almost continuous and easy to compute the circumference and the volume.

2 Literature Review

There is a research about using 3D stereophotogrammetry to compute the upper limb volume. In this article, it shows that 3D stereophotogrammetry technic is a method that can compute the value very precisely, and the error is found to be only 0.1 mm. But the disadvantage is that not every clinic could afford the 3D camera system. Other than that, the technicians and the physicians have to be trained to adapt to the system [6].

3 Design and Implement

3.1 Device Construction and Usage

This device is designed for quickly scanning patient's arm circumference. It is a cyclic construction with several grating sticks around the device (Fig. 1). At the initial state, all the grating sticks would form a circle in the middle of the device. While patient's arm passing through the device, the grating sticks will be pushed outward. And get each moving distance data from every grating stick (Fig. 2).

While the device pass through, the data is the distance between the device and patient's arm. Since the size and the radius of the device won't change, thus we can calculate the relative position of the device and patient's arm. And furthermore we can compute the arm circumference or even the volume at every time interval (Figs. 3 and 4).

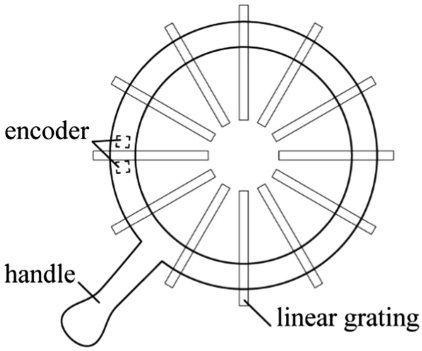

Fig. 1 The cyclic device with linear gratings and encoders at the initial state

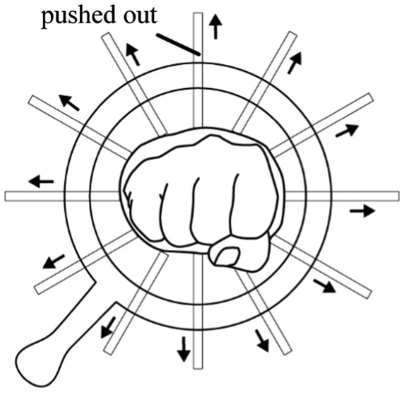

Fig. 2 The front view while using the device. The linear gratings will be pushed outward and the encoder will collect the distance data that grating moves

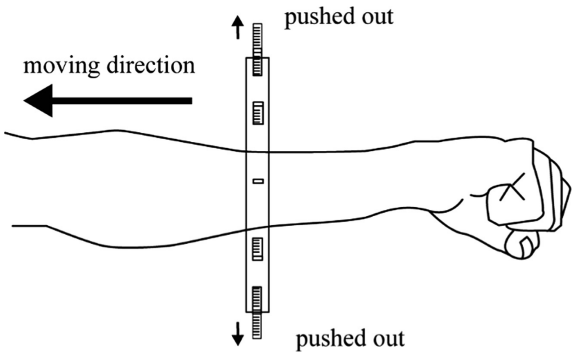

Fig. 3 The side view while using the device. The device will be moved along the arm and sent the data back every certain time interval

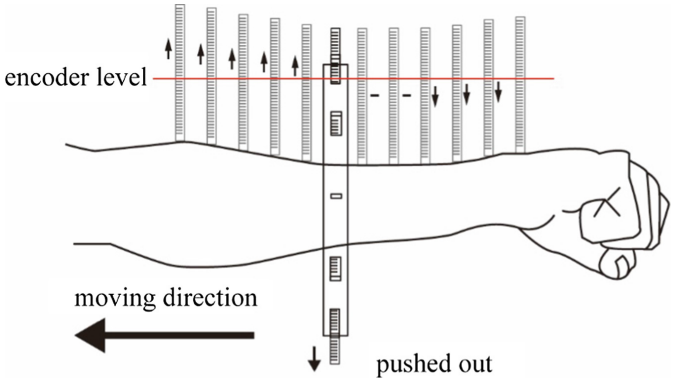

Fig. 4 The side view while using the device. The grating movement while the device move along the arm

3.2 Goal Orientation Development Flow

The device development is to improve the measuring methods (Fig. 5 Shows the development flow chart). Thus, the disadvantages are listed, and base on the disadvantages the conditions are set. To achieve these conditions, the form and operating method of the device are decided first.

There are some disadvantages in water displacement and circumference method. The disadvantages of water displacement are that it is not easy for preparing, only gets overall volume data, and is inconvenient to operate. And the disadvantages of circumference method are that the measuring spots might be different every time or too less, and the arm volume cannot be calculated by the data.

Fig. 5 The goal orientation develop flow chat

Base on the disadvantages of these two existing methods, the conditions have been set. This device should be portable, be easy to operate, receive nearly continuous data to calculate the arm volume, and cost less.

The scanning motion of 3D scanning is intuitive and straightforward. To be easy to operate the device, the operation is referred to the 3D scanning operation, such as swiping around the arm or making the device a large armband and scanning while the arm passing through.

At the end, the measuring method has to be combined with the armband like circumference device. Thus, the method has to be quick to collect instant data while the device move, convenient to operate, easy and cheap to conduct, and does not occupy too much space.

3.3 Rotary Encoder

The sensor which is used in this paper is a pair of infrared rotary encoder from a mechanical mouse and a stick with linear grating. The infrared rotary encoder is consisted of an infrared emitter and a receiver with two channel of the signal input.

When the grating moves upward or downward, the receiver will receive two different series of signals (Fig. 6). By analyzing the two series of signals we can distinguish the moving direction of the grating and compute how much distance it moved.

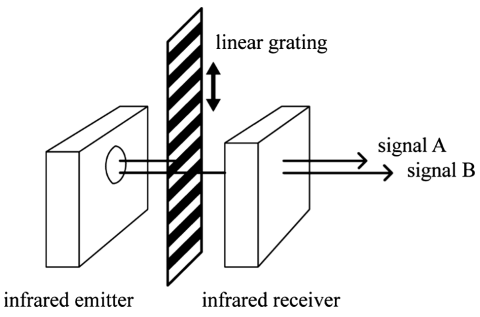

Fig. 6 How the encoder works with linear grating. The infrared emitter emits the light and the receiver receives two series of signals while the grating moves

3.4 Grating

The accuracy of this device is depend on the encoder sensor and the grating. There are two infrared detectors in the receiver at different spots. The size of the grids on the grating is the main parameter to influence the accuracy. But if the size of the grids is too small for the encoder to judge the movement of the grating, there would be no result or wrong data which is no reliability.

In this paper we turn the tradition rotary encoder with disk grating (Fig. 7) into linear grating (Fig. 8) to make the device more intuitive. And will try different sizes of grids on the gratings to find out the grating with the highest accuracy and recognition rate by the encoder in this paper.

3.5 Sensor Developing Flow

The sensor which is used in this device is from the mechanical mouse. Because in this paper we tried to compose the device with cheaper sensor and easier method (Fig. 9), we used the materials which are easy to get and conduct.

The data we need is different from the one we get directly from the mouse, because the data would have been processed. Thus, the encoder and the grating from the mouse have to be disassembled first. To get the raw data, the encoder has to be connected onto Arduino board and the code would be written for distinguishing the direction while the grating moves. At this point, the original disk

Fig. 7 The disk grating in mouse

Fig. 8 The linear grating

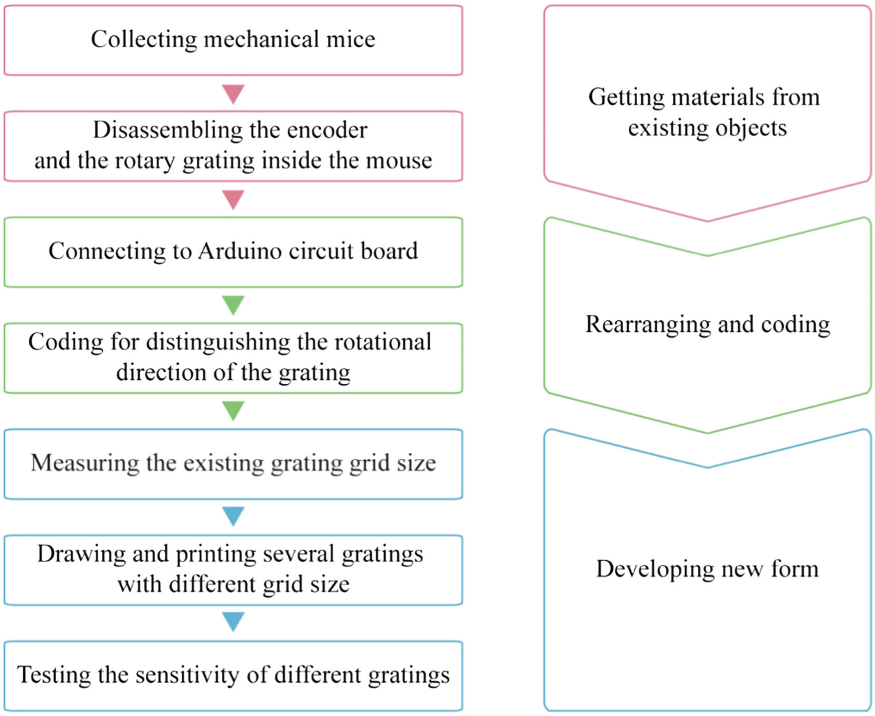

Fig. 9 The sensor developing flow chart

grating has still been used. But the stick would move outward and inward as the linear motion. Therefore the disk grating would be replaced with linear grating to make the data process more intuitively.

4 Conclusions and Discussions

The encoder and the linear grating were used as the distance measuring method in this article can be used in further development. By this method, we can apply at least 12 encoder and grating sets onto the device in advance. Furthermore, we can adjust the time interval between each data recording spot, and compute the data into the circumference and the arm volume. The data is adequate for determining the change of the lymphedema limb volume if properly done the circumference measurements [7].

This study is a pioneer study, according to this method we can develop the measuring device and in addition to developing the mobile application for the volume calculation software, which could be updated instantly.

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Study on Human Body Dimensions Used for Ergonomic Design and Evaluation of Mattress

Huimin Hu, Yanlong Yao, Chaoyi Zhao, Fan Yang, Ling Luo, Yinxia Li, Fan Zhang and Haimei Wu

Abstract Mattress is very closely related to people's life. The ergonomics design is very important to the comfort of mattress which directly influences the health, sleep quality and rest efficiency. A large number of studies show that the ergonomic design of the mattress has a direct relationship with human body dimensions, such as height, weight, spine curvature and so on. And human spine curvature is an important influence factor for the ergonomic design of mattress. This study aims at establishing the ergonomic design index of mattress and obtains the human body dimensions used for ergonomic design of mattress. Based on the collected human body data, the contrastive analysis on the spine curvature of different groups of people was conducted. It was found that there were obvious differences in the spine curvature between different groups of people. This experiment result has important reference significance on the ergonomic design of mattress.

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Keywords Mattress · Ergonomic design · Human body dimensions · Spine curvature

1 Introduction

As we all know, nearly 1/3 of people's life is spent in sleep, as the main bedding used by people, whether the mattress is comfortable or not is very important for the health, sleep quality and rest efficiency. There are a lot of factors such as the material, hardness, breathability and so on that influences the comfort of mattress. There have been many researches by related experts about the relationship between the various indexes of mattress and the sleep quality for a long time. In 1930, Laird and Miller did the research about the relationship between sleep condition and the type of mattress, and found that the both have close relationship [1]. In 1997, by comparing the mattress with different material, Mc Dannold M, Kaye H and Berkowitz DV found that the hardness of mattress affect sleep quality very much [2]. In 2001, Park analyzed the comfort of mattress by spine shape and body pressure distribution and subjective evaluation, the results showed that the spine shape and pressure distribution of interface between body and bed have a great influence on the comfort of mattress, far greater than the impact of other materials [3].

With the gradual improvement of the living standard, people pay more and more attention to the health of life. Benefit from the application of new materials and testing technologies brought by the progress of science and technology, it is becoming a hot topic to study the comfort of mattress by using the ergonomics principles. At the same time, a large number of studies show that the ergonomic design of the mattress has a direct relationship with human body dimensions. Therefore, this study aims at establishing the ergonomic design index of mattress and obtains the human body dimensions and analyzes the relationship between them, which can provide reference for the design and improvement of the mattress.

2 Confirmation of the Ergonomic Design Index of Mattress

2.1 Analysis of Factors Affecting the Comfort of Mattress

There are many factors which affect the comfort of mattress, if the ergonomics design of any index is not reasonable, it will affect the overall comfort of mattress. When studying the application of ergonomics in mattress design, Li and other persons from Wuhan Polytechnic University, divided the main factors into two categories, namely dimension and pad performance of mattress [4].

2.1.1 Dimensions of Mattress

Width of Mattress. Theoretically, as long as the surface area of mattress is no less than the projection area of the human body, the mattress can provide a reliable support for people's sleep. But considering the turning over of people when they sleep, if the width of mattress is too small, people will be in a state of tension when they sleep, needless to say, that would affect the quality of sleep. On the other hand, the width of mattress is not the bigger the better. Too wide a mattress is not only a waste of material, but also a waste of space as well as inharmonious. The width of mattress is generally determined by people's shoulder width and which is usually about 2.0–2.5 times the maximum shoulder width. The formula is expressed as formula (1), which B stands for width of mattress, W stands for maximum shoulder width.

$$B = 2.0 \sim 2.5W\,. \tag{1}$$

Length of Mattress. The length of mattress also affects sleep quality. If the length of mattress is less than people's height, then there is bound to be a part of the body out of mattress, this part of body can't be supported by mattress. That certainly affects the sleep quality. Suitable length of mattress, not only should meet the needs of people's height, but also need to keep enough space for the head and feet. The formula of mattress length is expressed as formula (2) [4], where L stands for the length of mattress, L1 stands for people's height, and L2 stands for the reserving space between the head and the upper side of bed, the reserving space is often taken as 80 mm; L3 stands for the reserving space of between the foot and the lower side of bed, the reserving space is often taken as 80 mm.

$$\mathrm{L} = \mathrm{L1} \times 1.05 + \mathrm{L2} + \mathrm{L3}. \tag{2}$$

2.1.2 Pad Performance of Mattress

The sleep quality is not only related to the dimensions of mattress, but also related to the pad performance of mattress, including the breathability, hardness, resilience and so on.

Breathability. The breathability of mattress surface is crucial to the temperature and humidity of the sleep environment. If the breathability is not good, it is disadvantageous to the heat dissipation of body surface. When the heat produced by the metabolism is difficult to discharge, it would lead to a rise in body temperature, and people will feel uncomfortable. So, the breathability of mattress is also an important factor which influences the sleep quality.

Hardness. The hardness of mattress has a great influence on the physiological characteristics in prone position. When people are in standing position, the spine is in its natural posture. At this time the spine is like "S" shape, the lumbar vertebra position generally concaves 4–6 cm, and the gravitational direction of head, chest

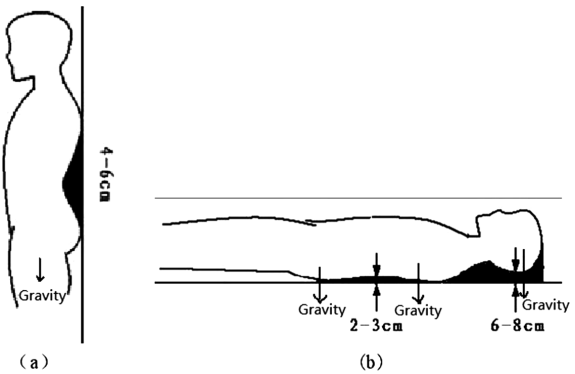

Fig. 1 The diagram of spine shape in standing and prone posture [5]

and hips is basically coincident. But when in prone position, the three main gravitational directions are parallel, and the spine will bend under the influence of these three main gravities. When the lumbar vertebra position concave half distance of standing position, that is 2–3 cm, people would feel comfortable in sleep. The spine shape in prone and standing posture is shown in Fig. 1a and b.

When people are in prone position, the weight of each part of body is equal to each other and vertical downward. Because the gravity of each part of human body is different, the stress on each position of spine is also different. If the mattress is too soft, the contact area between human body and mattress is very large; the heavy parts of body such as hips sag lower, and the light parts of body such as waist sag less than other positions. Thus, while the back and hip sag, the waist position would be raised, and the human body becomes a "W" shape. The W shape makes the spine has a lot of deformation, and the sag of the whole body brings extrusion from all directions, then the skeletal structure will be in unnatural state, and the body will feel uncomfortable. If the mattress is too hard, the contact area between human body and mattress is very small, the pressure of back and hips will increase, waist cannot be supported enough, and this also makes people feel uncomfortable.

Resilience. In case people use the mattress with consistent resilience, because the gravity of each part of human body is different; the amount of subsidence is not the same. When people lies on the mattress with larger resilience, the chest (accounts for 33 % of the body weight) and hip (accounts for 44 % of the body weight) will sag, the lumbar vertebra connecting the two parts will further raise up, the body becomes into a "W" shape and unwell. The larger resilience of the mattress, the degree of sag and rising is greater. So, the resilience of mattress is not the larger the better.

2.2 Establishing the Ergonomic Design Index of Mattress

According the analysis, we all know that each factor has different effect on the use of mattress. However, which indexes has the greatest impact on the feeling of

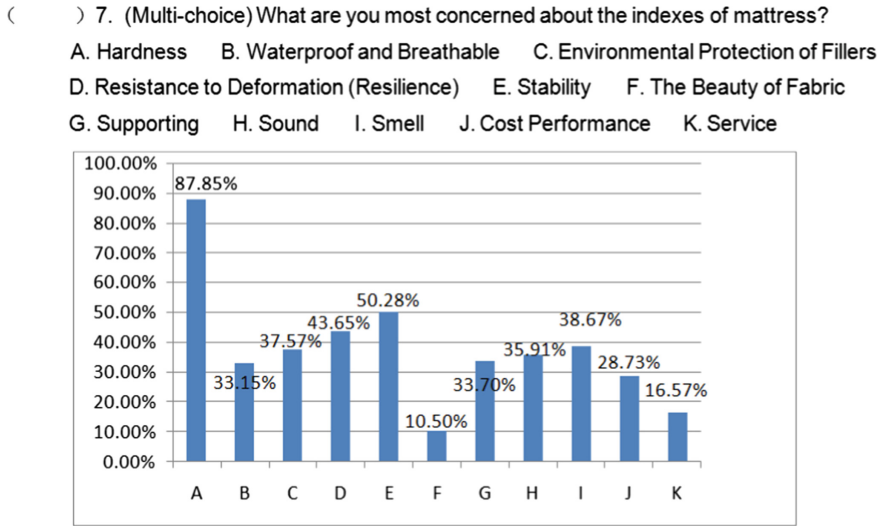

Fig. 2 The survey results of use conditions of the mattress

people? The survey method refers to obtaining original data by the form of conversation and questionnaire on the basis of consulting plenty of relevant research data and study relevant data by comparison, analysis, concluding and synthesizing etc. Firstly, on the basis of existing research results, the questionnaire about sleep habits and use habits of the mattress was made. Then, the subjects were recruited to investigate and interview.

The survey results showed that 93.37 % of the subjects used the mattress to sleep. More than 95 % of the subjects thought that the mattress is associated with sleep quality, and 43.65 % of the subjects thought they are closely related. The results also confirm the importance of the mattress to sleep quality. In addition, on the question that which index of mattress is most concerned about, 87.85 % of the subjects chose the hardness, and the followed is the stability and the resilience of mattress. The detailed survey results are shown in Fig. 2.

According to the existing research results on the mattress and human interaction and the results of the survey, the hardness, resilience, supporting, breathability and tactility of mattress are the most important indexes of the ergonomic design. Only consider the influence of each index in the design of mattress, which can satisfy the demand of high quality sleep.

3 Analysis of Human Spine Curvature Data

According to the analysis of mattress and human interaction, it is not difficult to see that the dimensions of mattress is closely related to the height, shoulder width and so on, the pad performance of mattress is closely related to human spine curvature.

In addition, the question survey results showed that 64.09 % of subjects thought that the uncomfortable mattress has a greatest impact on the waist of the human body. So the human body dimensions especially the data of human spine curvature are very important for the ergonomic design of mattress. In view of this, this study recruited subjects to measure the human body dimensions, including height, weight and spine curvature, and explore the difference on human body dimensions especially the spine curvature between different types of people. This can provide a reference for the ergonomics design of mattress.

3.1 Method for Measuring Human Body Physiological Dimensions

Considering the different habits of people on the use of mattress, the subjects used in this study were divided into twelve groups in total according to age, gender and BMI. Firstly, on the basis of age they were divided into two groups which include middle-old aged group (41–65 years old) and middle-young aged group (18–40 years old). Then another two groups were set up which were male group and female group according to the gender. Finally, based on BMI (Body Mass Index) value, it is divided into three groups, including fat group, middle group and thin group. The number of people of each group is 15 and the total number of the subjects taken in this study was 180.

The measurement tool used is the tape, body shape measuring ruler and vernier caliper and others. The total of 25 physiological dimensions, including the height and weight of the subjects, as well as spine curvature data were measured in this study. The specific measurement indexes are shown in Table 1. The specific location of position A, B and 1 to 5 is shown in Fig. 3.

The subjects had to change to tights and take off shoes when they are measured. The measurement of standing posture required the subjects maintain the standard anatomical posture and stick close to the wall or calibrating lever, in order to confirm the position of the five physiological curvature and A/B. The measurement site is shown in Fig. 4.

3.2 Measurement Results Analysis of Spine Curvature Data

The measurement results of human body physiological dimensions showed that there were obvious differences between different people groups in physiological structure. The vertical distance of position A and B directly reflected the curvature degree of cervical vertebra and lumbar vertebra. The two dimensions were analyzed with the gender, age and BMI value as the variable.

Table 1 Test indexes and methods of human body dimensions

Measurement indexes	Definition	Measurement methods
Position 1	The most prominent point of the back head	Contact point of head and calibrating lever
Position C7	Seventh cervical vertebrae	Seventh cervical vertebrae height
Position of jaw	Lower jaw	Chin height
Position A	Position of maximum curvature of cervical vertebra	Height of position A
Vertical distance of A	Bow altitude of A	Distance between A and calibrating lever
Arc length of A	Arc length of cervical curvature	Arc length of cervical curvature
Position 2	The most prominent point of back	Contact point of shoulder blade and calibrating lever (contact point of back and calibrating lever)
Position B	Position of maximum curvature of lumbar vertebra	Height of position B
Vertical distance of B	Bow altitude of B	Distance between B and calibrating lever
Arc length of B	Arc length of lumbar curvature	Arc length of lumbar curvature
Position 3	The most prominent point of hips	Contact point of hips and calibrating lever
Position 4	The most prominent point of calf muscles	Contact point of calf muscles and calibrating lever
Position 5	Heel	Contact point of heel and calibrating lever
Head girth	Full head circumference	Circumference between glabella and Position 1
Head side girth	Horizontal arc of the head	Head girth of two Tragus
Head front girth	Sagittal arc	Distance between occipital tuberosity and glabella
Neck girth	Circumference of Neck center	Circumference of neck from Fourth cervical vertebrae
Unilateral acromion to Earlobe	Length of neck	Arc length from earlobe to acromion
Shoulder length	Width of shoulder (arc length)	Arc length between left, right acromion and nape
Width of unilateral shoulder	Width of unilateral shoulder	Distance between neck lateral point and acromion

(continued)

Table 1 (continued)

Measurement indexes	Definition	Measurement methods
Width of acromion	Width of shoulder (length of line segment)	Distance between left and right acromion
The maximum shoulder breadth between double deltoid muscle	Width of shoulder plus arm	Distance between double deltoid muscle 5 cm under shoulder peak point
Height of Neck to head	Length of head to neck	Distance between neck root and top head
Occipital tuberosity to C7	Length of cervical vertebra	Length of occipital tuberosity to C7
Height of full head	Vertical height of head	Vertical distance from top head to lower jaw

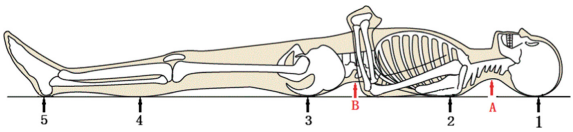

Fig. 3 Diagram of the position of measurement items

Fig. 4 Diagram of the measurement site of human dimensions

3.2.1 Analysis of Cervical Curvature Degree

The measurement results for vertical distance of position A are shown as Table 2. According to the analysis, it was found that the vertical distance of position A in male (62 ± 20 mm) was obviously greater than that in female (53 ± 13 mm). The vertical distance of position A in elder people was bigger than that in younger people, whether male or female. However, there were no regular changes with the difference of BMI value in the vertical distance of position A. That was to say, the degree of cervical curvature in male was greater than that in female, and elder people was greater than younger people.

Table 2 Measurement results for vertical distance of position B

Gender	Overall (n = 90)	Under 40 years			Over 40 years		
		BMI <19	BMI:19–24	BMI >24	BMI <19	BMI:19–24	BMI >24
Male	62 ± 20	50 ± 8	58 ± 8	55 ± 12	68 ± 26	74 ± 24	65 ± 19
Female	53 ± 13	45 ± 11	45 ± 6	57 ± 10	58 ± 13	56 ± 15	60 ± 13

3.2.2 Analysis of Lumbar Vertebra Curvature Degree

The measurement results for vertical distance of position B are shown as Table 3. According to the analysis, it was found that the vertical distance of position B in male (50 ± 12 mm) was roughly equivalent to that in female (50 ± 13 mm); the vertical distance of position B decreased with the increase of BMI in younger female, as was shown in Fig. 5. However, the vertical distance of position B for thin person was smallest in elder female. There were no regular changes for vertical distance of position B in male. That was to say, the degree of cervical curvature decreased with the increase of BMI in younger female.

Table 3 Measurement results for vertical distance of position B

Gender	Overall (n = 90)	Under 40 years			Over 40 years		
		BMI <19	BMI:19–24	BMI >24	BMI <19	BMI:19–24	BMI >24
Male	50 ± 12	51 ± 11	52 ± 10	48 ± 9	48 ± 13	49 ± 14	50 ± 12
Female	50 ± 13	58 ± 16	54 ± 16	49 ± 9	42 ± 8	48 ± 9	48 ± 10

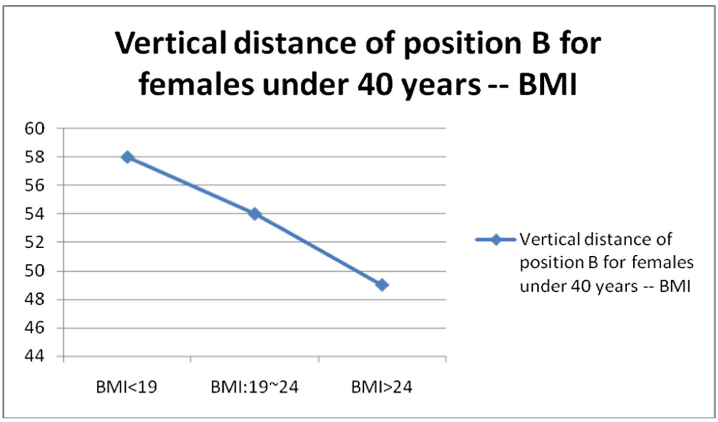

Fig. 5 Vertical distance of position B for females under 40 years with BMI as the independent variable

The measurement results of other physiological dimensions also showed a correlation with gender, age and BMI value. These measurement and analysis results have important reference significance to the ergonomics design of mattress.

4 Conclusion

This study knew the effects of each index of mattress on its comfort by analyzing of the interaction between human and mattress and established the ergonomic design index of mattress according to the questionnaire survey results. In the other hand, the ergonomic design of mattress has direct relationship with the data of physiological dimensions especially in the degree of spine curvature. According to the measurement results of the human body dimensions it was found that there were obvious differences between different people groups in physiological dimensions especially in the degree of spine curvature. When the mattress is designed, the human body dimensions of target users should be considered firstly which will influence the comfort of sleep.

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SizeNorthAmerica—The New North American Anthropometric Survey: Conceptual Design, Implementation and Results

Andreas Seidl, Rainer Trieb, Hans-Joachim Wirsching, Adam Smythe and Tim Guenzel

Abstract Size NorthAmerica is a comprehensive look at today's population to provide vital information of body shape and size to numerous industries. Understanding the human body provides a critical advantage for usability of any product or service. Prior studies are both out of date and had minimal industry input to ensure relevancy of final data gathered throughout the studies. There has been very little previous research focusing on children, ethnicities and regional differentiation. In addition, by including sociodemographic information of the subjects; it provides a realistic profile of how physical and characteristical data correlates amongst the participants. By incorporating the guidelines of ISO standards 20685, 15535, 8550 and 7250 and ASTM garment construction; the study will meet and exceed any requirements for products in Automotive, Apparel, Consumer, Digital, Medical and Military. An active sampling strategy will prioritize data as it is collected from near 18000 participants throughout the USA and Canada. Partnering with universities and the industry at large creates unique opportunities to create a clear picture of the population and target audiences simultaneously with the highest accuracy. It will also serve as a strong foundation for future projects focusing on body profiling, morphotypes and CAD application, while providing specific insights needed by each industry sector. While data from previous studies may be

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accelerated and extrapolated; it is still very much up to interpretation and prediction. Conducting studies actively to create concrete data that is representative reduces much of the variability that is biproduct and inherent of previous data and allows subscribers of the study the utmost accuracy in their work respectively.

Keywords Anthropometry · Anthropometric survey · Digital human model · Ergonomics · Human factors · 3D body scanning

1 Introduction

In an ongoing series of international size studies conducted by Human Solutions; Size NorthAmerica is the latest representative anthropometrical measurement survey of more than 17000 men, women and children. It will be carried out in the USA and Canada between March 2016 and September 2017, and will be the largest civilian study in the region to date. Measurement locations will be distributed across multiple regions in both the countries, complete with sociodemographic and three-dimensional body shape information consisting of more than 100 body measurements acquired using 3D scanners.

The objective of the survey is to detect and document temporal changes of the body measurements and proportions of men, women and children aged between 6 and 65 +. Based on the results, updated body measurement statistics (ISO 7250-compliant) will be acquired and an updated 3D human model database for the CAD model RAMSIS developed for the aerospace and automotive sectors. The apparel industry will subsequently be provided with updated body measurement statistics (ASTM D5219/ISO 8559 compliant) for clothing size charts and current market share information. These results also form the basis for an updated secular growth prognosis model for both the American and Canadian populations, which will last until 2040. The results of SizeNorthAmerica will be delivered by means of an online-portal, providing participating companies access to results online, with comprehensive functionality for data analysis. The project is implemented in close cooperation between Human Solutions and Vestechpro; partnering directly with industry and universities alike to ensure cohesiveness to the specific needs from each sector.

This paper will present the objectives of the participating companies, the conceptual design of the project, the scientific and technical challenges, and the basic results expected of the measurement survey. The difference between the current project results and the most important traditional anthropometrical data collections available will also be discussed.

Anthropometric design is one of the most important disciplines within the area of ergonomics. With the correct anthropometry layout, products and working tools can be used safely, comfortably and in a healthy manner. This is why many anthropometric studies were initiated in the last century—and in the second half of

that century anthropometric surveys were organized on a global scale [1]. Most of these were initiated by the logistic departments of national armies [2, 3].

The beginning of the 21st century saw a new era of anthropometric surveys. CAESAR (Civilian American and European Surface Anthropometry Resource) was the first survey which used a 3D body scanner to acquire 3D scans of body surfaces, as well as demographics data and traditional measurements [4, 5]. In 1999 and 2000 11000 subjects in Great Britain were scanned and manually measured (SizeUK); followed by SizeUSA in 2002. The "next step of evolution" was made in France in 2003–2005. 11562 subjects were scanned using a new technology, so parallel manual measurements were no longer used [6]. The Swedish survey of 2004/2005 scanned more than 4000 subjects, using the same technology and concept as the French survey. 2007 saw the initiation of several body scanning surveys in other countries like Spain and China; as well as SizeGERMANY (2009) and SizeItaly (2012).

Many institutes and universities such as UMTRI and PennState Open Design Lab rely on data collected in these and their own private studies for projects revolving around boundary manikins used in ergonomics software. Ensuring that they have the most current data reduces variance inherent in accelerating and extrapolating older data. The new survey Size NorthAmerica will be conducted throughout 2016/2017 in the United States and Canada.

2 Conceptual Design

The original objective of Size NorthAmerica is the acquisition of representative data for technical ergonomics use primarily in the apparel and automotive industries. The following features were defined as being required for the concept of a "new generation" of serial measurement programs. Measurement must take place solely with the help of body scanners in accordance with the ISO 20685. Standard body shapes must also be analyzed as a supplement to body dimensions.

The analysis of the body dimensions must take place in compliance with the market standards for technical ergonomics in accordance with ISO 7250 and for the apparel industry in accordance with ISO 8559. The results are made available in the form of a web-based, interactive data portal, enabling companies to carry out product-specific analyses online. The guidelines of the ISO 15535 [7] were also incorporated.

The expected results are offered to the industry in various packages, in accordance with scope of performance and market. Prior studies from Human Solutions included more than 100 companies from the apparel industry (e.g. adidas, BOSS, OTTO, C&A, Zara, QVC, Vaude…) and the automotive industry (BMW, Opel, Porsche, VW, Peugeot …) as participants.

Measurement of the test subjects will be conducted throughout early 2016 and the first half of 2017; the delivery of the final results are expected in September

2017. After a period of 18 months, the following definite focal points will be achieved:

- The measurement of the test subjects.
- The analysis of the dimensions and proportions of men's, women's and children's bodies.
- The derivation of all statistical characteristic measurements for the apparel and automotive industries.
- The development of market share tables for men, women and children.
- The analysis of the acquired data with regard to body shapes and proportions and the development of 3D standard body shapes. The provision of an anthropometric typology for CAD-Tool RAMSIS [8].
- The development of a secular growth simulation of the North American population which will last until 2040.
- The provision of all data and analyses in a web-based Online Portal and the support of companies participating in the Portal.

2.1 The Cornerstone—ISO 20685

In 2006 the ISO/TC 159 Technical Committee, Subcommittee SC3, announced the introduction of the ISO Standard 20685 (3D scanning methodologies for internationally compatible anthropometric databases). This standard goes into detail about the technical requirements of the body scanner and the characteristics of the hardware and software—for example, the scan volume of a test person is defined and a calibration method recommended. The clothing of the test persons and the methods for reducing errors in 3D scanning are also discussed. One further important element in the ISO 20685 is the functional properties of the software, by means of which the analysis of the scan data is carried out. This also includes the interaction between 3D measurement and combined measurement with landmarks, plus features of manual and automated measurement and the selection, segmentation and visualization of body parts and landmarks. Suitable postures for carrying out a study with body scanners are specified (ISO 20685 suggests four postures—three standing and one sitting). The ISO 20685 also discusses the different size definitions in the ISO 7250 and ISO 8559 and recommends the data set.

2.2 Selection of Subjects

The primary requirement for a serial measurement program is that it is represents the entire population. In most of the serial measurements which were carried out manually, two tenths of one percent of the population were selected as being

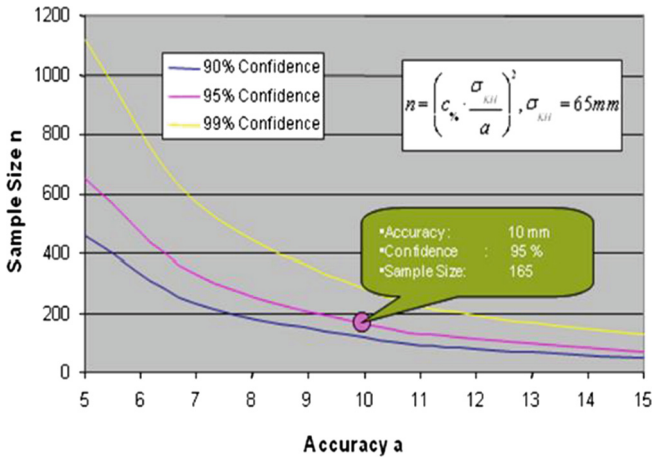

Fig. 1 Relation of Sample Size and required Accuracy

representative (based on the census information from the United States and Canada) and subsequently measured.

In addition to the incorporation of the ISO 15537 [9], current databases are constantly aligned with the statistically necessary data range [10]. In this dynamic monitoring of test persons, each person is classified with regard to gender, age and regional distribution. Based on the accuracy requirements of the partners, (10 mm for body length and 95 % confidence), this resulted in a sample size of at least 165 persons per group (Fig. 1). The number of test persons per class is aligned with the current census information from the United States and Canada. Due to the request to measure test persons of 6 years of age up to the maximum age, 18 age groups were specified. The first group began at 6 years of age, and the last age group was concluded by a group classed as open-ended (Table 1). To achieve an accurate regional distribution, sites are determined in accordance with population density in the main regions across the United States (Northeast, Midwest, South and West) and Canada (Quebec and Non-Quebec). This results in a minimum requirement of 17820 test persons (number of subjects = group size * number of age groups * number of regions).

During the survey of the test persons, their primary characteristics (age, region and gender) and secondary characteristics (ethnicity, weight and height); are acquired and analyzed online on a daily basis. All the measurement teams have online access to this analysis by means of web browser. As data is gathered, the type of test persons which are missing in the classes will be selectively measured and prioritized (Fig. 2).

Table 1 Age Groups of SizeNorthAmerica

Population	Age groups
Girls	6–10 years
	11–13 years
	14-17 years
Boys	6–10 years
	11–13 years
	14–17 years
Women	18–25 years
	26–35 years
	36–45 years
	46–55 years
	56–65 years
	Over 65 years
Men	18–25 years
	26–35 years
	36–45 years
	46–55 years
	56–65 years
	Over 65 years

Fig. 2 Web-based online analysis of sample sizes

2.3 Measurement Technology

VITUS Smart XXL body scanners with ANTHROSCAN software from Human Solutions are used to measure the test persons at the specified sites. This device was specially developed for extensive serial measurement programs—and is one of the only scanners which complies with the ISO 20685 [11]. These systems have proven themselves in numerous measurement surveys (Spain, France, Sweden, etc.).

The VITUS Smart XXL is a four-column, 3D body scanner which uses the optical triangulation measurement principle (laser technology and 100 % safe for the eyes). The 8 sensor heads have a measuring range of 2100 mm height, 1000 mm depth and 1200 mm width (ISO 20685). The level of accuracy of the system is very high—it has an average error (circumference) of less than 1 mm Within just 12s of scanning time, the sensors capture a density of 27 points/cm^2; approx. 550,000 3D points for each person are thus measured. Yet another advantage the system has is mobility. The weight of the measuring columns is less than 100 kg and the floor space required is only around 4.8 m^2.

2.4 Postures and Body Dimensions

In the selection of body dimensions, both the ISO Standards ISO 7250 [12] and ISO 8559 [13] are rigorously adhered to. This is advantageous in that the results for an industrial user already correspond to the way he uses body dimensions for his product development. The results are also very easily compared with those of older surveys. In cooperation with the industry partners, 43 body dimensions are defined for the apparel industry (ISO 8559) and 37 body dimensions for technical ergonomics (ISO 7250). 15 special body dimensions are also defined (used in the creation of 3D human models (e.g. RAMSIS) based on the measurements [5].

4 postures (three standing postures and one sitting posture) are necessary in order to analyze the 95 body dimensions (Fig. 3). On the left, the standing posture is represented by a stretched and angled arm posture—this enables the measurement of functional dimensions in standing posture. The second posture from the left is a

Fig. 3 Four Postures for Body Scanning

specific measurement posture for body circumferences. The third measurement posture from the left is a relaxed standing posture to determine the correct body lengths. The postures on the right shows the sitting posture with bent arms in order to correctly acquire all necessary measurements in sitting posture.

The weight of a test person is also electronically determined during scanning and more than 100 socio-demographic questions are asked by means of an electronic questionnaire.

2.5 *Data Quality Management*

A comprehensive and process-oriented data management process is used for SizeNorthAmerica to obtain exact body dimensions. This process is schematically displayed (Fig. 4). Each test person is reviewed after by a specialist during the entire measuring process. In a contact-free procedure, the test person is scanned in 4 different postures, wearing standardized apparel for measurement procedures. Then the electronic questionnaire is completed afterward. The entire timeframe involved totals between 20 and 30 min per test person. The measurement data is first saved locally but after each day of measurement, the data is transferred to the Analysis Portal during the night, in a fully automated process and stored in a central database. Data integrity, scanner quality and system calibration are checked during an additional quality control process. The initial analysis of the body dimensions takes place automatically by means of software.

In a second step, trained specialists used computers to check that the positions of the reference points are correct. Every change in the dimensions (and the dimensions' history) are saved in a local database. When the entire process is finished, the data is once again transferred into the central database.

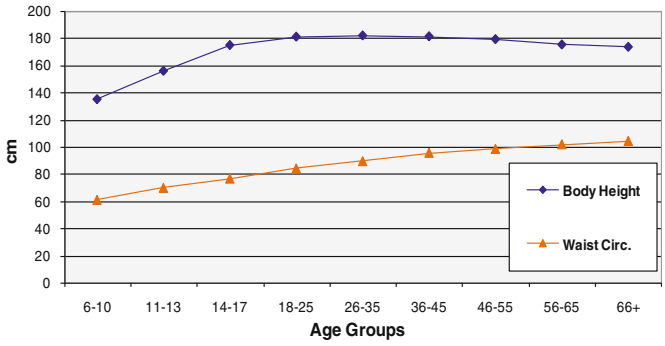

Fig. 4 Relation of Age Groups to body dimensions

3 Results

In order to adequately gauge the change in the North American population, it makes sense to compare the results with those of earlier serial measurements. We expect to see similar changes in the population that occurred with previous studies.

In the case of Size Germany, the most up-to-date available reference was the DIN 33402 study of 1999–2002. The analysis was based on various summarized measurements taken in East and West Germany. The results were analyzed in 4 age groups [14]—18–25, 26–40, 41–60 and 61–65 +. In order to compare these results with those of SizeGERMANY, the results were again analyzed for the DIN 33402 age groups.

Table 2 shows the changes in dimensions for body height and chest circumference. The 50th percentile for body height increased by 42 mm from 1,750–1,792 mm Height increased in the medium age groups amounts to more than 50 or 51 mm The chest circumference of men showed a greater increase for the 50th percentile than for all the other age groups—from 975 to 1049 mm—an increase of 74 mm This increase remains more or less constant throughout the age groups from 55 mm (18–25) to 93 mm (61–65).

Table 3 displays the differences between DIN 33402 and SizeGERMANY for the 50th percentile women. The body height of women increases throughout the age groups by 39 mm The waist circumference increases on average by 82 mm—however, growth in the oldest age group (61–65) has risen from 815 to 938 mm—an increase of 123 mm This marked increase could possibly be accounted for by the significantly greater number of SizeGERMANY subjects in this age group. A look at the sitting height shows that growth in this case is less than that of body height. This means that the increase in body height is mainly due to an increase in leg length.

Table 2 Difference SizeGERMANY to DIN33402

MEN	Age	**DIN 33402 P50 [mm]**	**SizeGERMANY 2008 P50 [mm]**	**Difference P50 [mm]**
Body Height	18–25	1790	1805	**15**
	26–40	1765	1815	**50**
	41–60	1735	1786	**51**
	61–65	1710	1746	**36**
	18–65	**1750**	**1792**	**42**
Chest circumference	18–25	930	985	**55**
	26–40	970	1032	**62**
	41–60	995	1081	**86**
	61–65	990	1083	**93**
	18–65	**975**	**1049**	**74**

Table 3 Difference SizeGERMANY to DIN33402

WOMEN	Age	DIN33402 P50 [mm]	SizeGERMANY P50 [mm]	Difference P50 [mm]
Korperhohe	18–25	1660	1673	13
	26–40	1635	1683	48
	41–60	1615	1654	39
	61–65	1595	1619	24
	18–65	**1625**	**1664**	**39**
Waist circumference	18–25	730	734	4
	26–40	780	775	-5
	41–60	820	859	39
	61–65	815	938	123
	18–65	**730**	**812**	**82**
Sitting height	18–25	880	883	3
	26-40	870	886	16
	41–60	855	869	14
	61–65	840	848	8
	18–65	**860**	**875**	**15**

The trend throughout the age groups for the most important characteristic measurements for men in SizeGERMANY (Fig. 4). It is apparent that average body height of the older age groups decreases. This decrease slows considerably in the case of the 26–35 and 36–45 age groups. This can be seen as an indication that the trend of secular growth in Germany is clearly slowing.

Yet another important trend can be seen in Table 4. Here the 5th percentile and the 95th percentile of body height and chest circumference from SizeGERMANY

Table 4 Change of 5th and 95th Percentile

MEN	Age	**DIN 33402**		**SizeGERMANY**		**Difference**	
		P5 [mm]	**P95 [mm]**	**P5 [mm]**	**P95 [mm]**	**P5 [mm]**	**P95 [mm]**
Body height	18-25	1685	1910	1683	1938	**-2**	**28**
	26-40	1665	1870	1690	1965	**25**	**95**
	41-60	1630	1835	1662	1923	**32**	**88**
	61-65	1605	1805	1636	1877	**31**	**72**
	18-65	**1650**	**1855**	**1668**	**1940**	**18**	**85**
Chest circumference	18-25	845	1055	885	1133	40	**78**
	26-40	860	1090	917	1222	**57**	**132**
	41-60	880	1145	948	1249	**68**	104
	61-65	880	1125	951	1271	**71**	**146**
	18-65	**870**	**1110**	**918**	**1235**	**48**	**125**

are shown in comparison to DIN 33402. If you look at the population from 18–65 years, the 5th percentile (body height) increases by only 18 mm In contrast, the 95th percentile (body height) shows a considerable increase of 85 mm (1,855–1,940 mm).

Chest circumference data behaves similarly. While the 5th percentile increases by 48 mm (from 870 to 918 mm), the 95th percentile (chest circumference) increases by 125 mm, from 1110 to 1235 mm In general, all body dimensions have one thing in common—the distribution function of the dimensions extends increasingly to the right.

4 iSize Portal

One of the important innovative objectives of SizeNorthAmerica is to provide the partners with an Online Portal which will give them access to the survey data. Fast access to the results is not the only focal point, however—the companies also want to be able to analyze the data themselves, and use the results for their customers and products.

This is why Human Solutions developed iSize. The challenge here was to develop a simple user interface and to provide a full range of analysis functions. The user can select whether all analyses should relate to any combination of genders for men, women, boys or girls; while also including the region age groups. Socio-demographic characteristics and body measurements within specific ranges may also be included as filters. Based on this selection of test subjects, further analyses for ergonomics are made possible for:

- socio-demographic data
- body dimensions
- percentiles
- correlations
- size table optimization
- market shares

The analysis on the portal can be accessed by standard web browsers which are available on the market. A desired analysis is calculated online on the central statistics server and made available to the user in the form of a preview and a detailed, automated data sheet.

5 Conclusion

The activities involved in Size NorthAmerica are carried out within an association of partner companies under the leadership of Human Solutions and the Vestechpro Institutes. Add-ons to the Portal are already in the pipeline, and the functions of the

Portal will be systematically expanded—e.g. a direct interface to the 3D ergonomics tool RAMSIS will be created.

Companies which offer their products worldwide will be able to use the latest anthropometric data to develop their products ergonomically—addressing the specific needs of their customers in multiple regions concurrently and allows subscribers of the study the utmost accuracy in their work respectively.

While data from previous studies may be accelerated and extrapolated; it is still very much up to interpretation and prediction. Conducting studies actively to create concrete data that is representative reduces much of the variability that is biproduct and inherent of previous data.

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Assessing the Relationship Between Hand Dimensions and Manual Dexterity Performance for Turkish Dental Students

Erman Çakıt, Behice Durgun and Oya Cetik

Abstract The objectives of this study included: (i) a determination of whether there is a difference in manual dexterity as a function of gender and dentistry curriculum and (ii) an assessment of hand anthropometric characteristics on manual dexterity test performance. In total, 155 dental students (86 males and 69 females) in their first, second, third, fourth, and fifth years of a five-year undergraduate program took part in the study that involved a simple manual dexterity test. We used a paired sample t-test to compare differences between males and females and among students of different years. Pearson's correlation coefficients were computed as a measure of association between parameters. The results demonstrate that anthropometric data of both hands have small but significant effects on test performance, and that small hands are associated with better test performance.

Keywords Hand anthropometry · Manual dexterity · Dentistry

1 Introduction

Hand dexterity is particularly important for activities that require fine and rough muscle control. Fine motor hand dexterity becomes important for drawing, machine operations and effectively using hand tools. Dentistry is a good example of fine work that requires hand and finger dexterity. There are a number of established tests that can be used to measure dexterity, though the two most common tests reported

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in the literature are the Box and Block [1] and the Purdue Pegboard Tests [2]. These two tests are complementary, as they measure gross versus fine dexterity respectively by measuring 'power grip' versus 'pinch grip' [3]. Both tests are simple and easy to administer and have high test-retest reliability (see for example [4–6]). Other manual dexterity tests exist in the literature that assess an individual's ability to manipulate objects with their hands such as the Jebsen Taylor Test [7], 9-Hole peg test [8] and Roeder manipulative Aptitude test [9]. In this study, we used the Roeder Manipulative Aptitude Test as a measure of hand, arm, finger dexterity, and speed; this test is suitable for testing elementary-school through college-aged students when dexterity is a primary requirement.

Hand anthropometry is also very important to be used in designing projects dealing with human hands [10]. The examples of such facilities are machine guards, hand tools, handles of luggage, and so on [11]. With reviewing the literature, hand dexterity has been related with many factors. Considering these studies, deficiency of relation between hand dexterity and hand dimensions is observed. Salvendy [12] studied the importance of hand sizes in the job accommodations. Totally, twelve hand dimensions were associated with the results of hand dexterity tests. Gansky et al. [13] applied dexterity tests to see how much the students were ready for clinical applications. Ojimba et al. [14] highlighted the importance of hand dexterity acquisition at early stages for dentistry education. Lundergan et al. [15] applied dexterity tests to predict dentistry students' school performance at theoric and pratic courses. Giuliani [16] aimed to assess whether initial manual dexterity can improve with training in pre-clinical and clinical practice. The objectives of this study included: (i) an assessment of hand anthropometric characteristics on manual dexterity test performance and (ii) a determination of whether there is a difference in manual dexterity as a function of gender and dentistry curriculum.

2 Materials and Methods

2.1 Participants

One hundred and fifty-five participants (86 males and 69 females) were recruited randomly from dentistry students of the Cukurova University. A total of 20 students (13 %) were in their first year, 40 students (26 %) were in their second year, 33 students (21 %) were in their third year, 26 students (17 %) were in their fourth year and 36 students (23 %) were in their fifth year. Their average age (standard deviation) of the cohort was 22.06 (2.14) years, and their average height was 169.83 (8.80) cm. The students furthermore had an average body mass of 67.41 (12.72) kg. Of the 86 males, only 11 were left-handed, and the remaining 75 were right-handed; of the 69 females, only 1 was left-handed, and the remaining 68 were right-handed. All participants were notified for the study and they each indicated their willingness to participate by signing 'Consent to Participate' form. This study was approved by the Institutional Review Board for Research with Human Subjects at Cukurova

University. Three experimenters were trained to take the measurements in this survey by practice on themselves. They started data collection only after their measurements were considered accurate and consistent. Measurements were taken repeatedly from the same people on a daily basis between 08:00 to 17:00 and it took over a period of two months.

2.2 Apparatus and Measurements

A manual stopwatch was used to time the test activities. Finger dimensions, hand and palm breadth, and hand depth were measured using an electronic digital caliper, with an accuracy of 0.01 mm/0.0005 inch.

Finger circumferences were measured using a finger circumference gauge, with an accuracy of 0.0625 inch, and then converted to mm. Hand length was measured using a digital tape measure, with an accuracy of 1 mm. All definitions and technique of hand measurements correspond to the guidelines in [18, 19]. Hand dimensions are summarized in Table 1 and corresponding diagrams are illustrated in Fig. 1.

2.3 Roeder Manipulative Aptitude Test

The Roeder Manipulative Aptitude Test has been selected as a measure of hand, arm, finger dexterity, and speed for testing elementary through college students when dexterity is a primary requirement. The styrene-plexiglass board has four receptacles for the separate reception of the washers, rods, caps and nuts (Fig. 2). The test manual is available in the literature for further explanations of Roeder Manipulative Aptitude Test [9].

2.4 Test Procedure

There are four tests in the testing procedure; however, five scores were calculated from the three tests. Each subject was informed about performing each test as quickly and accurately as possible. The test was explained and each participant was allowed to practice before each experiment.

The first test is assembly test. Subjects were instructed, “This is a Manipulative Aptitude or Dexterity Test to determine how accurately and fast you can work with your hands. Pick up a rod in this manner and, with a quick twist, screw it into the socket at the far left in the top row. Then take a cap and, with a quick twist, screw the cap onto the rod. If you are right-handed, use your right hand. If you are left-handed, use your left hand. In other words, use whichever hand is more

Table 1 Hand dimensions

1	Fingertip to root digit 1	7	Breadth at first joint of digit 2	13	Breadth at second joint of digit 3	19	Circumference at first joint of digit 4	25	Circumference at second joint of digit 5
2	Fingertip to root digit 2	8	Breadth at first joint of digit 3	14	Breadth at second joint of digit 4	20	Circumference at first joint of digit 5	26	Hand breadth across thumb
3	Fingertip to root digit 3	9	Breadth at first joint of digit 4	15	Breadth at second joint of digit 5	21	Circumference at second joint of digit 1	27	Hand length
4	Fingertip to root digit 4	10	Breadth at first joint of digit 5	16	Circumference at first joint of digit 1	22	Circumference at second joint of digit 2	28	Palm breadth
5	Fingertip to root digit 5	11	Breadth at second joint of digit 1	17	Circumference at first joint of digit 2	23	Circumference at second joint of digit 3	29	Hand depth
6	Breadth at first joint of digit 1	12	Breadth at second joint of digit 2	18	Circumference at first joint of digit 3	24	Circumference at second joint of digit 4	30	Hand breadth at metacarpals

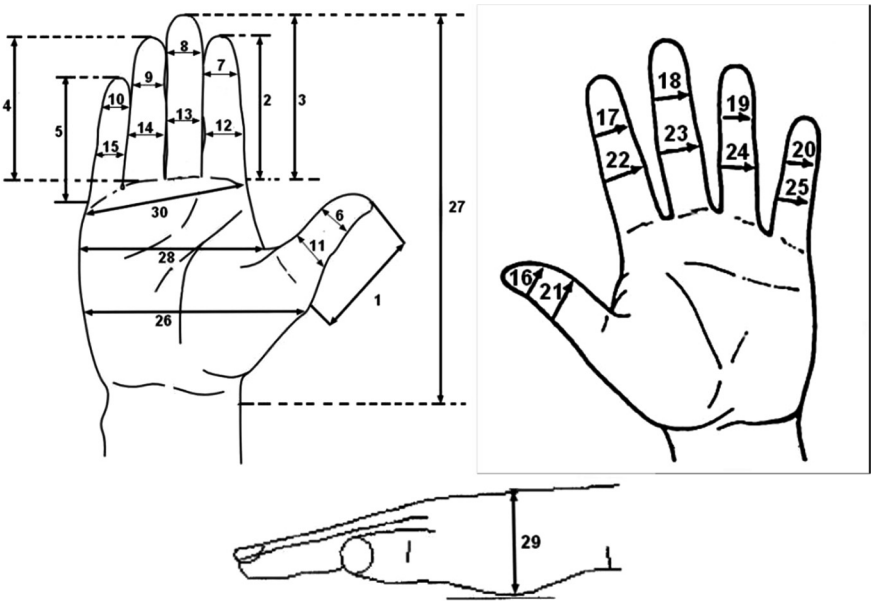

Fig. 1 Hand dimensions; refer to corresponding numbers in Table 1 *Source* [17]

Fig. 2 Roeder manipulative aptitude test

comfortable or convenient for you but use only one hand. Steady the board with the other hand. The object is to make as many of these assembly jobs as possible in a time limit of 3 min. Start at the upper left corner and move along the row to the right. After one row has been assembled, move down the next row, etc., always starting at the far left. Remember, place a rod and cap it, place a rod and cap it, etc. You may practice assembling several. If you are left-handed start at the opposite side of the board and work to the left." The second test involved both hand. "Slide as many washers and nuts onto the T-Bar as possible in a 40-s time period.

Using both hands together, pick up a washer in each hand and slide them onto each end of the T-Bar next to the washers. Continue in this fashion, alternating one washer and one nut, etc., for a time period of 40-seconds. Using both hands at the same time, try to place as many washers and nuts as possible."

For the third and fourth test, this procedure was repeated with the right hand and left hand respectively. A fifth score (Total Manipulative Score) was derived from the previous tests:

1. Calculate the number of rods screwed and write the total number under the label "Rods".
2. Calculate the number of caps screwed and write the total number under the label "Caps".
3. Calculate the total number of washers and nuts on the T-Bar and write the total number in under the label "Washers and Nuts-Both Hands".
4. Finally, sum all three scores obtained previously and write this total raw score under the label "Total Manipulative Score" [9].

2.5 Statistical Analysis

The descriptive statistics for manual dexterity tests were summarized in terms of mean and standard deviation (SD). The paired sample t-test was conducted to compare differences between males and females and among classes. Pearson's correlation coefficients were computed as a measure of association between parameters. The correlation of all anthropometric parameters with hand dexterity was tabulated. All statistical analysis was performed using a IBM SPSS, Version 22 for Windows (IBM SPSS Inc., Chicago, IL, USA) software package.

3 Results and Discussion

The mean and standard deviation of the dexterity test results are given in Table 2. For dexterity test results, all 5 female means were greater than the corresponding male's and *t*-tests showed that 4 of the 5 differences in means were statistically significant ($p < 0.01$) Among classes, the differences between 3rd and 4th classes were found statistically significant for both total and assembly score ($p < 0.01$) (Table 3). The theoretical courses are intensive at first and second year of dentistry faculties in Turkey, and then the practical courses are getting intensive. These results may be due to the development of manual skills and increasing the coordination of fine and gross movements developed through learning and experience. The Pearson correlation coefficient for each anthropometric data with test scores was tabulated. Tables 4 and 5 illustrate that anthropometric data of both hands have little but significant effects on test performances.

Table 2 Descriptive statistics for manual dexterity of Turkish male and female dentistry students

	Males (n = 86)				Females (n = 69)	
	Right-handed (n = 75)		Left-handed (n = 11)		Right-handed (n = 68)*	
Dexterity test	Mean	SD	Mean	SD	Mean	SD
Total score	66.29	9.08	52.36	5.59	71.10	9.15
Assembly score	44.14	7.60	31.45	4.80	47.39	7.81
Right hand score	17.45	2.10	15.18	1.53	18.35	2.16
Left hand score	15.78	2.20	16.27	2.10	16.50	2.09
Pair hand score	22.12	2.91	20.90	2.73	23.70	3.22

S.D Standard Deviation
*left-handed person (n = 1) was not included

Table 3 Comparison of genders and classes for each dexterity score (n = 155)

Gender/class comparison	Measurement	Total score	Assembly score	Right hand score	Left hand score	Pair hand score
Males versus Females	t	−4.020	−3.462	−3.297	−1.950	−3.376
	Mean diff.	−6.271	−4.607	−1.156	−0.673	−1.687
	p	0.000**	0.001**	0.001**	0.053	0.001**
1st versus 2nd	t	−1.013	−0.732	0.038	−0.990	−1.035
	Mean diff.	−2.650	−1.650	0.025	−0.600	−0.950
	p	0.316	0.468	0.971	0.328	0.306
1st versus 3rd	t	−1.979	−1.732	−0.147	−1.581	−1.355
	Mean diff.	−5.398	−4.192	−0.090	−0.968	−1.206
	p	0.054	0.090	0.884	0.121	0.183
1st versus 4th	t	0.887	0.801	0.182	−0.179	0.497
	Mean diff.	2.450	1.973	0.115	−0.111	0.476
	p	0.380	0.428	0.857	0.859	0.622
1st versus 5th	t	−0.754	−1.010	2.269	0.670	0.662
	Mean diff.	−1.855	−2.311	1.361	0.350	0.455
	p	0.455	0.318	0.030*	0.506	0.511
2nd versus 3rd	t	−1.081	−1.242	−0.208	−0.675	−0.315
	Mean diff.	−2.748	−2.542	−0.115	−0.368	−0.256
	p	0.283	0.219	0.836	0.502	0.754
2nd versus 4th	t	1.937	1.726	0.151	0.848	1.626
	Mean diff.	5.100	3.623	0.090	0.488	1.426
	p	0.057	0.090	0.880	0.400	0.109
2nd versus 5th	t	0.349	−0.350	2.516	1.956	2.020
	Mean diff.	0.794	−0.661	1.336	0.950	1.405
	p	0.728	0.727	0.014*	0.054	0.047*

(continued)

Table 3 (continued)

Gender/class comparison	Measurement	Total score	Assembly score	Right hand score	Left hand score	Pair hand score
3rd versus 4th	t	2.916	2.708	0.396	1.514	1.984
	Mean diff.	7.848	6.165	0.206	0.856	1.682
	p	0.005**	0.009**	0.694	0.136	0.053
3rd versus 5th	t	1.501	0.907	3.044	2.746	2.655
	Mean diff.	3.542	1.881	1.452	1.318	1.661
	p	0.138	0.368	0.003**	0.008**	0.010*
4th versus 5th	t	−1.779	−2.007	2.504	0.950	−0.032
	Mean diff.	−4.305	−4.284	1.245	0.461	−0.021
	p	0.081	0.050	0.015*	0.346	0.975

* Statistically significant ($p < 0.05$)
** Statistically significant ($p < 0.01$)

Table 4 Pearson's correlation between right hand dimensions and dexterity scores for all students (n = 155)

Right hand dimension	Total score	Assembly score	Right hand score	Left hand score	Pair hand score
(1)	−0.195*	−0.180*	−0.118	−0.119	−0.144
(2)	−0.199*	−0.185*	−0.144	−0.140	−0.147
(3)	−0.196*	−0.177*	−0.157	−0.154	−0.158*
(4)	−0.229**	−0.204*	−0.142	−0.149	−0.191*
(5)	−0.238**	−0.224**	−0.161*	−0.141	−0.167*
(6)	−0.222**	−0.149	−0.293**	−0.233**	−0.317**
(7)	−0.289**	−0.249**	−0.199*	−0.173*	−0.255**
(8)	−0.343**	−0.303**	−0.248**	−0.169*	−0.288**
(9)	−0.320**	−0.272**	−0.230**	−0.156	−0.298**
(10)	−0.337**	−0.294**	−0.246**	−0.137	−0.291**
(11)	−0.246**	−0.197*	−0.206*	−0.176	−0.259**
(12)	−0.324**	−0.275**	−0.243**	−0.215**	−0.299**
(13)	−0.333**	−0.295**	−0.239**	−0.169*	−0.276**
(14)	−0.337**	−0.295**	−0.240**	−0.191*	−0.288**
(15)	−0.345**	−0.291**	−0.286**	−0.200*	−0.326**
(16)	−0.208**	−0.154	−0.283**	−0.198*	−0.256**
(17)	−0.210**	−0.174*	−0.223**	−0.137	−0.208**
(18)	−0.221**	−0.193*	−0.197*	−0.089	−0.191*
(19)	−0.283**	−0.250**	−0.247**	−0.120	−0.235**
(20)	−0.206*	−0.182*	−0.234**	−0.078	−0.174*
(21)	−0.241**	−0.218**	−0.198*	−0.124	−0.188*
(22)	−0.314**	−0.278**	−0.208**	−0.175*	−0.260**

(continued)

Table 4 (continued)

Right hand dimension	Total score	Assembly score	Right hand score	Left hand score	Pair hand score
(23)	−0.318**	−0.278**	−0.212**	−0.150	−0.273**
(24)	−0.278**	−0.229**	−0.202*	−0.157	−0.278**
(25)	−0.358**	−0.331**	−0.224**	−0.159*	−0.261**
(26)	−0.227**	−0.203*	−0.117	−0.087	−0.183*
(27)	−0.220**	−0.195*	−0.143	−0.103	−0.184*
(28)	−0.295**	−0.258**	−0.234**	−0.167*	−0.253**
(29)	−0.315**	−0.285**	−0.195*	−0.124	−0.240**
(30)	−0.270**	−0.245**	−0.207**	−0.155	−0.209**

**Correlation is significant at the 0.01 level (2-tailed)
*Correlation is significant at the 0.05 level (2-tailed)

Table 5 Pearson's correlation between left hand dimensions and dexterity scores for all students (n = 155)

Left hand dimension	Total score	Assembly score	Right Hand score	Left Hand score	Pair hand score
(1)	−0.227**	−0.202*	−0.188*	−0.144	−0.187*
(2)	−0.204*	−0.197*	−0.137	−0.124	−0.130
(3)	−0.211**	−0.186*	−0.147	−0.173*	−0.182*
(4)	−0.227**	−0.203*	−0.156	−0.177*	−0.188*
(5)	−0.199*	−0.185*	−0.176*	−0.147	−0.145
(6)	−0.309**	−0.231**	−0.310**	−0.201*	−0.375**
(7)	−0.375**	−0.334**	−0.297**	−0.132	−0.307**
(8)	−0.397**	−0.357**	−0.304**	−0.126	−0.311**
(9)	−0.361**	−0.317**	−0.292**	−0.144	−0.308**
(10)	−0.297**	−0.260**	−0.225**	−0.137	−0.254**
(11)	−0.333**	−0.278**	−0.302**	−0.177*	−0.322**
(12)	−0.385**	−0.335**	−0.312**	−0.181*	−0.336**
(13)	−0.364**	−0.321**	−0.281**	−0.181*	−0.304**
(14)	−0.384**	−0.334**	−0.311**	−0.199*	−0.335**
(15)	−0.386**	−0.347**	−0.283**	−0.168*	−0.304**
(16)	−0.285**	−0.217**	−0.344**	−0.194*	−0.334**
(17)	−0.267**	−0.246**	−0.286**	−0.081	−0.198*
(18)	−0.313**	−0.281**	−0.326**	−0.112	−0.249**
(19)	−0.339**	−0.302**	−0.323**	−0.101	−0.276**
(20)	−0.280**	−0.256**	−0.253**	−0.101	−0.211**
(21)	−0.310**	−0.276**	−0.270**	−0.121	−0.257**
(22)	−0.350**	−0.315**	−0.236**	−0.134	−0.279**

(continued)

Table 5 (continued)

Left hand dimension	Total score	Assembly score	Right Hand score	Left Hand score	Pair hand score
(23)	−0.318**	−0.276**	−0.238**	−0.162*	−0.278**
(24)	−0.354**	−0.320**	−0.244**	−0.151	−0.276**
(25)	−0.353**	−0.323**	−0.262**	−0.158*	−0.266**
(26)	−0.258**	−0.236**	−0.181*	−0.085	−0.197*
(27)	−0.236**	−0.204*	−0.156	−0.122	−0.210**
(28)	−0.283**	−0.251**	−0.219**	−0.125	−0.234**
(29)	−0.294**	−0.258**	−0.194*	−0.134	−0.245**
(30)	−0.314**	−0.292**	−0.254**	−0.165*	−0.225**

**Correlation is significant at the 0.01 level (2-tailed)
*Correlation is significant at the 0.05 level (2-tailed)

4 Conclusion

This study was conducted to investigate the relationship between hand measurements and manual dexterity of Turkish dental students. The manual dexterity test performances of female students seem to be better than male students. In other words, the results show that small hands have better test performances. The differences among classes show the development of manual skills and increasing the coordination of fine and gross movements developed through learning and experience. In conclusion, hand dimensions may be used to helpful as part of a test battery during the curriculum of dental students.

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Part VII
Performance and Productivity

Optimal Arrangement of Inertial Sensors for Workload Estimation Using Digital Human Model Based on Body Surface Deformation Analysis

Saori Miyajima, Natsuki Miyata, Mitsunori Tada, Takayuki Tanaka and Masaaki Mochimaru

Abstract Nowadays, digital human models are often used to evaluate the usability of manufactured products. Such models can also be used to estimate loads on the body when motions are input and musculoskeletal simulations are carried out. When actual work motions are input into the digital human correctly, an accurate workload can be estimated. We used the "Dhaiba" digital human to estimate workload, and we used inertial sensors to measure work motion. In this paper, we propose the optimal sensor arrangement on the back for measuring waist posture based on analysis of body surface deformation due to motion.

Keywords Digital human model · Motion capturing · Sensor arrangement · Posture estimation · Body surface shape

1 Introduction

Digital human models (DHMs) are often used for ergonomic design [1, 2]. It is also used to calculate a burden on the body by inputting motion data and running inverse dynamics analysis. This approach is effective finding the problems with work and

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optimizing work environments [3, 4]. We are currently developing a system for evaluating workload and the effect of a wearable assistive device using a DHM [5]. In this system, work motion in a real environment is measured by inertial sensors. Each sensor comprises a three-axis accelerometer and a three-axis gyroscope. There are mainly three ways measuring motion to instruct for DHM. One is using marker based optical motion capture system [6]. Second is using markerless optical motion capture system which uses depth camera, such as Microsoft Kinect [7]. Third is using inertial sensors. In these three ways, using inertial sensors is the most suitable one for measuring motion in actual work space. When inertial sensors are used to obtain motion data for a DHM, measured angles need to be converted into bone inclination angles to give motion information. This conversion involves not only the positional relationship between the bones and sensors, but also the deformation of the body surface through changes in posture and variation according to individual physique. The position and number of sensors affect these deformations and differences. Thus, this report aims to determine the optimal arrangement of inertial sensors that is able to measure body motions to be analyzed with DHM and that is least affected by deformation and individual differences of the body surface. In other words, we aim to find the position where the relational model between bone angle and sensor angle is the same for all participants and motions.

Accordingly, sensor position was evaluated in terms of robustness for this condition. The posture of the back was observed while the knees and waist were bent without twisting. First, we obtained data for the full-body posture and back surface shape using an optical motion capture system with markers arranged along the spine. Instead of sensor on the back, a vector connecting two adjacent markers on the spine represented the inclination of the back surface shape. A posture of the DHM's bone was instructed by inputting the motion data. Next, a linear model was used to express the relationship between inclination of the DHM's bone and the sensor at each candidate sensor position. Robustness for surface deformation of a certain position was expressed as an average of standard deviation of the model from four motions for each participant, and robustness for individual differences was also regarded as standard deviation of the model of participants. After that, an evaluation function is defined by the sum of above two standard deviations.

2 Sensor Arrangement Optimization Using Digital Human Model

2.1 Procedure of Optimization

The measurement target in this report was the motion of bending the waist, knees, and ankles without twisting the torso. The optimal sensor position for estimating the DHM's back posture was evaluated using the following procedure, on the assumption that only one inertial sensor on the back would be used to measure motion.

1. Determining DHM's back posture θ_l, θ_t
2. Obtaining inclination angle ψ_n of the sensor at candidate point P_n
3. Substituting θ_l, θ_t, and ψ_n into the evaluation function
4. Repeating the above steps for all candidate points P_n and comparing the results of evaluation function

2.2 Digital Human Model "Dhaiba"

We used Digital human model called "Dhaiba" [8], which was developed by the Digital Human Research Group in National Institute of Advanced Industrial Science and Technology in Japan in this research. The Dhaiba model, shown in Fig. 1 consists of a linkage model "armature" composed of "bones" as well as a skin mesh model that forms a body surface shape. and feature points arranged on the body surface. The Dhaiba deforms and can reproduce body surface shape according to the change in the bones' posture. Using an optical motion capture data with the same marker arrangement as the feature points defined on the Dhaiba model enables the model to reproduce the participant's physical build and motions. [9, 10].

2.3 Definition of DHM's Posture

The target was the angle of two bones: SPINE and STERNUM, which constitute the back posture of the Dhaiba model. The angle of the bones was defined as the angle with respect to the direction of gravity on the sagittal plane and written as $\boldsymbol{\theta} = [\theta_l, \theta_t]^{\mathrm{T}}$. Each bone has a local coordinate system based on its proximal link coordinate system. The root of all bones is PELVIS. In this research, the coordinate

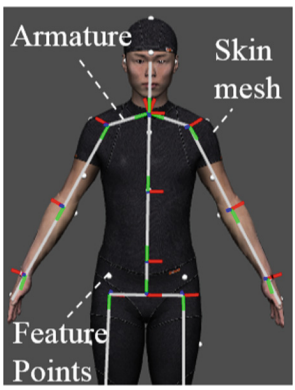


Fig. 1 Dhaiba model

system of PELVIS, written as (X_P, Y_P, Z_P) was set in the same direction as the global coordinates system (X_W, Y_W, Z_W), and all bones' X-axis were parallel to X_W. The angles with respect to the Z_W-axis were obtained using R_{PELVIS}, R_{SPINE} and $R_{STERNUM}$, which was the bone rotation angle around the X-axis from the following equation.

$$\begin{aligned} \theta_l &= R_{PELVIS} + R_{SPINE} \\ \theta_t &= R_{PELVIS} + R_{SPINE} + R_{STERNUM} \end{aligned} \tag{1}$$

These bone rotation angle is inclination from its parent link and positive rotational direction was set to the one of right handed screw around X-axis. The positional relationship of these bones and angles is shown in Fig. 2. Axis Z_W'' and Z_W' is parallel to Z_W. The coordinate system (x_s, y_s, z_s) is a sensor coordinate system, as explained in the next section.

2.4 Sensor Definition

Next, the candidate area for setting sensors was defined. The attachment position was set on the spine at the center of the back. The candidate area was defined by dividing the curve of the spine from the seventh cervical vertebrae (C7) to the sacral bone into ten equal sections. The center point of each divided curve was set as candidate point P_n and the points were numbered in descending order from the C7 side following the format P_1, P_2, P_3, …, P_{10}. The angle, written as ψ_n, was the inclination of the accelerometer on the point P_n with respect to the direction of gravity on the sagittal plane. When a 3-axis accelerometer is put on P_n so that y_s axis faces toward lower end of spine and x_s axis faces toward the direction perpendicular to the back, sensor angle ψ_n is calculated from the gravitational acceleration ($^a x_n$, $^a y_n$, $^a z_n$) detected by the accelerometer as

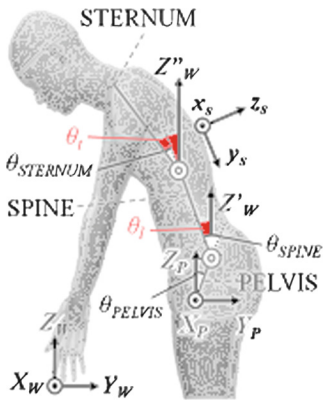


Fig. 2 Elements and direction of each axis

$$\psi_n = \tan^{-1} \frac{{}^{a}z_n}{{}^{a}y_n} \tag{2}$$

The bone angle $\boldsymbol{\theta}$ was described using the angle ψ_n. The formula estimating $\boldsymbol{\theta}$ was expressed with a coefficient matrix $\boldsymbol{A}_n \in R^{2\times 2}$ as

$$\begin{bmatrix} \theta_l \\ \theta_t \end{bmatrix} = \boldsymbol{A}_n \begin{bmatrix} \psi_n \\ 1 \end{bmatrix} \tag{3}$$

Although the spine is a structure made of multiple links, each candidate area can be considered a rigid body due to its division into ten parts. For this reason, the relationship between ψ_n and $\boldsymbol{\theta}$ was assumed to be a linear relationship and the elements of the coefficient matrix $\boldsymbol{A}_n$ were defined as real-valued constants.

$$\boldsymbol{A}_n = \begin{bmatrix} a_n^{11} & a_n^{12} \\ a_n^{21} & a_n^{22} \end{bmatrix} \tag{4}$$

Each coefficient a_n^{ij} was calculated by a single regression analysis using a linear model. Optimal sensor position was detected under these conditions.

2.5 Evaluation Method

The following two properties were considered requirements of an optimal sensor position.

(a) Less affected by surface deformation caused by posture change
(b) Less affected by individual difference of body shape

If item (a) is satisfied, the same estimation formula can be used to obtain $\boldsymbol{\theta}$ from ψ_n for all motions. Thus, item (a) was evaluated by the standard deviation of $\boldsymbol{A}_n$ in formula (3) for different postures. When there are different K motions, the standard deviation ${}^{m}\sigma_n^{ij}$ is calculated from the element ${}_k^{m}a_n^{ij}$ in the coefficient matrix ${}_k^{m}\boldsymbol{A}_n$ for the kth motion of the mth participant by the following equation.

$${}^{m}\sigma_n^{ij} = \sqrt{\frac{1}{K}\sum_{k=1}^{K}\left({}_k^{m}a_n^{ij} - {}^{m}\bar{a}_n^{ij}\right)^2} \tag{5}$$

Here, ${}^{m}\bar{a}_n^{ij}$ expresses the average of ${}_k^{m}a_n^{ij}$ for all motions k.

However, if item (b) is satisfied, then ψ_n of all participants is equal when their angles θ_l and θ_t are equal, even when there are individual differences in physique. Thus, item (a) was evaluated by the standard deviation of $\boldsymbol{A}_n$ for different

participants. The standard deviation ς_n^{ij} is calculated from the element ${}^m a_n^{ij}$ in the matrix ${}^m\boldsymbol{A}_n$ for the mth participant in M participants by the following equation.

$$\varsigma_n^{ij} = \sqrt{\frac{1}{M}\sum_{m=1}^{M}\left({}^m a_n^{ij} - {}^m \bar{a}_n^{ij}\right)^2} \tag{6}$$

Accordingly, evaluation function $X(n)$ for sensor position was expressed by formula (7). The point P_n that minimized $X(n)$ was chosen as the sensor position.

$$X(n) = \sum_{(i,j)=(1,1)}^{(2,2)} \left(\varsigma_n^{ij} + \frac{1}{M}\sum_{m=1}^{M} {}^m\sigma_n^{ij}\right) \tag{7}$$
$$\arg_n \min X(n)$$

3 Experiment on Motion Measurement

3.1 Experimental Methods

A motion of lifting a 5-kg box was captured in order to examine the relationship between the posture of the Dhaiba model and the actual shape of back surface in a live trial. The measured motions and direction of the global coordinate axes are shown in Fig. 3. Participants were instructed to time their movements, using a metronome, such that each part of the motion was 3s. The set of motion was measured three times and two of the three resultant datasets were analyzed for each participant. Furthermore, static posture was measured to construct the individual model for reproducing the participant's physical build as mentioned in Sect. 2.2. Participants were 6 males in their 20s. The height and weight of each participant are listed in Table 1. The VICON optical motion capture system with ten MX-13 cameras and five T-160 cameras was used for all experiments. In addition to 55 markers for capturing full-body motion, 8 markers were set on the spine to measure

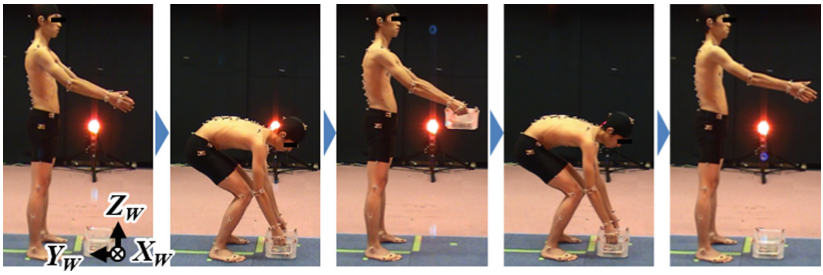


Fig. 3 Series of measured motion

Table 1 Weight and height of each participant

Participant	A	B	C	D	E	F	
Weight [kg]	63	93	69	56	62	74	
Height [m]	1.70	1.64	1.73	1.77		1.75	1.75

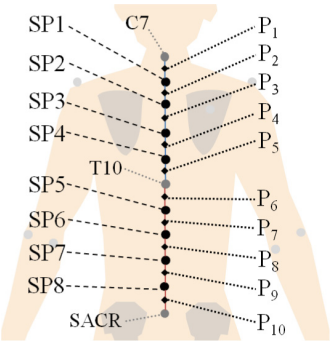


Fig. 4 Marker arrangement on the spine

the shape of back along the spine in detail. The name and position of markers on the spine is shown in Fig. 4. Location of these markers were defined as following:

- SP1–SP4: points dividing spine between marker C7 and T10 (marker on the tenth thoracic vertebrae) into five equal parts
- SP5–SP8: points dividing spine between marker T10 and SACR (marker on the sacral bone) into five equal parts

As shown in Fig. 4, all candidate points were set between two markers on both the upper and lower side of the T10 marker. In this experiment, the angle of the sensor placed on point P_n was defined using the vector connecting the markers above and below point P_n instead of using the actual position of the sensor. The coordinate of upper and lower marker of P_n was defined as $({}^{u}x_n, {}^{u}y_n, {}^{u}z_n)$ and $({}^{l}x_n, {}^{l}y_n, {}^{l}z_n)$. The angle ψ_n was expressed as

$$\psi_n = \tan^{-1} \frac{({}^{u}z_n - {}^{l}z_n)}{({}^{u}y_n - {}^{l}y_n)} \tag{8}$$

For example, let us consider angle ψ_1 of the sensor at P_1. The marker above P_1 is marker C7 and the marker below is marker SP1. Thus, $({}^{u}x_1, {}^{u}y_1, {}^{u}z_1)$ is the coordinate of C7 and $({}^{l}x_1, {}^{l}y_1, {}^{l}z_1)$ is the coordinate of SP1. The angle ψ_1 is obtained by substituting these values into formula (8).

3.2 Experimental Results

Figures 5 and 6 show the relationship between sensor angle $\psi_n (1 \leq n \leq 10)$ and the angle θ_l or θ_t in participant F. This relationship can be linearly approximated,

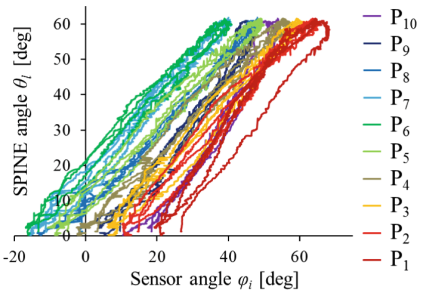


Fig. 5 Relationship of sensor angle and STERNUM angle

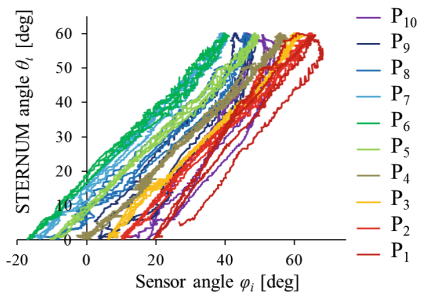


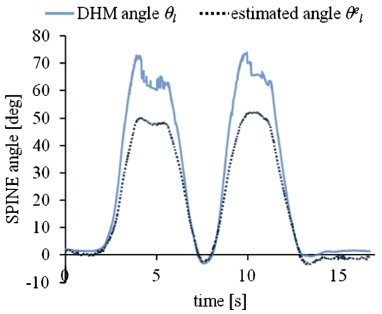
Fig. 6 Relationship of sensor angle and SPINE angle

because the value for the correlation coefficient of the relationship for all angles ψ_n, excepting ψ_9, was greater than 0.95 in all participants. Therefore, sensor position was evaluated by the method noted in Sect. 2. Results showed that P_3 was the optimal sensor position because min$X(n) = X(3)$. On the assumption that the sensor was put on point P_3, the coefficient matrix $\boldsymbol{A}_3$ in formula (3) was determined by a single linear regression analysis using all motion data of all participants where ψ_3 was used as an explanatory variable and θ_l and θ_t were objective variables. As a result of analysis, $\boldsymbol{A}_3$ was expressed as

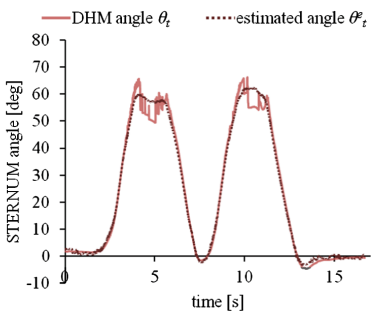
$$\boldsymbol{A}_3 = \begin{bmatrix} 0.794 & -6.37 \\ 0.939 & -6.70 \end{bmatrix} \tag{9}$$

4 Evaluation of Estimating Formula

In this section, we verify the usability of estimation formula. As one example, participant C's estimated angle $\theta^e = [\theta_l^e, \theta_t^e]^{\mathrm{T}}$ and the corresponding angle $\boldsymbol{\theta} = [\theta_l, \theta_t]^{\mathrm{T}}$ of the Dhaiba model are shown in Fig. 71, 2. In the graphs, unnatural vibrations are present in angles θ_l and θ_t, as a result of fitting errors of the Dhaiba model that are caused by large bending of the waist and knee joints. Table 2 shows the error rate of angle estimation for each participant. The error rate is the sum of



(1) Estimation result of SPINE Bone angle



(2) Estimation result of STERNUM Bone angle

Fig. 7 Estimated angle using ψ_3; θ_l^e, θ_t^e in participant C and the same angle in the Dhaiba model; θ_l, θ_t. *1* Estimation result of SPINE bone angle, *2* Estimation result of STERNUM Bone angle

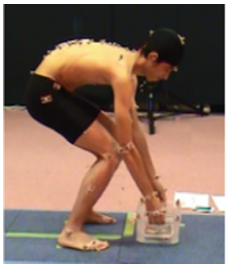
Table 2 Error rate of angle estimation using ψ_3 for each subject [%]

Subject name	A	B	C	D	E	F
e_l	16.3	23.6	25.3	33.5	12.5	33.6
e_t	6.1	15.7	7.4	4.9	6.4	15.2

e_l error rate of angle θ_l^e,; e_t error rate of angle θ_t^e

angle error divided by the sum of angle $\boldsymbol{\theta}$. Though there were individual differences by participant, there was also a tendency for the error rate of SPINE angle θ_l to be larger than that of STERNUM angle θ_t. Two main reasons were considered for explaining this error.

The first possible reason was a posture difference between the thoracic spine and lumbar spine. In this experiment, participants were not given detailed instructions about their motion, leading to posture differences of the knees and back between participants. For example, participant D had his back rounded to the largest degree and had a back shape very different from that of participant F, who kept his back straightest (Fig. 8). This difference had a strong influence on the accuracy of SPINE angle estimation. Because the shape of the lumbar spine is greatly changed based on whether the back is rounded or straightened, it is difficult to estimate the angle of the SPINE bone (the angle of the lumbar spine from the sensor on the P_3 on the thoracic spine). It is also difficult to estimate the angle of the STERNUM bone (the angle of the thoracic spine from sensor on the lumbar spine). Hence, we considered putting sensors on both the thoracic spine and lumbar spine. Point P_8 was the best sensor position on the lumbar spine in the evaluation formula. Estimation formula (10) was made by multi-linear regression analysis using ψ_3 and ψ_8 as explanatory variables and θ_l and θ_t as objective variables.



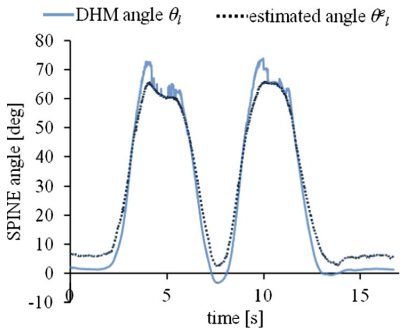
(1) Posture of participant D

(2) Posture of participant F

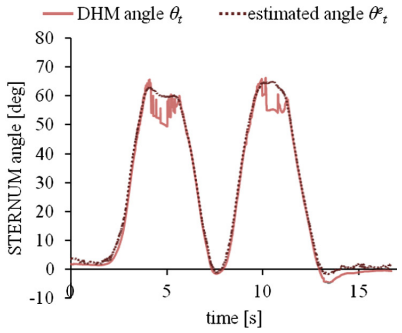
Fig. 8 Difference of spine shape depends on posture. *1* Posture of participant D, *2* Posture of participant F

$$\begin{bmatrix} \theta_l \\ \theta_t \end{bmatrix} = \begin{bmatrix} -0.064 & 0.982 & 9.45 \\ 0.767 & 0.196 & -3.53 \end{bmatrix} \begin{bmatrix} \psi_3 \\ \psi_8 \\ 1 \end{bmatrix} \tag{10}$$

The results of angle estimation using formula (10) in participant C are shown in Fig. 9. Furthermore, the error rate of angle estimation for each participant is shown in Table 3. Comparing this with the results from using ψ_3 only, the accuracy of estimating θ_l was improved by 9 % points on average and 18 % points at most. However, although the accuracy of estimating θ_t angle was improved in participants A, B, and F, it was decreased in participants C, D, and E. This seemed to be attributable to the individual differences described below. Therefore, placing sensors on both the thoracic spine and lumbar spine was effective for improving the accuracy of estimating lumbar angle. However, the number of sensors should be considered in light of measurement costs and accuracy required. In this report, the



(1) Estimation result of SPINE Bone angle



(2) Estimation result of STERNUM Bone angle

Fig. 9 Estimated angle using ψ_3 and ψ_8; θ^e_l, θ^e_t and same angle of Dhaiba model; θ_l, θ_t of participant C. *1* Estimation result of SPINE bone angle, *2* Estimation result of STERNUM bone angle

Table 3 Error rate of angle estimation using ψ_3 and ψ_8 for each participant [%]

Subject name	A	B	C	D	E	F
e_l	15.5	11.6	15.4	19.7	7.4	15.3
e_t	4.2	12.6	10.9	17.2	18.5	14.5

e_l; error rate of angle θ_l^e,; e_t error rate of angle θ_t^e

Table 4 Error rate of angle estimation using ${}^m\hat{a}_3^{22}$ for each participant [%]

Subject name	A	B	C	D	E	F
e_l	6.1	15.7	7.4	4.9	6.4	15.2
$\hat{e}_t$	6.0	5.6	6.0	4.1	4.9	10.1

e_l error rate of angle θ_l^e,; e_t error rate of angle θ_t^e

number of sensors was one, as defined above, and increasing the accuracy of θ_l is left for future study.

The second possible reason was individual difference in body shape. In this verification, the same estimation formula was used for all participants, so the difference of coefficients for each participant was reflected in the angle error. This seemed to affect both θ_l and θ_t. To account for the individual differences of estimation formula from individual physical information, multi-linear regression analysis was performed for all elements of ${}^m\boldsymbol{A}_3$ for each participant using height h [m], weight w [kg], chest circumference l_c [m], and waist circumference l_w [m] as explanatory valuables. Results showed that p-value tended to be high, owing to low variation in the participants' physiques. Significant results were obtained for only one element; ${}^m a_3^{22}$. Participant m's intercept ${}^m a_3^{22}$ of the estimation formula was modified using height ${}^m h$ [m], and weight ${}^m w$ [kg] as

$$ {}^m\hat{a}_3^{22} = 88.03\,{}^m h + 0.11\,{}^m w - 166.87 \tag{11}$$

Table 4 shows the comparison of the error rate from the θ_t estimation result using ${}^m\hat{a}_3^{22}$ with the error rate when ${}^m a_3^{22}$ was used. As shown in Table 3, we could verify that modifying ${}^m a_3^{22}$ improved the estimation accuracy of θ_t.

5 Conclusion

This paper explained a method for optimizing inertial sensor position to reproduce human motions on a DHM, the Dhaiba model, using inclination of body surface as measured by inertial sensors. In the present experiment, back surface shape and posture during a lifting motion were measured simultaneously. Results revealed the best sensor position for obtaining the posture of the Dhaiba model, which was less affected by surface deformation caused by posture change and individual differences in body shape. Using the detected position, a formula was calculated that

estimates the angle of the SPINE and STERNUM bones in the Dhaiba model from sensors placed on the back. Usability of the formula was evaluated from estimation accuracy, and the results can be used to improve accuracy and increase simplicity in motion measurements using DHMs.

Future work should focus on verification of the usability of the estimation formula for other motions or other groups of participants.

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Application of Actigraphy on Shift Workers for Sleep Quality

Fang-Ling Lin, Chih-Lin Chang, Zhi-Xuan Chen, Ching-Chung Chen and Chien-Wen Wang

Abstract The subjects of this study are based on 36 manufacturing operators working on a shift system, there are respectively 12 operators in the day shift, middle shift and night shift being examined. The study uses actigraphy to measure the quality of sleep of the employees under different shift schedules. The results of the study are as follows. On the measurement aspect of quality of sleep on each respective shift, the sleep latency on the night shift is relatively longer as compared to those in the day shift ($p < 0.05$). The instances of sleep barriers on the night shift are relatively more as compared to those in the day shift ($p < 0.05$). The total sleep time on the night shift is relatively longer as compared to those in the day shift ($p < 0.05$). The study discovered that sleep latency is the longest for the middle shift, and differs with the conclusion of past literature stating that employees working in the night shift needed a relatively longer time to fall asleep. The total sleep time for employees working in the night shift is the shortest.

Keywords Work shift · Sleep quality · Sleep time · Sleep latency

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1 Introduction

1.1 Motives

Sleep disorders and poor quality suffered by shift workers do not only affect their health, but also increase the likelihood of occupational accidents [1]. Cohen et al. [2] indicate that poor quality of sleep is defined as one of the following: over 30 min for sleep latency, waking up three times or more during sleep and less than 6 h in total sleep.

Sufficient sleep restores the body, regular biological needs and capacities. It also helps to cope with stress, diseases or job tasks. Poor sleep quality leads to deteriorating immunity and mental alert. It also affects health, job safety and cognitive abilities such as memory, learning, logics and calculation. It also undermines the ability in verbal expressions and judgments. Poor quality of sleep causes work absence, reduces productivity, increases occupational accidents and lowers job satisfaction [3]. There are a long list of factors contributing to poor sleep quality. In general, females are more vulnerable to such factors than males [4]. Households with lower incomes or inferior social and economic status suffer from poor sleep quality [5]. Those who are addicted to stimulus such as coffee report poor sleep quality [6]. Long-term smokers suffer from insomnia due to the stimulus caused by nicotine to the central nervous system [7]. Nightcaps or sleep pills might shorten the time to fall asleep but increase the number of wake-ups, cause shallow sleep or reduced dreams and lead to more psychological or physical symptoms [8]. Occupational factors such as work shifts [9], labor conditions (long hours and late hours) [3], work attributes [10] can all affect sleep quality. Sleep-wake cycles are controlled by our biological clock. In fact, sleep problems may be caused by disrupted circadian rhythms such as jet lags or work shifts [11].

Benjamin [12] defines shift work as the tasks required to increase production or facility utilization with a number of workers working in different shifts. National Institute of Occupational Safety and Health defines shift work as the working hours not between 7 a.m. and 6 p.m. Akerstedt [13] suggests that rotating workers usually sleep approximately 5.1–5.9 h when working on night shifts. As many as 32 % of shift workers suffer from insomnia and hypersomnia; in contrast, only 18 % of regular hour workers have these problems. Shift workers may leave jobs if they suffer from a lack of sleep due to sleep disorders [14]. Drowsiness caused by insufficient sleep may increase accidents and jeopardize the safety of individuals, companies and the society [15]. Sudo and Ohtsuka [16] examine the sleep quality of night shift workers and day shift workers and conclude that night shift employees report poorer sleep quality. Ohayon et al. [17] indicate that night shift workers need longer sleep latency than day time shifts and at the same time have the shortest sleep hours. Scholars in Finland conduct an investigation on the employees of airliners, railway companies and factories and find that the workers on two shifts, three shifts and rotating shifts are more likely to report insomnia, deprived sleep and drowsiness [18]. Studies in the U.S. indicate that rotating shift employees are twice

more likely to drowse off when driving or report traffic accidents than regular shift workers. This can cause serious road accidents, occupational disasters and major safety events [19].

Poor sleep quality leads to a reduced focus, slowness in response and memorization and increased errors. Liou and Wang [20] contend that regular shifts and hours have significant positive influence on outputs and yields. Daytime shifts exhibit better performances, outputs and yields than night shifts and graveyard shifts. Fixed three shifts also report higher performances than rotating three shifts. Folkard et al. [21] refer to five factors (i.e. error rates, sleep and accumulative fatigue, interference to circadian rhythms, absentee and accident rates) to evaluate work performances. The study indicates that night shift workers are most prone to mistakes, crankiness, sleep deprivation and difficulty in falling into asleep. They are also most likely to experience accidents and report the worst performances. Folkard and Monk [22] believe that people who have a tough time adjusting to different shifts are likely to have occupational accidents as a result of drowsiness, reduced alert and unstable emotions.

The effects on the circadian rhythms of rotating shift and night shift workers mean they sleep 15–20 % than regular day workers. The quality of their daytime sleep is also poorer [13]. Hossain et al. [23] suggest that the total sleep hours, cycles and REM hours that night shift workers have during the day time are all significantly shorter than what regular workers have at night. Sleep-wake cycles are controlled by our biological clock. Sleep disorders may also be caused if this biological rhythm is disrupted by jet lags or shift work [11].

In sum, shift duties affect sleep quality of workers. The degree of effects differs from different work hours. This paper examines the sleep latency, wake-up times and total sleep hours of the workers on day shifts, night shifts and graveyard shifts.

1.2 Purposes

This study endeavours to examine whether there are significant variances in sleep latency, wake-up times and total sleep hours among the workers for the three shifts (day shifts, night shifts and graveyard shifts).

2 Methodology

2.1 Subjects

This paper conducts a survey on the employees working rotating shifts in the manufacturers in Dali Industrial Park, Dali District of Taichung. Twelve workers from each shift (day shift, night shift and graveyard shift) are randomly selected for the monitoring of sleep quality.

2.2 Research Tools

SOMNOwatch gathers information each 1/30 s and continuously monitors the activities of the device wearer during sleep and non-sleep hours on a 24-h basis. The records are kept for the five days of sleep quality for each participant.

3 Discussion

3.1 Participants

The sample consists of 34 males (94.4 %) and 2 females (5.6 %), as the majority of shift workers in the manufacturing industry are males. The biggest group in terms of education is high schools and vocational schools (36.1 %). Most of them have a tenure of 1–5 years (75.0 %) and are aged 20–30 (66.7 %). The employees working different shifts in the manufacturing industry are mostly young and single men (69.4 %).

3.2 Comparison of Sleep Quality Among Workers of Day Shifts, Night Shifts and Graveyard Shifts

Table 1 summarizes the analytical findings.

Sleep Latency. The results indicate that the p value between shifts is 0.013, reaching statistical significance ($p < 0.05$). A post hoc test is performed to assess

Table 1 ANOVA analysis on sleep quality of day shift, night shift and graveyard shift workers

	Shift	Mean	F	*P*	Post Hoc	
Sleep latency (min)	Day shift	10.2	4.99	0.013*	Night shift > day shift	0.009*
	Night shift	24.1				
	Graveyard shift	16.9				
Wake times (times)	Day shift	1.0	1.53	0.232		
	Night shift	1.4				
	Graveyard shift	1.3				
Sleep hours (min)	Day shift	386	14.26	0.000*	Day shift and night shift > graveyard shift	0.003* and 0.000*
	Night shift	407				
	Graveyard shift	339				

$p < 0.05$*

the variances between shifts. The turkey method is employed on the same sample. The test results indicate that the p value between day shifts and night shifts is 0.009, reaching statistical significance ($p < 0.05$), but the p value is not statistical significant for other shifts. In other words, the sleep latency among day shift workers is shorter than night shift workers and such variances are statistically significant.

Wake Times. An ANOVA analysis suggests that the p value between shifts is 0.232, not statistically significant ($p < 0.05$). The null hypothesis for the variances among shifts in terms of wake times is not accepted.

Sleep Hours. The ANOVA analysis indicates that the p value among shifts is 0.000, statistically significant ($p < 0.05$). The post hoc test on variances is performed with the turkey given the same sample. The results show no statistical variances between day shifts and night shifts. However, the p value is 0.003 for the comparison between day shifts and graveyard shifts and the p value is 0.000 for the comparison between night shifts and graveyard shifts. Both numbers are statically significant ($p < 0.05$). In other words, the day shifts and the night shifts enjoy longer sleep hours than graveyard shifts.

4 Results

4.1 Profile of Shift Workers

The survey participants are entry-level employees working for different shifts in the non-tech manufacturing industries. They are mostly male (94.4 % of the sample), indicating the demanding nature of tasks that involve mechanical manoeuvers and assemblies. They are mostly aged 20–30 (66.7 %), with a tenure of 1–5 years (75.0 %). None of the participants has tenure of longer than five years, indicating a lack of willingness of rotating shifts for a long period of time.

Working between shifts requires deviation from regular hours of a family life. Singles account for 69.4 % of the survey participants, who are able to ensure sleep quality, free from family disruptions.

4.2 Sleep Quality of Shift Workers

This paper conducts an ANOVA analysis to compare the sleep quality of day shift, night shift and graveyard shift workers in the manufacturing industry. The results indicate significant variances in sleep latency and total sleep hours. A post hoc analysis is then performed and the results suggest day shift workers have a shorten sleep latency than night shift workers. Graveyard shift workers suffer from shorter sleep hours than day shift and night shift workers.

Studies indicate that the rotating shift workers report poorer quality of sleep than regular shift workers. This paper refers to sleep latency, wake times and sleep hours as the three indicators to sleep quality. Regular shift workers enjoy better quality of sleep, evidenced by shorten sleep latency, fewer wake times and over 6 h of total sleep. In fact, the variances in sleep latency and total sleep hours between day shift workers and other shifts are statistically significant. This is consistent with prior studies concluding that shift workers have a hard time falling into sleep [13].

Regular shift workers enjoy better sleep quality than rotating shift workers because their hours are in sync with circadian rhythms. Meanwhile, rotating shift workers report a lower mean in wake times than regular shift workers, although the numbers are not statistically significant. This is not in line with past studies arguing that night shift and day shift workers are most likely to suffer from sleep disorders. Generally speaking, night shift workers have shorter and shallower sleep at day time due to light and noise factors. They also find it difficult to recover from fatigue [14]. In this study, night shift workers do not experience sleep disorders because they are mostly single. This means they have evaluated their personal situations before taking up different shifts. They are able to ensure ample sleep, without disturbance of family matters. Finally, the graveyard shift workers have shorter sleep hours than day shift workers and night shift workers, and the variances are statistically significant. This is consistent with prior studies that rotating shift workers suffer from poor quality of sleep than regular shift workers because of the disrupted circadian rhythms.

The survey conducted by this paper is on mechanical operators who job tasks meet the descriptions above, i.e. monotonous repetitions for long hours and pacing controlled by machines. Regular shift operators report higher performances than rotating shift workers, although such variances are not statistically significant.

In other words, rotating shift workers report poorer job performances than day shift workers due to poorer sleep quality. However, the numbers related to job performance variances in this paper are not statistically significant. This is because of the standard operating procedures set up for all the tasks for mechanical operators to ensure best efficiency and quality. Operators working different shifts are required to maintain their physical status in a goal-oriented work environment of the manufacturing industry. Poor performances should have been led to position changes or dismissals. Put differently, the survey participants are those who have been proved their worth by working for different shifts in the manufacturing industry.

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Ergonomics and Increasing Marginal Returns

Igor Bello and Acran Salmen-Navarro

Abstract One of the biggest challenges for humans is to find a middle ground. This applies to a wide variety of situations and is especially useful when it comes to increasing productivity and preserve the health of people, taking into account that these two variables seem to be inversely proportional. This work aims to design a system to estimate the optimum point, related to the theory of diminishing marginal returns. The central idea is to get the point at which the additional resources generated higher returns, just before they a decreasing yield curve. From an ergonomic perspective, the resources used can be biomechanical or psychosocial: weights, repetitions, worktime or cognitive load. Through mathematical modeling work situations, and the results obtained and documented in industrial activity, we completed a model of two variables where the maximum point is where we get a derivative zero.

Keywords Ergonomics · Fatigue · Decreasing marginal returns · Biomechanics · Productivity · Derivatives · Optimization

1 Introduction

Often life confronts us with the problem of finding the best way to accomplish certain tasks. For example, a doctor may try to find the exact dose of a drug to cure the patient in the shortest time possible, but with minimal side effects; a manufacturer will want to get the maximum possible production of machinery at a point just where it won't break down by excessive use and can continue running for long. Generally speaking, we commonly find situations that require to choose an optimal point at which the description curve reaches its peak and after which starts its

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downfall; At that point, since the time of Leibniz (1646–1716) German mathematician father of the differential calculus—is known as the maximum value of the function, if it is continuous and within the range of possible values.

From an ergonomic perspective, such a diatribe is as follows: on the one hand, the company seeks the highest possible productivity based on more intensive use of all available resources; on the other hand, we have the human being as a key productive resource, with their abilities and needs to which must adapt work to provide adequate working conditions enabling him to enjoy the best attainable state of physical, psychological and social well-being possible.

However, in the center of the variables that appear to move inversely (Productivity vs. Welfare), is the notion of sustainability. It is not possible to maintain production levels over time if in the process capabilities as a result of wear of productive resources are lost, and in particular, fatigue and stress on the human factor. Then the problem is translated into a slider bar to find the right spot where converges a good rate of productivity with the ability to sustain it over time, through ergonomic strategies that allow, for example, a suitable recovery rate, frequency uprisings safe for the back or a level of mental burden that can handle the subject with their own coping resources.

Another key concept to understand this work is that of diminishing marginal returns. This economic law states that the addition of a new production factor, keeping all others constant (*ceteris paribus*) Latin phrase meaning "all or other things being equal or held constant"—will cause performance that adds this new factor is less than the above added. A clear example of this theory is the frequency of manual liftings. If a production manager asks his workers to increase this frequency, probably for each lift/additional minute you will get a higher marginal performance; but with increasing frequency it reaches the point at which workers begin to need more recovery time (fatigue) or sick leave for low back pain, which ends up lowering the production rate, and therefore the marginal performance are presented each lift/additional minute.

The central idea of this research is to find a system for estimating the marginal maximum working capacity under an ergonomic perspective and labor productivity.

Three different approaches were used. First, the approach biomechanics and physiological evaluation methodologies sufficiently validated, as a starting point to build an ergonomically viable model. Second, the historical data of a large group of companies grouped in the Chamber of Industries of the State of Carabobo (Venezuela) on productivity rates contrasted with working arrangements reported by a respected Industrial Health and Safety Services was used; this data allowed to construct mathematical models of productivity/resources based on empirical evidence. Finally it based on the differential calculus to find the optimal points within mathematical constructs based on a production functions approach. This was applied to three different work situations, which were analyzed under these three approaches, obtaining a simulation model of productive functions that maximizes performance, but within a range that ensures ergonomic sustainability and thus, a system for estimation of maximum working capabilities that may lead to maintain optimal and sustainable marginal returns.

2 Method

This research is based on the compilation of bibliographic sources collected longitudinally and by cohort, without experimental component. Research has a projective character as it aims to design a system for estimating, based on a set of defined variables. Documentary research focused on the study of health and safety results, on one hand, and the resulting business productivity, on the other. The data was based on the results reported to the Industrial Chamber of Carabobo State (Venezuela) to which reported 159 companies in the automotive, chemical, metallurgical, food and tires industries, with a combined workforce of about 45,000 workers; data was collected by production volume, number of employees (productivity indicator), duration of working time, absenteeism, incidence of occupational diseases, accidents and labor environment. We studied data collected between 2008 and 2014. The respective matrix were constructed stating data analysis of total production, average product and marginal product, as in Table 1.

Applying the generic formulation of the yield curve theorized by Cobb and Douglas in the form (for one variable):

$$f(x) = a + bX + cX^2 + dX^3 \tag{1}$$

"Cobb-Douglas production function"

This function can be represented graphically and generically by curves as in Fig. 1.

So that it can be approximated in the mathematical construct of several production function evaluation points: Maximum Point Total Physical Product (TPP), Maximum Point Marginal Physical Product (MgPP), Maximum Point Average Physical Product (APP), Maximum Point Human Factor (from ergonomic assessment). To insert into the construct, ergonomic evaluation models were used:

- NIOSH lifting equation (1994)
- Method OCRA Check List (Occupational Repetitive Actions)

Table 1 Summary table of production data (proposed)

Control Date	Added factor	TPP	Increased factor	Increased production	MgPP	APP
	x	y	Δx	Δy	$\frac{\Delta y}{\Delta x}$	$\frac{y}{x}$
(0)	(1)	(2)	(3)	(4)	(5) = (4)/(3)	(6) = (2)/(1)
When cutting data is taken	contributed additional resource	Retrieved Total physical product	Additional amount of factor contributed	Additional amount of production obtained	Marginal Physical Product	Average Physical Product

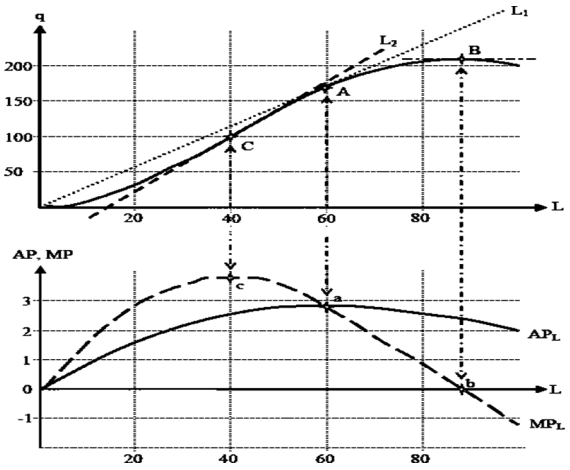

Fig. 1 Curve descriptor of the production function of Cobb-Douglas

- JSI Method (Job Strain Index)
- INSHT Guide for Evaluating Repetitive Tasks
- Method of Metabolic Consumption Calculation (ISO 8996)
- Drudgery Level of Activity (coefficient FRIMAT)
- Cardiac Absolute Cost (Criterion CHAMOUX)

To facilitate complex calculations and simulations of analytical models, the basics of differential calculus were used to complement the assessment model: derivatives, maxima and minima, monotony and concavity. It is appreciated that the provided data models found in the form of discrete data; however, through the differential calculus it was possible to approximate descriptive models and continuous rather close to the observed phenomenon, useful for discrete results of practical value. Three specific cases were studied to compare the mathematical models with empirical information obtained from industrial data:

- CASE 1: Manual lifting. Builders on a tire rubber industry were evaluated.
- CASE 2: Repeatability of movements. The operator workstation packing snacks in a food industry was evaluated.
- CASE 3: Cardio metabolic consumption. The operator position of vitrified isolating electrical parts in a manufacturing industry was evaluated.

The correlation of production data was analyzed with variations in working arrangements to validate the consistency of the model using historical data, since there was no experimental control by the researcher. With the information obtained from the analysis of the cases, an estimation model based on work schemes—an analytical approach and other graphic—was constructed.

3 Results

For the purposes of this article, only the analysis of study case No. 1, based on the manual lifting point guard in a tire manufacturer it is presented in detail.

3.1 Manual Lifting

This modeling was performed based on experimentation that production management had to implement to find the optimal point of production for a number of workers who were being reinserted after sick leave due to low back pain at tire builder. So in this case the company was setting in reverse: the regime of "normal" production was decreasing the level of frequency of lifting (the critical factor for this job) to obtain acceptable levels of fatigue in workers, as measured by application of Kuorynka questionnaires. The task studied consisted in Radial Builder Module 15 Phase II, where the level of high risk is due to the high load handling oscillating about 17 kg., with a frequency variable lifting up to 18 times per hour (it has tested in various frequency options), which is equal to 144 tires, each shift lifted by the operator. In addition, they must flex the trunk to take the sides of the container when it is located below the full 58.7 cm but high above 32 cm height (measured from the ground); flexes the trunk to take the shells found in the lower level of container hanger (96 cm de height); to place the covers on the drum of the machine and to place crude rubbers in the container, so that the position requires repetitive movements of back bending during working hours. According to this description of the task, it was selected for modeling the frequency parameter uprisings.

A first approach in finding the optimal frequency factor was its analytical assessment using the NIOSH Index Liftings which aims at a frequency of lifting up to 18 times per hour, which translates into 0.3 times per minute; This assessment yielded a recommended weight limit of 9.08 kg in contrast to the 17 kg that were manipulating effectively, leaving the worker exposed to biomechanical risk index of 1.87 which represents a risk of back injury, in need of intervention. Using the analysis capabilities of the software application tool, where it was found that around 0.2 liftings per minute (12 per hour) a biomechanical index of 1.02, that is located within the limits of worker safety, is obtained.

Consequently, one might intuit that if we lower the work regime 12 liftings per hour, workers will be protected of musculoskeletal diseases in this task. However, it is possible that this work cycle is not convenient for production, in terms of productivity if we take into account factors such as job fatigue, heat stress, the effect of noise and breathing of particles and vapors that emerge from the production process. The results obtained with a group of operators, varying the frequency of

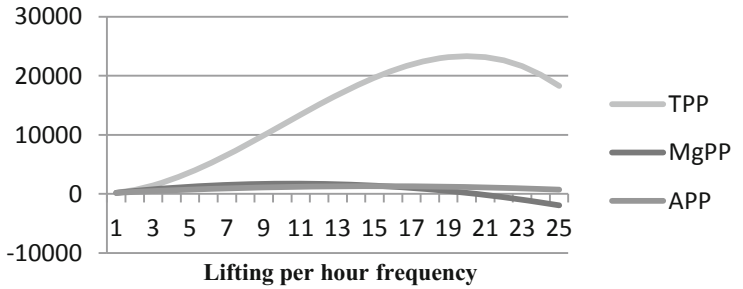

Fig. 2 Graphical analysis case 1: tire production builder

liftings per hour between 1 and 25 times, correlated with the average monthly production (Relevant range is showed).

The previous table shows that the peak production is at a frequency of 20 liftings per hour, obtaining a monthly output of 23,316 tires. However, the marginal increase the frequency contribution is negligible and the average throughput per lifting is also low (1166), compared with 1311 units produced at a rate of 15 lifts per hour. It can also be seen that at a rate of 10 liftings per hour increases the delivery rate, improving returns in terms of productivity.

Another approach to estimating the optimal working regimes is the graphical analysis. The graph shows at critical points special behavior. At the turning point (10 lift/h) of the total output curve, the marginal product is highest. Where the curves of marginal product and average product converge, the average product is optimal. At the point at which the marginal product is zero, total production reaches the peak. The curves can be seen in Fig. 2.

Another approach is the use of modeling differential calculus. Suppose the equation that is closest to the discrete values obtained in this case (least squares modeling):

$$f(x) = x + 30x^2 - x^3 \tag{2}$$

Production function reinforced tire constructed from production data.

We can get the peak of the production curve where the derivative is zero:

$$f(x)' = 1 + 60x - 3x^2 = 0 \quad for\, x \cong 20 \tag{3}$$

TPP optimization curve. The first derivative is zero. And obtain the peak of the curve marginal product where the second derivative is zero:

$$f(x)'' = 60 - 6x = 0 \quad for\, x = 10 \tag{4}$$

MpPP optimization curve. The second derivative is zero. And analogously calculate the peak of the curve of average product, where the first derivative of the

curve f (x)/x is zero, or where the values of average product and marginal product are equal:

$$\text{PFMe} = \frac{x + 30x^2 - x^3}{x} = 1 + 30x - x^2 \tag{5}$$

Average Product function.

$$\text{PFMe}' = 30 - 2x = 0 \quad donde\, x = 15 \tag{6}$$

APP optimization curve. The first derivative is zero.

In short, they can denote four areas of the curve, differentiated by the critical points:

- Zone 1 (0–10 lift/h) ranging from zero frequency the tipping point where the marginal return is highest. In this area the marginal and average performance are increasing, but the total production is low.
- Zone 2 (10–15 lift/h) ranging from marginal performance peak until the peak of the average yield, in what may be called "biological optimum." This is an area where it is convenient to operate from a viewpoint of productivity; also draws attention to the outcome of biomechanical analysis yielded a result in this area.
- Zone 3 (15–20 lift/h) ranging from the peak of the average yield the peak of the production curve. Note that in this area, although production is maximum, average yields are decreasing and the marginal return reaches zero.
- Zone 4 (over 20 lift/h) after the peak of the curve of total production, production begins to fall despite of major efforts. Marginal returns are negative in this area.

Similarly they range optimization case studies 2 and 3 were found to behave according to the Cobb-Douglas function.

4 Discussion

Although from a theoretical approach, this paper provides the basis for the conciliation of the production model with human labor, and necessary not only for the promotion of the workers health, but also for strengthening the productivity and sustainability of organizations; it constitutes an effort to deepen the mathematical modeling of productive situations, to take advantage the power of differential calculus, but taking account of biological variables involved in the work, and mainly fatigue, based on the premise that it is not enough to preserve illness-free workers, but also at an optimum production level that can maintain throughout working life and allows to enjoy a full life quality.

Taking as an example the NIOSH Lifting Index, we can determine that under ideal conditions rising for a long duration, a load of 5 kg can be lifted safely to the lumbar region of the back, even with a rate of 5.7 lifts/min (a lifting every 10.52 s determined by the speed of the conveyor belt). However, if one takes into account only this argument to set the frequency of uprisings it could be making a mistake. Not only in the sense that this calculation does not reflect physiological and psychological variables, or the biomechanical associated with the cumulative effect of the repetitions, nor the values of the environmental conditions such as temperature, humidity, lack of lighting or vibration. Then, an empirical approach can give us a hint on the problem through organized collection of data on productivity obtained in various schemes of work, from a low speed (2–3 repetitions per minute), and collecting data in different regimes to that total productivity begins to decline. This allows for a "map" of the overall system performance in action and thus monitors the evolution of marginal returns and averages. Note that although one might think that if work schemes varies proportionately output should vary. This however does not work this way because:

- A higher rate of uprisings caused by the increased occurrence of "short breaks" also called fatigue supplements: toileting, hydration, etc. difficult to quantify (personal allowance, delay allowance).
- A higher rate must pace themselves with other elements that are vertically integrated from other departments, with global consequences on system performance.
- A higher labor rate produces more fatigue, which has short, medium and long-term effects; definitely focusing on maintenance work regime (presenteeism, cardio metabolic imbalance, absenteeism, chronic decreased functional capacity or the open appearance of occupational diseases).

According to the results, one can determine a general methodology to find the optimal range of biomechanical and physiological need in relation to the model of increasing marginal returns and quantitative tools for ergonomic analysis. Regarding this theoretical optimal range, the uncertainty will be linked to some fundamental premises:

1. The quality of the production data collected. They must have been collected from the zero level and linearly, with a resolution that can build the model; also data should be collected until total productivity (TPP) have a tendency to fall.
2. The correlation between the human component and total production. The contribution of the human factor can be very small in certain processes, to the point of having a very low or no correlation with production.
3. Descriptors phenomena involved human factor (repetitiveness, physical or mental load, etc.) need to be evaluated quantitatively through a validated method. That is, by means of an equation such as NIOSH, OCRA, JSI, OWAS, etc.

4. The production function must be continuous. Data should behave "normally" according to the Law of Diminishing Marginal Returns, following the curve analogous to the Cobb-Douglas distribution.

The general methodology for determining the optimum operating range for biologically marginal results and average maximum efficiency is described as follow, consisting of three phases:

4.1 Phase 1: Preparation of Data

- Define the dependent and independent variables (e.g. task duration vs. productivity obtained, or repetitions per minute vs. gross production).
- Determine a model valid for the analysis that aims to reach out (NIOSH, REBA, OCRA, OWAS, etc.). Force the equation to match with the acceptable upper limit; this establishes a "safe" point based on ergonomic analysis within the curve.
- Build a data table with information from experimental evidence of the production process. It is important to raise in dependent production units factor (repetitions, duration of the task, load weight, operating temperature, etc.) is varied for its construction, the table structure shown in Table 1, which must contain the date of data collection, Factor Contributed (x), the Physical Product Total (y) is proposed, increased Factor (Δx), the Production Increase (Δy) Marginal Physical Product ($\Delta y/\Delta x$) and Physical Product Medium (y/x).
- Confirm that there is a high degree of correlation between variables (>0.8) for the analysis to be relevant (the variation of an essential consequence of the change in the other). The other independent factors must remain constant.

4.2 Phase 2: Estimation of the Critical Points (Choose Between Two Methods)

Graphical Method.

- Plot the data in the table as follows: Place on the horizontal axis (x) the resource provided. In the vertical axis (y) expresses the resulting total product (TPP). You can take the same graph to locate on the vertical axis the result of Marginal Product ($\Delta y/\Delta x$) and the Middle Product (y/x), or you can use a parallel axis under the graph of Total Physical Product, changing the scale the vertical axis, to better appreciate the MgPP and APP curves.
- Set the three critical points on the graph. The first step is to locate the turning point of the total output curve where the peak of the maximum marginal product

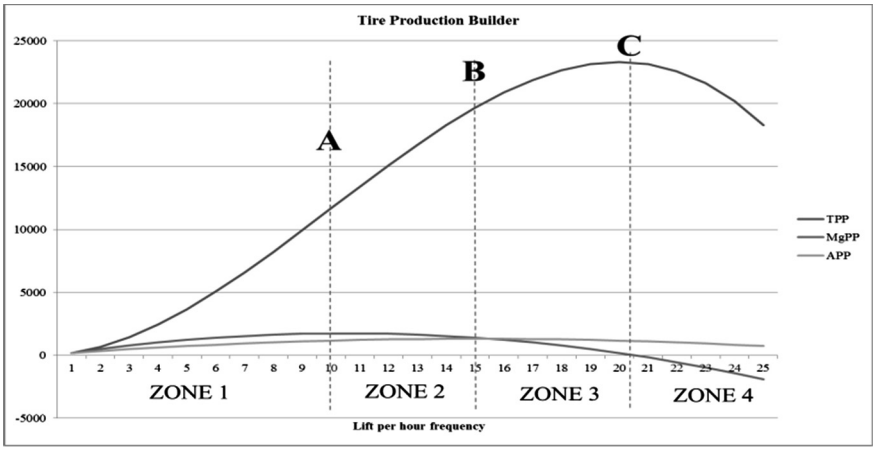

Fig. 3 Construction of the graph to estimate optimum operating ranges

(concave and continuous curves, Cobb-Douglas function) is also located, this is the point "A". Where the curves of marginal product and average product are equal, the average product is optimal; this is the point "B". At the point at which the marginal product is zero, total production reaches the peak; is the "C" point.

- Refine the areas bounded by the critical points. Zero point "A" will be zone 1 (zone of increasing marginal returns, but low production); from point "A" to point "B" will be zone 2 (zone between the maximum marginal performance and maximum average yield); Point "B" to point "C" will be zone 3 (the production is maximized, but the marginal contribution is very inefficient and tends to zero); and point "C" on, will be the Zone 4 (production decreases, negative marginal contribution). See a model construction in Fig. 3.

Analytical Method.

- Build an equation that emulates the behavior of the data, in the form of a function. Remember that the data obtained empirically are discrete, so basically the mathematical model emulates the production function continuously. To do this, use the emulation model of Cobb-Douglas and determine the method of logarithmic correlation indices, linearizing the equation using logarithms 10-base. The basic form of the function is defined by, Cobb-Douglas Equation Model:

$$f(x) = ax + bx^2 - cx^3 \tag{7}$$

- Get the height of the marginal product curve where the second derivative is zero (and the point of change of concavity):

$$f(x)'' = 2b - 6cx = 0 \quad > > x = \frac{b}{3c} \quad (A) \tag{8}$$

Generic model of the second derivative of the equation of Cobb-Douglas (point "A")

- Similarly, calculate the height of the average product curve, where the first derivative of the curve f(x)/x is zero, or where the values of average product and marginal product is equal:

$$PFMe = \frac{ax + bx^2 - cx^3}{x} = a + bx - cx^2 \tag{9}$$

$$PFMe' = b - 2cx = 0 \gg x = \frac{b}{2c} \quad (B) \tag{10}$$

- Get the peak of the production curve where the derivative is zero:

$$f(x)' = a + 2bx - 3cx^2 = 0 \tag{11}$$

$$x = \frac{-b \pm \sqrt{b^2 + 3ac}}{a} \quad (C) \tag{12}$$

Table 2 Table summary data reinforced tire

Added factor	TPP	Increased factor	Increased production	MgPP	APP
x	y	Δx	Δy	$\frac{\Delta y}{\Delta x}$	$\frac{y}{x}$
(1)	(2)	(3)	(4)	(5) = (4)/(3)	(6) = (2)/(1)
9	9918	1	1705	1705	1102
10	11658	1	1740	**1740**	1166
11	13398	1	1740	1740	1218
12	15103	1	1705	1705	1259
13	16739	1	1636	1636	1288
14	18270	1	1531	1531	1305
15	19662	1	1392	1392	**1311**
16	20880	1	1218	1218	1305
17	21889	1	1009	1009	1288
18	22655	1	766	766	1259
19	23142	1	487	487	1218
20	**23316**	1	174	174	1166
21	23142	1	−174	−174	1102
22	22585	1	−557	−557	1027

4.3 Phase 3: Setting the Optimal Operating Range

- Validate that the "safe point" determined by the ergonomic task analysis is between "A" and "B" of the equation.
- Take a production decision with this input. Biological optimum production is located between points "A" and "B". Placing in "B" will get the highest average yields of the human factor; but producing at a point between "A" and "safe point" you will get the best sustainability in the production of medium and long term.
- If you used the graphical method, you can easily estimate these points on the graph (Table 2). If you used the analytical method can obtain more accurate values, using the generic equation:

$$\frac{b}{2c} > x > \frac{b}{3c} \quad c > 0 \tag{13}$$

Estimation Method of Muscle Fatigue and Recovery Progress Using a Muscular Fatigue Model

Isamu Nishida, Kazuya Sata, Masato Maeda, Tsuneo Kawano and Keiich Shirase

Abstract This study investigated a mechanism of muscle fatigue and proposed a muscular fatigue model to evaluate muscle fatigue progress under several muscular force patterns. Previous studies have already proposed a muscular fatigue model. However, these previous studies discussed about the condition of the maximum voluntary contraction. The new point of this study is considering several muscular force patterns including muscle recovery progress. This study proposed the method to estimate the endurance time for keeping constant forces considering the physical characteristics. This study also proposed the method to estimate the iteration numbers for keeping constant forces with interval. To validate the effectiveness of the proposed method, experimental verifications were conducted. The experimental results had a good agreement with the evaluation of muscle fatigue progress using the proposed method. The results of this study will provide ergonomically safe and efficient working environments considering the physical properties of each worker.

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Keywords Muscle fatigue · Muscle recovery · Endurance time · Iteration numbers

1 Introduction

For several decades, factory automation or unmanned factory productivity has been progressed to realize much higher productivity in manufacturing. However, human centered manufacturing system is getting attention to realize much more flexibility for manufacturing of wide product variety and volume. Previously, computer human models that duplicate the properties and the functions of human have been developed. Various researches [1, 2] for the evaluation of human properties have been investigated to improve the computer human models. These previous studies used solid segment models or musculo-skeletal models. Estimation of muscle fatigue progress is important to evaluate the operability and the workability. Especially, the muscle fatigue cannot be neglected to evaluate the operations that give great physical workload or need long hours. However, the previous computer human models have not considered the muscle fatigue practically. So the previous models are considered limited to apply to the short-hours motion that can neglect the muscle fatigue [3]. A few researches to model a mechanism of muscle fatigue have been investigated [4, 5]. However, unfortunately they have only been applied to the muscle fatigue progress under the condition of the maximum voluntary contraction.

Then, this study investigated a mechanism of muscle fatigue and proposed a muscular fatigue model to evaluate the muscle fatigue progress under several muscular force patterns. This study proposed the method to estimate the endurance time under the condition for keeping constant forces considering physical characteristics. This study also proposed the method to estimate the iteration numbers under the condition for keeping constant forces with interval.

2 Methodology

2.1 Muscular Fatigue Model

Jing et al. [4] suggested the muscular fatigue model including the states of activity, fatigue and recovery of a muscle. This model as shown in Fig. 1 includes three groups of the muscular motor unit: the standby unit M_{uc}, the active unit M_A and the fatigue unit M_F. The total number of the motor unit existing in a muscle is represented by M_0. The parameter that effects on the strength to change the standby unit M_{uc} to the active unit M_A is represented by B. The parameter that effects on the strength to change the active unit M_A to the fatigue unit M_F is represented by F.

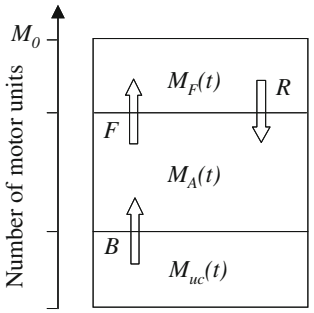

Fig. 1 Dynamic relationship among three groups of the muscular motor units; standby, activity and fatigue state

The parameter that effects on the strength to change the fatigue unit M_F to the active unit M_A is represented by R. Then, this model defined the variation of each muscle state based on the physiological mechanism. The time variation of each motor unit is described as follows.

$$\frac{dM_A(t)}{dt} = B \cdot M_{uc}(t) - F \cdot M_A(t) + R \cdot M_F(t) \tag{1}$$

$$\frac{dM_F(t)}{dt} = F \cdot M_A(t) - R \cdot M_F(t) \tag{2}$$

$$M_{uc}(t) = M_0 - M_A(t) - M_F(t) \tag{3}$$

The number of each motor unit is determined under the maximum voluntary contraction when the initial state ($t = 0$) is assumed as follows. Then, the time variation of each motor unit under the maximum voluntary contraction is shown as Fig. 2.

$$\begin{aligned} M_{uc}(0) &= M_0 \\ M_A(0) &= 0 \\ M_F(0) &= 0 \end{aligned} \tag{4}$$

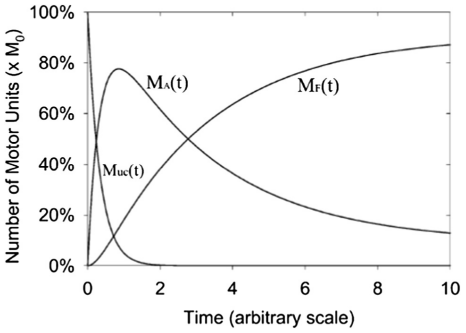

Fig. 2 Time variation of each motor unit in the muscular fatigue model suggested by Jing et al. [4]

2.2 *Estimation of Muscle Fatigue Under the Condition for Keeping Constant Output Force*

Muscular fatigue model suggested by Jing et al. [4] applied to the maximum voluntary contraction. This study proposed the method to evaluate the muscle fatigue progress and estimate the endurance time under the condition for keeping constant output force. Figure 3 shows the muscle fatigue progress under the condition for keeping constant output force.

The state *a* is the ready state for output, then every motor unit is the standby unit M_{uc}. The state *b* is the state just after beginning to output, and then the standby unit M_{uc} is gradually changing to the active unit M_A. Subsequently, the state is changed to the state *c*, then the standby unit M_{uc} is changed to the active unit M_A and the active unit M_A is gradually changed to the fatigue unit M_F. The state *d* is the limit state to keep constant output force, and then the active unit M_A gets short to output constant force. The state *e* is the stagnated state, and then the changing volume of the active unit M_A to the fatigue unit M_F is same as that of the fatigue unit M_F to the active unit M_A. The ratio of the constant output force to the maximum voluntary contraction is represented by *X* %. Then, the time variation between the state *a* and the state *b* is calculated using Eqs. (1)–(3). The time variation between the state *b* and the state *d* is described as follows.

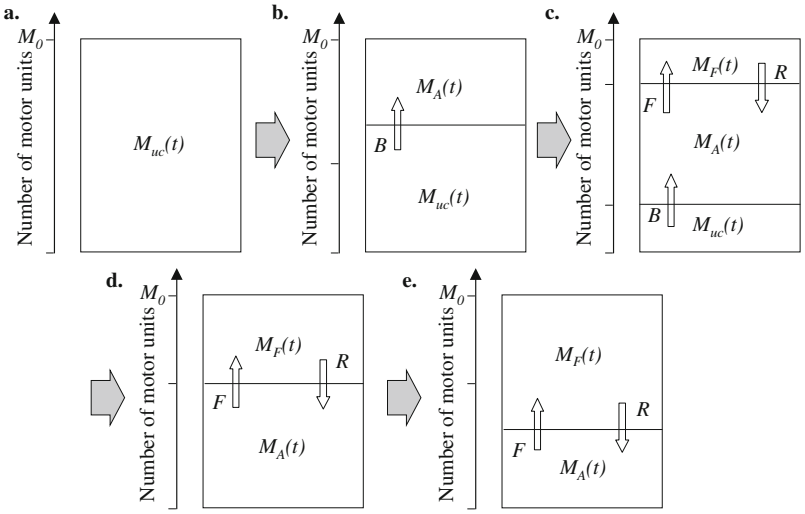

Fig. 3 Muscle fatigue progress under the condition for keeping constant output force. (*a*: Ready state for output, *b*: Beginning to output, then the standby unit M_{uc} is gradually changing to the active unit M_A, *c*: Keeping constant output, then the fatigue unit M_F is gradually increased, *d*: Limit state to keep constant output, then the active unit M_A gets short to output constant force, **e**: Stagnated state, then the changing volume of the active unit M_A to the fatigue unit M_F is same as that of the fatigue unit M_F to the active unit M_A)

$$M_A(t) = M_0 \times X/100 \tag{5}$$

$$\frac{dM_F(t)}{dt} = F \cdot M_A(t) - R \cdot M_F(t) \tag{6}$$

$$\frac{dM_{uc}(t)}{dt} = -B \cdot M_{uc}(t) \tag{7}$$

The time-variation between the state d and the state e is described as follows.

$$\frac{dM_A(t)}{dt} = -F \cdot M_A(t) + R \cdot M_A(t) \tag{8}$$

$$\frac{dM_F(t)}{dt} = F \cdot M_A(t) - R \cdot M_F(t) \tag{9}$$

$$M_{uc}(t) = 0 \tag{10}$$

The number of each motor unit for each instant time can be calculated with the formula described as follows. Δt is difference between t_{scene} and $t_{scene+1}$, that means the inverse number of the sampling frequency.

$$M_i(t+1) = M_i(t) + \frac{dM_i(t)}{dt} \cdot \Delta t \quad (i = A, F, uc) \tag{11}$$

2.3 Estimation of Muscle Fatigue and Recovery with Interval

This study also proposed the method to evaluate the muscle fatigue and recovery progress and estimate the iteration numbers under the condition for keeping constant output force with interval. Figure 4 shows the muscle fatigue and recovery progress under the condition for keeping constant output force with interval repeatedly. The state f is the same as the state c (in Fig. 3), then the standby unit M_{uc} is changed to the active unit M_A and the active unit M_A is gradually changed to the fatigue unit M_F. The state g is the state just after stopping output, then every active unit M_A is switched to the standby unit M_{uc} with interval. The state h is the recovery state, then the fatigue unit M_F is changed to the standby unit M_{uc} gradually during interval. Subsequently, after beginning constant output force again, the state is changed to the state i, that is the same as the state f, and changed to the state k, and then the standby unit M_{uc} is decreasing and the fatigue unit M_F is increasing for

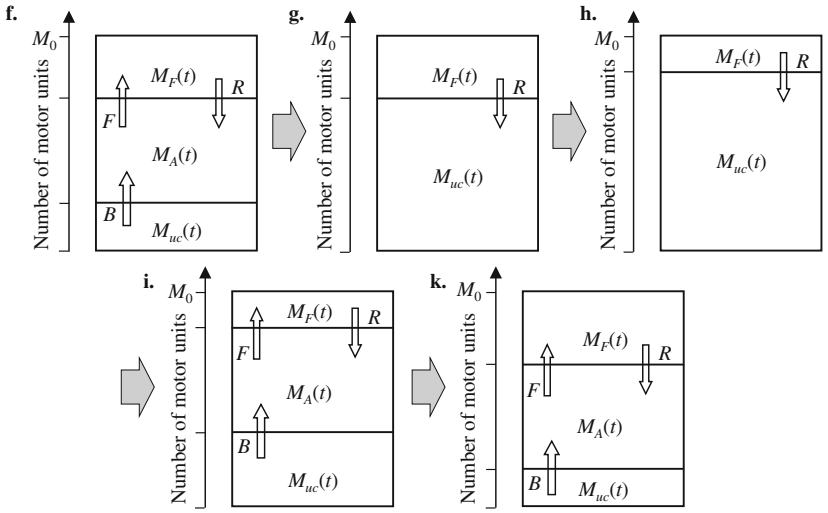

Fig. 4 Muscle fatigue and recovery progress under the condition for keeping constant output force with interval. (*f*: Keeping constant output, which is the same state as Fig. 3c, *g*: Stopping to output, then all active unit M_A switches to the standby unit M_{uc}, *h*: Recovery state, then the fatigue unit M_F is gradually changing to the standby unit M_{uc}, *i*: Keeping constant output again, *k*: Keeping constant output, then the fatigue unit M_F is gradually increased)

keeping constant output force. Subsequently, the state is changed to the state *g* with interval and the repeated variation takes turns doing the same thing. When the interval time is short, the fatigue unit M_F is gradually increasing. The constant output force cannot be kept when the volume of the active unit M_A is larger than that of the standby unit M_{uc} in the state *g*. Then, the time variation between the state *i* and the state *k* is calculated using Eqs. (5)–(7). The time variation between the state *g* and the state *h* is described as follows.

$$M_A(t) = 0 \tag{12}$$

$$\frac{dM_F(t)}{dt} = R \cdot M_F(t) \tag{13}$$

$$\frac{dM_{uc}(t)}{dt} R \cdot M_{uc}(t) \tag{14}$$

When the physical parameters are determined beforehand, the endurance time under the condition for keeping constant output force and the iteration numbers with interval can be estimated. The physical parameters are M_0 that is determined by the maximum muscle force, B that represents the muscle activity level, F that represents the muscle fatigue level and R that represents the muscle recovery level.

3 Validation Experiment

3.1 Determination of Physical Parameters

The physical parameters M_0 (maximum muscle force), B (muscle activity level), F (muscle fatigue level), R (muscle recovery level) are needed to be determined beforehand in order to estimate the endurance time and the iteration numbers by using the method described in Sects. 2.2 and 2.3. Two university students (heights: 169.0 ± 2 [cm], masses; 55.5 ± 0.5 [kg]), after informed consent, participated in this study. The participants kept maximum output forces to one direction until the output force was stagnated due to the muscle fatigue. Then, the parameters were determined with the sum of squares of differences between the measured output forces and the theoretical variation defined in the muscular fatigue model by Jing et al. [4]. The aluminum frame with a handgrip on a three component dynamometer (KYOWA Corp. LSM-B-SAI) shown in Fig. 5 was used to measure the output force.

3.2 Estimation of Endurance Time

The endurance time under the condition for keeping constant output force is estimated by using the physical parameters determined in Sect. 3.1 and the method described in Sect. 2.2. This validation experiment was conducted under the condition that the output force is 50 % of the maximum output force. The participants output 50 % of the maximum output force to one direction until the participants could not keep 50 % of the maximum output force because of the muscle fatigue. Then, the endurance time was measured. The aluminum frame with a handgrip on a three component dynamometer (KYOWA Corp. LSM-B-SAI) shown in Fig. 5 was used to measure the output force. The participants output to one direction with 50 % of their maximum output force while watching the monitor displaying the output force. The trial was quit when the participants could not keep 50 % of their maximum output force.

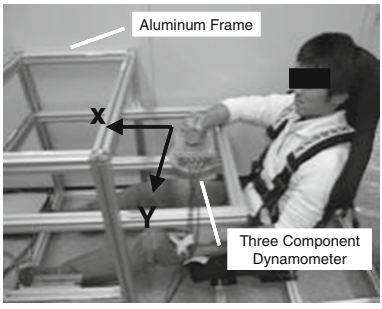

Fig. 5 Measuring equipment of output forces at the distal extremity

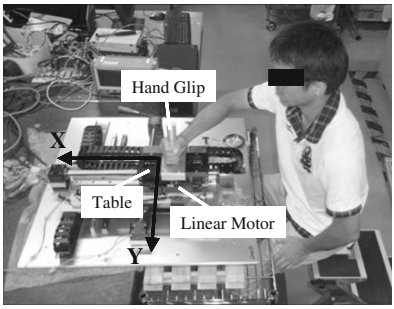

Fig. 6 Measuring equipment of endurance time and iteration numbers

3.3 Estimation of Iteration Numbers

The iteration numbers under the condition for keeping constant output force with interval are estimated by using the physical parameters determined in Sect. 3.1 and the method described in Sect. 2.3. This validation experiment was conducted under the condition that the output force is 50 % of the maximum output force. This validation experiment was also conducted with the condition that the length of output force is 20 s and the length of interval is 10 s. The participants repeated output force and interval until the participants could not output 50 % of the maximum output force because of the muscle fatigue. Then, the iteration numbers were measured. The measuring equipment as shown in Fig. 6 was used to measure the iteration numbers. The participants keep the handgrip, which moves the opposite direction with 50 % of their maximum output force. The trial was quit when the handgrip moved 30 mm because the participants could not output 50 % of the maximum output force with the muscle fatigue.

4 Result and Discussion

Figure 7 shows the results of the measured output forces and the theoretical variation defined in the muscular fatigue model by Jing et al. [4], which were conducted in the experiment determining the physical parameters described in Sect. 3.1. Table 1 shows the results of the physical parameters determined in Sect. 3.1. The physical parameter B represents the muscle activity level. The parameter B is determined by the time to reach the maximum output force. In this study, the time to reach the maximum output force is assumed same among the participants. Therefore, the physical parameter B of every participants were assumed to be $B = 5$. The physical parameter F represents the muscle fatigue level. As the parameter F is larger, the degree of depression of the output force in the maximum voluntary contraction is larger. As the parameter F is smaller, the output force in the maximum voluntary contraction is depressed moderately. The physical parameter R represents the muscle recovery level. The parameter R determines the stagnated

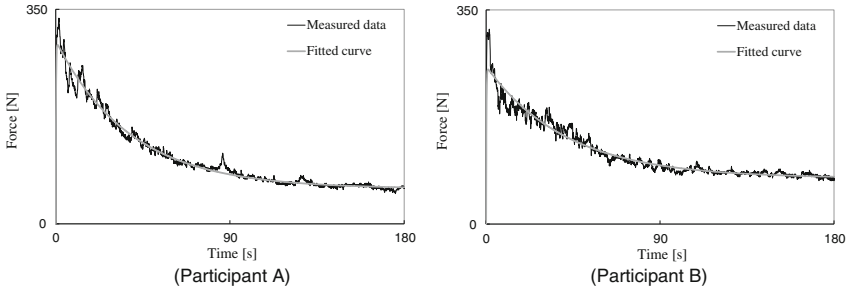

Fig. 7 Comparison of the measured output forces and the theoretical curve

Table 1 Physical parameters determined by the muscle fatigue mode

	M_0	F	B	R
Participant A	298	0.0210	5	0.0050
Participant B	261	0.0180	5	0.0075

output force. As the parameter R is larger, the stagnated output force is larger. As the parameter R is smaller, the stagnated output force is smaller.

Figure 8 shows the result of the variation of each motor unit in the endurance time experience described in Sect. 3.2. The measured data is the data that the participants output. The variation of motor unit was calculated by the method described in Sect. 2.2 with the variable value $X = 50$. Table 2 shows the measured result and the estimated one. The results of the endurance times of participant A and participant B showed that the measured endurance times were almost the same as the estimated ones (the differences were less than 10 %).

Figure 9 shows the result of the variation of each motor unit in the iteration numbers experience described in Sect. 3.3. The variation of motor unit was calculated by the method described in Sect. 2.3 with the variable value $X = 50$, the length of output force 20 s and the length of interval 10 s. Table 3 shows the

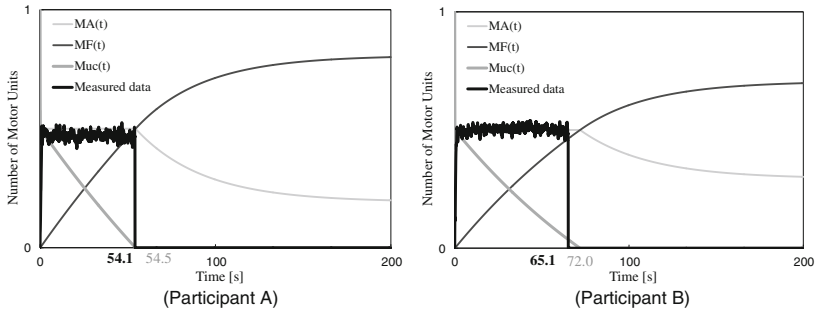

Fig. 8 Variations of the measured output force and motor units under the condition for keeping constant output force

Table 2 Comparison of the measured endurance times and the estimated ones

	Measured time [s]	Estimated time [s]	Differences [%]
Participant A	54.1	54.5	0.7
Participant B	65.1	71.95	9.5

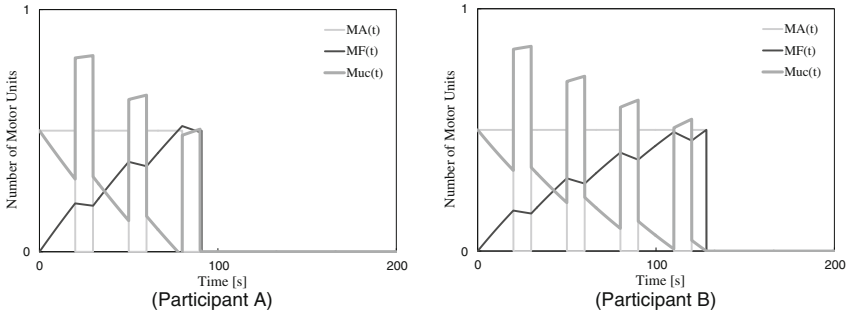

Fig. 9 Variations of the motor units under the condition for keeping constant output force with interval

Table 3 Comparison of the measured iteration numbers and the estimated ones

	Measured iteration numbers	Estimated iteration numbers
Participant A	2	2
Participant B	6	4

measured result and the estimated result. The results of the iteration numbers of participant A and participant B showed that there were the differences between the measured iteration numbers and the estimated ones. The reasons of the differences are considered the precision of the experiment to determine the physical parameters conducted in Sect. 3.1. The iteration numbers depend largely on the parameters F (muscle fatigue level) and the parameter R (muscle recovery level). Therefore, the iteration numbers are different from the measured ones without the physical parameters determined precisely. One of the reasons that the physical parameters were not determined precisely is considered that the physical and mental conditions of the participants were not always constant and made effects on the determined physical parameters.

5 Conclusions

This study investigated a mechanism of muscle fatigue and proposed a muscular fatigue model to evaluate the muscle fatigue progress under several muscular force patterns. This study proposed the method to estimate the endurance time under the

condition for keeping constant forces considering the physical characteristics. This study also proposed the method to estimate the iteration numbers under the condition for keeping constant forces with interval. The results of the validation experience indicated the necessities to improve the precision to determine the physical parameters. However, when the physical parameters are determined precisely, the muscle fatigue and recovery progress can be evaluated by the proposed method. The results of this study will provide ergonomically safe and efficient working environments considering the physical properties of each worker.

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The Effect of Back-Carrying Load and Fatigue on Gait Characteristics at Heel Contact

Xinyao Hu and Xingda Qu

Abstract Slip is one of the leading causes of accidental falls. Load-carrying and fatigue might increase risk of slip-induced falls during locomotion. The objective of this study was to determine the main and interactive effects of load carriage and fatigue on gait characteristics at heel contact. An experiment was carried out with five participants walking on a medical treadmill. Different back-carrying loads were applied before and right after the fatiguing exercise. The heel velocity and heel deceleration right before heel contact and the heel contact angles were examined. The results showed that the both heel contact velocity and deceleration increased with fatigue and with the application of the heavy load. These findings suggest that both fatigue and back-carrying load increase the risk of slip-induced falls by compromising gait stability at heel contact. Findings from this study can aid in developing interventions that are able to minimize fall risks especially with the application of fatigue and/or external load.

Keywords Fatigue · Back-carrying load · Gait characteristics · Heel contact

1 Introduction

Falls are a major health concern. Fourteen percent of accidental deaths in the workplace were reportedly caused by falls [1]. The consequences of falls are often devastating. Falls often lead to physical injuries such as hip fracture and head injuries. Falls are also associated with high mortality and morbidity [2]. The cost of occupational fall-related injuries in the US was approximately $13.7 billion in 2010 [3].

Falls are often initiated by external perturbations during locomotion [4]. One of the most common perturbations that lead to falls is slip [5–7]. Slips contributed to

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43 % of occupational fall incidents [8]. Slips were also considered as a major cause of injuries in working place such as food service and mail delivery [9–11].

Most slip related falls occurred during walking. Slips are often associated with task related risk factors that compromise gait characteristics [12]. Back-carrying load and fatigue have been identified as two major task-related risk factors that have effects on gait [13]. Earlier studies suggested that walking while carrying load can result in compensatory gait behaviour [14]. Back-carrying load are associated with decreased range of motion (ROM) of knee, pelvis and craniovertebral joints rotation and lead to change of kinetics during push-off and braking phase of gait [15, 16]. Recently, Liu and Lockhart [17] revealed that load carrying was associated with declined local dynamics stability. Thus it might increase the risk of falls. On the other hand, fatigue has been reported to have negative effect on gait characteristics during stair negotiation and balance recovery from slips [18, 19].

As back-carrying load often lead to fatigue. Therefore, it is important to examine their interaction effect on gait. Qu and Yeo [20] investigated the effects of back-carrying load and fatigue on gait characteristics. Their results showed that step width variability, hip range of motion, and trunk range of motion increased with fatigue and with the application of the heavy load. These findings suggested that both fatigue and back-carrying load compromise gait. Similarly, Kong et al. [21] suggested the gait characteristics changed when people who wear heavy firefighter equipment are fatigue.

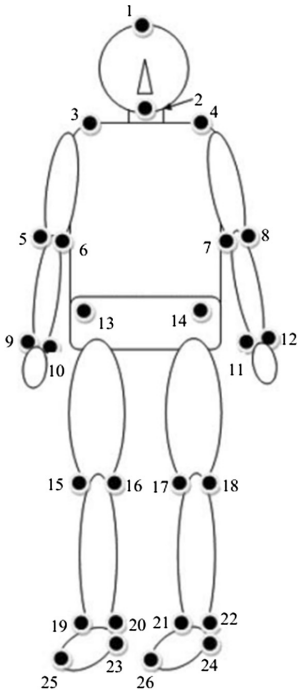
However, the current research has only examined how the back-carrying load and fatigue affect gait variability and a few gait kinematic measures. It is unclear about how the back-carrying load and fatigue affect the gait kinematics at the time of heel contact. Previous research revealed that the heel contact kinematics have significant effect on slip initiation. They are important parameters to determine whether the slip will eventually lead to fall [6].

The present study aimed to investigate the main and interactive effects of back-carrying load and fatigue on gait characteristics at heel contact. We hypothesized that (1) both back-carrying load and fatigue would have effects on gait characteristics at heel contact velocity and heel deceleration before heel strike (2) there is an interaction effect between back-carrying load and fatigue on gait characteristics at heel contact.

2 Method

2.1 Experiment

The experiment involved 5 young male participants (age = 25.6 ± 2.2 years; height = 1.78 ± 0.04 m; body mass = 65.9 ± 8.0 kg). They all had no injuries, illness, or musculoskeletal disorders that could affect their gait patterns. An eight-camera motion capture system (Motion Analysis Eagle System, Santa Rosa,



1	Forehead
2	Chin
3 and 4	Right and left acromions
5 and 6	Right lateral and medial epicondyles of humerus
7 and 8	Left lateral and medial epicondyles of humerus
9 and 10	Right styloid processes of radius and ulna
11 and 12	Left styloid processes of radius and ulna
13 and 14	Right and left ASIS (Anterior Superior Iliac Spines)
15 and 16	Right lateral and medial epicondyles of femur
17 and 18	Left lateral and medial epicondyles of femur
19 and 20	Right lateral and medial malleoli
21 and 22	Left lateral and medial malleoli
23 and 24	Right and left heels
25 and 26	Right and left 5th metatarsal

Fig. 1 Marker placement

CA, USA) was used to capture the whole-body kinematics in three dimensions with the sampling frequency of 100 Hz. Twenty-six markers were attached to the selected bony-landmarks (Fig. 1). This marker placement helped form a 12-segment biomechanical model including head, upper arms, lower arms, trunk, thighs, shanks and feet [22].

The experiment had two sessions, i.e. the pre-fatigue and the post-fatigue session. During the pre-fatigue session, three pre-fatigue walking trials were performed by each participant under the three back-carrying loading conditions, namely, "no load" = 0 kg, "low load" = 7.5 kg, and "high load" = 15 kg. In each walking trial, the participant was instructed to walk on a medical treadmill (Biodex RTM 600, Shirley, NY, USA) for 2 min at their comfortable speed. And a minimum of 3-min break was taken between two consecutive walking trials in order to minimize carryover effects and confounding fatigue effects. The applied loading levels were randomized to minimize order effects. After the pre-fatigue session, fatigue was induced by a running exercise. The Borg's rating of perceived exertion (RPE) [23] was used to assess the fatigue level. Fatigue was considered to be induced when the participants first gave an RPE rating at or above 17. Right after the fatigue onset, the participants were asked to perform three post-fatigue walking trials under the three loading conditions in a random order. To ensure the consistency of the fatigue level across post-fatigue trials, fatiguing exercise was reinitiated before the second and

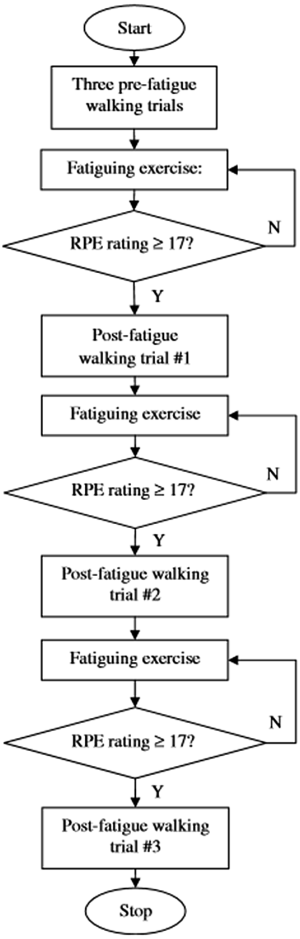


Fig. 2 Experiment procedure

the third post-fatigue trials. The experimental procedure has been summarized in Fig. 2.

2.2 Data Analysis

The dependent variables in this study were gait characteristics at heel contact, including heel velocity (HV), heel deceleration (HD) and heel contact angle (HCA). To counter the effect of treadmill speed, the heel velocity and heel deceleration right before heel contact were examined. Heel velocity was calculated by differentiating the heel marker trajectory in horizontal direction with respect to the sampling interval of motion capture data (i.e. 0.01 s) [26]. The HCV was taken instantaneously at heel

strike of 40 steps after establishing a steady-state gait pattern in each walking trial. The heel strike was determined by the position of foot markers suggested by Zeni et al. [24]. HDE was calculated by differentiating the HCV with respect to the sampling interval of motion capture data determined.

The independent variables are back-carrying load and fatigue. Back-carrying load has three levels: no load (i.e. 0 kg), low load (i.e. 7.5 kg), and high load (i.e. 15 kg). Fatigue has two levels: pre-fatigue and post-fatigue. A two-way ANOVA was performed to determine the main and interactive effects of independent variables on each dependent variable. Post hoc pair-wise comparisons were conducted using Tukey's honestly significant difference criterion. The level of significance was set at $\alpha = 0.05$. Statistical analyses were performed using SPSS (SPSS Inc, Chicago, IL, USA).

3 Results

Fatigue has significant effect on heel contact velocity and heel deceleration. Specifically, after fatigue was induced, heel contact velocity became larger compared to the pre-fatigue condition, in contrast, heel deceleration became smaller compared to the pre-fatigue condition (Table 1). However, fatigue does not have significant effect on heel contact angle (p-value = 0.12). On the other hand, back-carrying load has significant effect on heel contact velocity. However, it does not have significant effect on heel deceleration and heel contact angle. Post hoc comparison indicated that heel contact velocity is significantly smaller in the no load condition versus the high load condition and in the low load condition versus the high load condition (Table 2). Fatigue and back-carrying load were not interacted with each other, since no significant interactive effects on dependent measures were found in the present study (Table 1).

4 Discussion

The present study investigated the main and interactive effects of back-carrying load and fatigue on gait characteristics at heel contact. The results revealed that both back carrying load and fatigue have significant effects on heel contact velocity (Table 1). The heel velocity right before heel contact increased when the participant was fatigue and carrying load. As indicated by many researchers, faster heel contact velocity is a risk factor that is closely related to the slip initiation [25]. During the swing phase, the horizontal heel velocity should rise gradually after heel-off, reaches a maximum velocity in the late swing phase, then falls to near zero just prior to heel contact. Right after the heel contact, the horizontal heel velocity should become zero to prevent foot slipping and support the stance leg. Increased heel velocity right before heel contact might results in increased horizontal shear force at

Table 1 Comparisons of HV, HD and HCA

	Fatigue			Load				FxL
	NF	F	*p* value	NL	LL	HL	*p* value	*p* value
HV (m/s)	0.36 (0.12)	0.41 (0.11)	0.012	0.29 (0.08)	0.42(0.08)	0.44 (0.13)	<0.001	0.998
HD (m^2/s)	−33.2 (6.8)	−24.8 (13.5)	<0.001	−30.8 (4.8)	−31.6 (7.2)	−27.2 (7.4)	0.098	0.674
HCA (degree)	78.2 (6.3)	80.2 (10.1)	0.12	79.2 (8.2)	79.2 (13.5)	80.4 (8.2)	0.41	0.454

NF-non fatigue, F-fatigue, NL-no load, LL-low load, HL-high load, FxL-the interactive effect of fatigue and load

Table 2 Post-hoc comparison result for heel contact velocity

	95 % CI (I minus II)		*p*-value
	Lower bound (cm)	Upper bound (cm)	
0 kg (I) versus 7.5 kg (II)	7.09	21.33	<0.001
0 kg (I) versus 15 kg (II)	10.21	24.45	<0.001
7.5 kg (I) versus 15 kg (II)	3.13	2.94	0.524

heel contact. Therefore it might increase the friction demand, as measured by required coefficient of friction (RCOF) and increased the risk of slip. An early study suggested that the heel contact velocity for participants who fell is in general faster than that from participants who did not fall [26].

Fatigue also has significant effect on heel deceleration. Heel deceleration prior to the heel contact is a result of the combined effort of joint toques of lower limbs and the foot motion [27]. The results of the presenting study revealed that heel deceleration was smaller when the participant is fatigue. Such smaller deceleration at heel contact was associated with lower chance of successful recovery after slip initiation [27]. In other words, fatigue might results in increased chance of slip-induced fall.

One limitation of this study is that, in order to obtain sufficient amount of data for statistical analysis, the experiment was base on treadmill walking. The gait characteristics of treadmill walking might be different from level walking. Also, dependent variables examined in this study might be affected by the treadmill speed. To account such effect, the heel velocity and heel deceleration right before heel contact were examined. Future studies need to carry out to investigate whether similar effects exist in level walking.

5 Conclusion

In summary, both fatigue and back-carrying load had significant effects on gait characteristics at heel contact. Thus, our first hypothesis was supported. However, our second hypothesis appeared to be false since we did not find any interactive effects between these two factors. Findings from this study can help better understand how fatigue and back carrying load might be a risk factor for slip-induced falls, and further aid in developing interventions that are able to minimize fall risks especially with the application of fatigue and/or external load.

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The Impact of Man-Seat Interface on Long-Time-Sitting Fatigue and Comfort

Xingwei Wang, Heqing Liu, Xianxue Li, Li Ding and Weiping Bu

Abstract To explore the impact of man-seat interfaces on long-time-sitting fatigue and comfort, a simulating flight facility in which can fix three different seats(A, B and C) was set up. 4 volunteers carried out simulated flight operation in it for 8 h continuously. 8 objective indicators were monitored, and the subjective fatigue and discomfort feelings were investigated too. The results showed 5 objective indicators were significant to long-time-sitting fatigue. Visual sensitivity declined along with the increase of fatigue. The fatigue feelings of neck, back, waist, buttocks and thighs all had an increasing tendency with the extending of sitting time. The comfort of seat A was superior to that of seat B, and seat C was superior to both A and B. Adjustable lumbar pad could effectively improve comfort, and a modeling designed man-seat interface could do that significantly.

Keywords Seat · Interface · Fatigue · Comfort · Impact

1 Introduction

To the people sitting on a seat for a long time and accomplishing some accurate operating task simultaneously, the sitting comfort of seat can not only influence his subjective feelings, but also influence his cognition ability and operating efficiency, and then influence the task fulfilling [1, 2]. So the sitting comfort of seat has already been paid more and more attention. The research work showed the tolerance sitting time was different when the comfort degree of man-seat interface was different [3]. Improving the comfort design of man-seat interface was the effective means to enhance the seat comfort.

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How to evaluate the seat comfort? A kind of commonly used method is subjective evaluation, and the other is objective evaluation [1, 4]. Subjective method is to evaluate comfort by the using feelings of rider, its advantage is reflecting the subjective feelings directly, and the disadvantage is the individual differences and the vulnerability to physical state, mental state, behavior and other factors. Objective evaluation method is to determine the seat comfort by the measure and analysis of some objective indicators. This method can effectively avoid the individual differences and the influence of subjective factors. This paper, by using of different man-seat interfaces, carried out experimental research of simulated long-time-sitting flight task. The influence of different man-seat interfaces to long-time-sitting fatigue and comfort was studied, and the effectiveness of the objective evaluation indicators was verified.

2 Experiment Methods

2.1 Subjects

Four healthy male volunteers were selected according to the medium height standard of aircrew. They were 20–28 years old, 168–173 cm in height and 63–70 kg in weight. In the 24 h before the experiment they make no strength physical activities, and had no fatigue and discomfort feelings.

2.2 Materials

A certain kind of flight seat(seat A), an office chair with adjustable lumbar pad (seat B), and a seat with man-seat interface designed according to the buttocks and back surface characteristics of sitting posture (seat C) were used as experiment seats. A simulated flight operating experiment device was constituted with joystick, throttle pedal rudder, computer, flight game software “Tom Clancy’s HAWK”, a projector, and the experiment seat (Fig. 1).

2.3 Methods

In accordance with the requirements for flight status, volunteer sat in one kind experiment seat and completed simulating flight operating task in 8 h continuously. After four volunteers all completed, the seat was changed to another kind and the above experiments were repeated, until the three kind seats all done. Experiments are conducted in the daytime. In the process of experiment, 8 indicators such as

Fig. 1 Simulated flight operating control device and air combat scene

reaction time, movement time, cognitive ability, visual sensitivity, lower limb blood oxygen saturation, heart rate, median frequency of shoulder EMG (MFsEMG) and median frequency of waist EMG (MFwEMG) were periodically examined, and the subjective feelings of fatigue and discomfort of neck, back, waist, buttocks and thighs were surveyed too. The statistical software SPSS13.0 was used in the statistical analysis processing of experimental data.

3 Results

3.1 Reaction Ability

By using BD-II-513 reaction time tester (Fig. 2), the reaction time (RT) and movement time (MT) were measured at the beginning of the experiment and after each hour until to the end. The subject pressed the central button down first, then loosed it and pressed another random lighting button to make it out as soon as possible when he heard a signal voice, and then quickly back to press the central button down again as soon as possible too. The average reaction time and movement time of 3 times' were recorded.

The reaction time and movement time results of the 3 experiment seats were shown in Tables 1 and 2 and Fig. 3. Statistical analysis showed that there were no

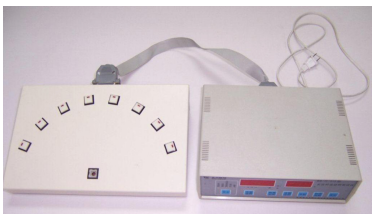


Fig. 2 BD-II-513 reaction time tester

Table 1 The reaction time (RT) results on 3 kinds of experiment seats

Time (h)	Seat A		Seat B		Seat C	
0	0.2525	±0.07	0.2533	±0.06	0.2245	±0.04
1	0.2393	±0.05	0.2373	±0.04	0.223	±0.04
2	0.2573	±0.05	0.2253	±0.03	.2163	±0.03
3	0.2235	±0.02	0.272	±0.05	0.2203	±0.04
4	0.2433	±0.04	0.2555	±0.06	0.23	±0.03
5	0.251	±0.03	0.2383	±0.04	0.2528	±0.04
6	0.259	±0.06	0.2443	±0.04	0.229	±0.04
7	0.2465	±0.04	0.2365	±0.04	0.245	±0.06
8	0.2643	±0.03	0.2395	±0.04	0.2425	±0.06

Table 2 The movement time (MT) results on 3 kinds of experiment seats

Time (h)	Seat A		Seat B		Seat C	
0	0. 5098	±0.06	0.477	±0.10	0.4473	±0.07
1	0.5393	±0.05	0.5095	±0.11	0.481	±0.11
2	0.482	±0.05	0.474	±0.08	0.4623	±0.09
3	0.4985	±0.02	0.485	±0.13	0.4828	±0.06
4	0.53	±0.09	0.4853	±0.10	0.4823	±0.07
5	0.504	±0.09	0.4865	±0.06	0.4325	±0.02
6	0.484	±0.08	0.484	±0.07	0.491	±0.10
7	0.4823	±0.10	0.49	±0.07	0.4765	±0.10
8	0.5465	±0.11	0.5073	±0.11	0.454	±0.08

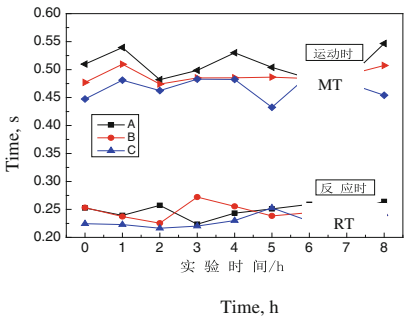


Fig. 3 The reaction time and movement time results of the 3 experiment seats

significant differences among the reaction times of the three seats ($p > 0.05$), and there was significant difference only between the movement times of seat A and seat C ($p = 0.025 < 0.05$).

3.2 Cognition Ability

The cognition ability of the subject was evaluated by accomplishing add and subtract arithmetic operations within 100 at the beginning of the experiment and after each hour until to the end. For each subject, 50 questions were provided randomly, the mental arithmetic results were input through keyboard, and the available time was 60 s. The operation process ended when the time out. The cognition abilities were assessed according to the amount of the correct calculation results. The correct calculation results on the three seats were shown in Table 3 and Fig. 4. There were significant difference between the cognition abilities on seat B and seat C ($p = 0.025 < 0.05$).

3.3 Visual Sensitivity

BD-II-118 luminescent spot scintiloscope was used to test the visual sensitivity (Fig. 5). The visual sensitivity was determined at the beginning of the experiment and after each hour until to the end. Subjects observed the blinking luminescent spot in the scintiloscope, and adjusted the flicker frequency slowly at the same time. Once he found the luminescent spot no longer glittered, the frequency value was recorded. The test results were shown in Table 4 and Fig. 6. There was a significant difference between the visual sensitivities on seat B and seat C ($p = 0.043 < 0.05$).

3.4 Heart Rate and Oxygen Saturation of Blood

NONIN Onyx II blood oxygen saturation and heart rate tester was used to test the blood oxygen saturation and heart rate (Fig. 7).

Table 3 Correct calculation result numbers on the three seats

Time (h)	Seat A		Seat B		Seat C	
0	18.25	±4.79	17.25	±0.96	19	±2.94
1	20	±4.24	17.25	±2.06	18	±3.56
2	17	±1.83	18.75	±2.99	17.75	±3.20
3	18	±4.69	17	±1.83	20.5	±3.32
4	18.25	±2.36	17.5	±2.65	21	±3.37
5	18.5	±2.65	17.5	±1.29	18.5	±3.32
6	18.25	±4.27	18.25	±3.77	21.75	±2.99
7	19	±4.69	18.25	±2.63	18.75	±2.63
8	18.5	±2.38	19.25	±3.10	20	±3.16

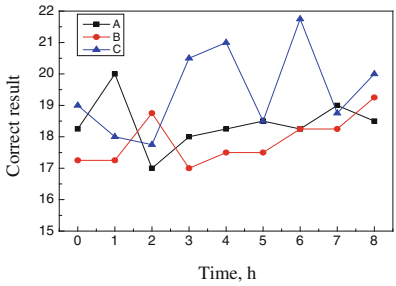


Fig. 4 The graph of the correct calculation result numbers on three seats

Fig. 5 BD-II-118 luminescent spot scintiloscope

Table 4 The flicker frequency results on three seats

Time (h)	Seat A		Seat B		Seat C	
0	32.35	±1.23	33.575	±2.30	32.025	±3.39
1	32.425	±2.25	32.125	±2.06	31.25	±3.76
2	32.675	±3.45	32.425	±2.89	31.675	±3.84
3	31.5	±2.29	32.125	±2.70	31.575	±3.59
4	31.525	±2.24	33.425	±2.54	30.75	±3.33
5	30.9	±1.61	32.275	±3.29	32.05	±3.99
6	31.425	±2.17	32.475	±3.05	31.1	±3.38
7	31.325	±2.26	32.625	±4.16	31.15	±3.63
8	31.425	±1.27	32.525	±2.54	30.4	±4.12

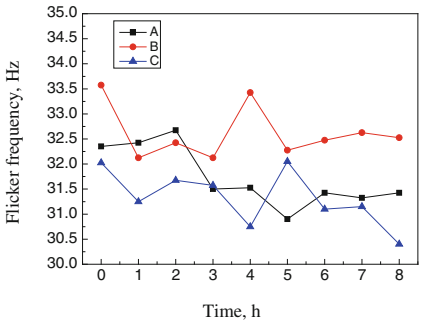


Fig. 6 The graph of the flicker frequency results on three seats

Fig. 7 NONIN Onyx II blood oxygen saturation and heart rate tester

Table 5 The blood oxygen saturation results on three seats

Time (h)	Seat A		Seat B		Seat C	
0	99	±1.41	98	±0.00	97.25	±0.50
1	98.5	±0.58	98.25	±0.50	98.5	±0.58
2	98.5	±0.58	98.75	±0.96	98.75	±0.96
3	98.5	±1.29	98.25	±0.50	98.25	±0.50
4	98	±0.00	98.75	±0.50	98.5	±0.58
5	97.5	±1.29	97.5	±0.58	98.25	±1.26
6	97.75	±0.50	97.75	±1.26	98.25	±0.50
7	98	±0.82	98.25	±0.50	98.75	±0.50
8	98.5	±0.58	98.75	±0.50	98.75	±0.50

Table 6 The heart rate results on three seats

Time (h)	Seat A		Seat B		Seat C	
0	81.75	±9.43	81.75	±10.47	78.25	±15.38
1	78.75	±9.64	78.75	±8.49	79	±14.80
2	78.75	±10.24	78.75	±6.75	73.75	±11.79
3	78.25	±11.27	78.25	±9.46	81.25	±3.79
4	83	±17.07	83	±10.87	79.75	±9.02
5	83.5	±12.37	83.5	±11.03	80.25	±12.04
6	83.5	±11.82	83.5	±7.05	82.5	±12.28
7	79.75	±14.97	79.75	±6.19	77.5	±4.55
8	79.75	±11.64	79.75	±7.63	75.75	±6.85

The subject‘s heart rate and the blood oxygen saturation of foot thumb were measured at the beginning of the experiment and after each hour until to the end. The blood oxygen saturation and heart rate results were listed in Tables 5 and 6 and shown in Fig. 8.

Statistical analysis showed that there were no significant differences among the oxygen saturations on the three seats ($p > 0.05$), and the same to heart rates.

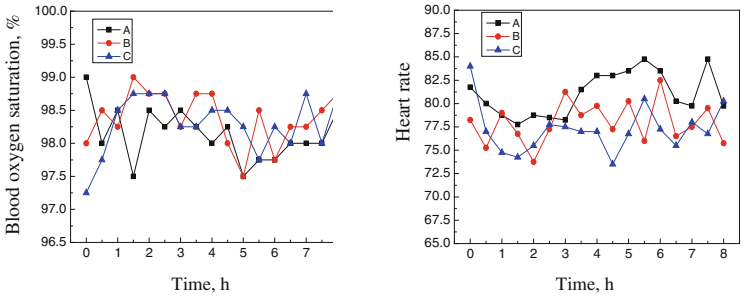


Fig. 8 The graph of the blood oxygen saturation and heart rate results on three seats

Fig. 9 MP150 physiological signal acquisition system

3.5 *Electromyogram*

With 8 channel MP150 BIOPAC system (Fig. 9), the electrical signals in the trapezius muscle and the latissimus dorsi muscle were gathered. The amplifier frequency band was 1–500 Hz, and the sampling frequency was 1000 Hz. The electrical signals were gathered every other 10 min, and each times for 10 s. The results of median frequency of shoulder EMG (MFsEMG) and median frequency of waist EMG (MFwEMG) were shown in Fig. 10.

Statistical analysis showed that for MFsEMG, there was very significant difference between seat A and B ($p = 0.000 < 0.01$), and the same to seat A and C, and seat B and C. For MFwEMG, there was no significant difference between seat A and B ($p = 0.068 > 0.05$), while there was very significant difference between seat A and C ($p = 0.000 < 0.01$), and the same to seat B and C ($p = 0.000 < 0.01$).

3.6 *Survey of Subjective Fatigue and Discomfort Feeling*

The subjective fatigue and discomfort feelings of the neck, back, waist, buttocks and thighs were surveyed at the beginning of the experiment and after each hour until to the end. The results of buttocks were shown as Fig. 11.

Statistical analysis showed that to the subjective fatigue and discomfort felling of neck, there was significant difference between seat A and B ($p = 0.04 < 0.05$), and

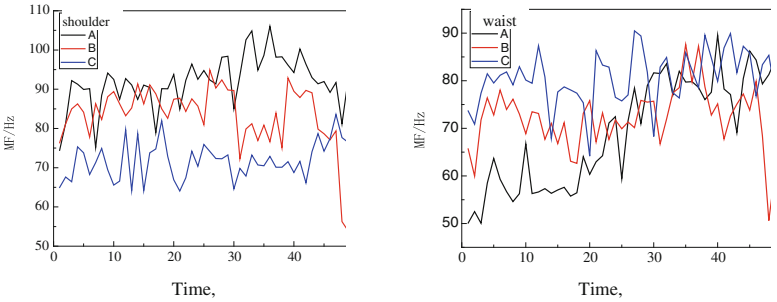
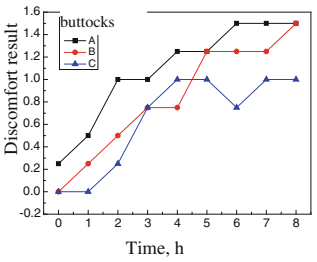


Fig. 10 The results of middle frequency of EMG

Fig. 11 The buttocks discomfort survey results of volunteers on seat A, B and C



very significant difference between seat A and C ($p = 0.001 < 0.01$); there were no significant differences between seat B and C. To back, there was very significant difference between seat A and B ($p = 0.001 < 0.01$), and between seat A and C ($p = 0.000 < 0.01$). To waist, there was significant difference between A and B ($p = 0.021 < 0.05$), and very significant difference between A and C ($p = 0.001 < 0.01$). To buttocks, there was only significant difference between A and C ($p = 0.025 < 0.05$). To thighs, there was very significant difference between A and B, and between A and C ($p = 0.000 < 0.01$), there was no significant difference between B and C. The fatigue feeling of neck, back, waist, buttocks, and thighs all assumed escalating trends along with the sitting time extension.

The comfort of seat B was better than that of seat A, and seat C was better than the first two seats on the whole.

4 Discussions

4.1 Influence of Man-Seat Interface to Seat Comfort

The man-seat interface was the right part that the rider contacted directly with the seat. When main structure of a seat had been determined, the man-seat interface

played a key role to sitting comfort feeling. The research results showed that a man-seat interface designed according to the three-dimensional form of buttocks and back of rider could make the body pressure distribution more appropriate, and then could well improve the sitting comfort [5]. In this article, seat C had a man-seat interface designed according with the three-dimensional form of buttocks and back of rider, although its surface was hard, and with no additional soft mat layer, the overall experiment result showed that the comfort of seat C was significantly better than that of the flight seat A. Therefore, improving the design of man-seat interface is necessary measures to be taken to enhance the seat comfort.

The research results also showed that backrest with adjustable inclination angle and adjustable lumbar pad could well meet the mechanics support demand of human body, and the fatigue could be reduced efficiently [6]. The seat B had a backrest with adjustable inclination angle, and had a lumbar pad which was adjustable in both up-down and back-forward directions, and its sit surface was soft. Although it could not fit the rider body surface as well as seat C, it could still well meet the support demand of rider by adjusting the adjustable parts. The experimental results showed that comfort of seat B was significantly better than seat A. This ass the further evidence that a well designed man-seat interface can play an important role to seat comfort. On the other hand it also showed that the adjustment and softness of man-seat interface had also important contribution to the seat comfort. Therefore, designing man-seat interface considering factors such as surface modeling, adjustability and flexibility would be able to further improve the long-time sitting comfort.

4.2 Effectiveness of Evaluating Indicator

The 8 kinds of objective monitoring indicators used in the experiment were usually considered to reflect the index of fatigue and comfort. But the experiment results showed that to 3 indicators of lower limb blood oxygen saturation, heart rate and reaction time, there was no significant difference between each pair of the 3 seats, so they did not suitable for evaluating the fatigue and comfort in this simulated flight control task experiment. The other 5 indicators such as movement time could reflect the comfort difference among the 3 seats at different degrees. The survey of fatigue and discomfort feeling of neck, back, waist, buttocks and thighs could more directly reflects the seat comfort of A, B and C, so it was direct and effective indicator for evaluating the seat comfort.

Of the 5 effective objective indicators, only visual sensitivity showed a downward trend along with the increase of fatigue, so it could indicate the accumulation degree of fatigue and discomfort at a certain extent. The survey showed the subjective fatigue and discomfort feelings of neck, back, waist, buttocks and thighs had all upward trends along with the accumulation of sitting time, so they were also effective indicators for a long time accumulation of fatigue and discomfort.

5 Conclusion

As one part of the man-seat interface, adjustable lumbar pad played a very important role in improving comfort and reducing fatigue. The modeling design of man-seat interface had significant effect to reduce fatigue and improve comfort. To seat for long time consecutive using, the man-seat interface should be designed according to the shape characteristics of the human body and combining with adjustable lumbar pad technology.

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Light: Visual Comfort Versus Artwork Health

Sandra Preto and Cristina Caramelo Gomes

Abstract The lighting of museum exhibition's spaces involves different areas of knowledge to guaranty the preservation of the master pieces as well as the good understanding of them by the spectator. This paper aims to study the impact of natural daylight in museum exhibition spatial areas particularly, the ones where natural light is the main lighting source remembering that exhibited works require a good conservation. From this awareness different questions emerge seeking the answer to the previous question: How to balance our individual understanding of a master piece and its integrity? Would a replica be a solution to preserve original master pieces leaving them intact for more demanding studies? Is this replica exhibition an ethical solution for the observer and the author? To achieve such goals the research will be conducted throughout literature review and the analysis of three case studies: Nordjyllands Kunstmuseum, Museum Solomon R. Guggenheim, and Tate Modern.

Keywords Light · Work of art · Visual comfort · Museum · Inclusive design

1 Introduction

The purpose of this paper is to investigate the impact of natural lighting in museums display spaces. In order to fulfill this objective is essential to understand what constitutes light, as well as the understanding of the role of museums display spaces, and how it interaction with Man. It matters, also, to comprehend in what way natural light can influence the environment, its relation with the visitor and

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how to show the true beauty of the artwork on display. Natural daylight can jeopardize the artwork causing fading and damaging them permanently, nevertheless, it's essential for a perfect visualization. The main question is: how to achieve the balance? By using reflexes, we can control light's incidence on the artwork displayed, and prevent the damage caused by the solar ray's incidence and the exposure to infra-red and ultra-violet rays. But, we cannot forget Man's primordial relation with solar energy at biologic and psychological levels. It is intended, based on the balance between light and space, to provide visual comfort and to promote the preservation of artwork. The influence of light's intensity and color in artwork is also relevant, because our sight looks for the most luminous areas/objects and higher luminosity contrasts. Furthermore, nowadays the museum is seeing as a part and acts as a symbol of the city, promotes collective living, and makes the citizens feel like members of the city.

2 Literature Review

2.1 The Contribution of Light on the Space Qualification

Vision, space, Man and light are all interconnected, since they all play a part of the same complex relationship. And this happens because light provides warmth, energy and has a significant impact in human physical, and psychologically. The light, at a quantitative level must have in mind the space's dimensions, its orientation, area, spacing of the glass surface, the presence of obstructions, and the surface's reflective characteristics. At a qualitative level it's fundamental to understand which portion of the sky is visible, its luminance and position in the field of vision. Natural light has a continuous spectrum and it's colder in the middle of the day. The highest the colour temperature (Kelvin) the colder the tone. Whilst artificial light must prevent imposing muscular adaptations to the eye, which causes visual fatigue. Vision depends on the adaptation of the cones, responsible for the ability to see colour, and visualization of details, while the rods (more sensible to light) allow peripheral sight and are dependent of the strength/intensity of the light. Visual acuity, in turn, is connected to the lighting angle, the distance to the object and we must have these issues into account for the visual characteristics, visitor's age, visual fixation time (duration), the contrast, and must not underestimate its impact on the emotional level. Artificial light is easily adjustable when it is based on tungsten lighting, emitting little ultra-violet radiation, however its temperature and heat loss are difficult to control, but when it has low voltage it becomes the ideal lighting for museums. While, fluorescent lighting is less expensive, more efficient, has a wider variety of CCT and emits less heat and, when hidden in diffusers, potentiates ambient light. To achieve a good visibility it is necessary a good contrast without shadows, CRI and the annulment of brightness/glare [1–3].

2.2 Artwork

Investment in preventive conservation is a good practice because it reduces the need for conservation recovery. Photochemical reactions and the radiant heat effect should be avoided and the levels of light, temperature and humidity must be controlled. The values of relative humidity should be between 40 and 60 %, in order to avoid causing dimensional changes in objects, especially in organic. A temperature of 18º C (±2 °C) is acceptable for exhibition spaces, while a temperature of 15 °C is suitable for storage areas [2, 3]. For the lighting of two-dimensional painting, it is required different light conditions than of a three-dimensional one. Several low-voltage spotlights are the best way to light three-dimensional artworks, but it is necessary to calculate the angles by which the observer will not see the reflection of the incident light. For lighting a two-dimensional artworks the fixtures must have an angle of 30° and when the frames have a greater thickness a higher angle is required. Excavations should be exposed to natural light but not be exposed to weather conditions because they could damage them. The positioning of a light source should be equal to the incidence angle, and be directed to the object. The lower the visual acuity the greater the distance between the observer and the object should be, nonetheless we cannot forget that the iris colour is a relevant factor, especially when the angles are greater than 30º. The desk cases should have the joints well sealed in order to prevent vibration and. light should be in a separate box light, well ventilated, or alternatively, use fiber optic or LED. The use of fiber optic or LED, which has the same characteristics (the optical fiber is more expensive), within the desk cases is a great choice, for pieces of jewelry especially, because the lamps cannot be perceived by the observer. Another solution is the ambient light, however, may not result so good, it is better to use materials that do not potentiate the reflection, such as acrylic. Natural light has more ultraviolet radiation and, therefore, should be filtered. The use of glass with UV filtering partially blocks the shorter wavelengths, which gives a yellowish light. The alternative is to use acrylic instead, however, when the acrylic used has a high density, it also gets yellowish. The exception is when we want to show phosphorescence, in which UV radiation can be the best solution. The glass must transmit a large amount of light, but must have an UV filter or be replaced by an acrylic that blocks ultraviolet rays in order to protect the artworks. Another way of eliminate UV radiation is to use varnish UV absorbent, an adhesive film or with white ink (containing titanium dioxide which is a good UV absorber). There are also other alternatives, such as neutral gray glass, which are not noticeable on the inside (but outside the windows seem really dark) or, even, the placement of an aluminum layer on the outer side, which will make them appear mirrors. Glass “sandwich” with a plastic film that contains a UV absorber is also a possibility. If we opt for acrylic sheet (a rigid plastic, also known as Perspex or Plexiglas) it should be remembered that it has weaker properties than the UV absorber. The blue spectrum (arising from natural light) is more harmful than the

red due to the exposure to artificial light, but the reddish surfaces damages more easily than blue ones. One solution may be to use cold light to prevent the surface temperature increases and causes damage. It is difficult to reduce the light level to 200 lux when the museum exhibits are lit by natural light, because the degradation depends on the duration of radiation. Exposures at 1000 lux in 1 h are equivalent to 1 lux in 1000 h [1–3].

2.3 Visual Comfort

With ageing, the ability of the human eye to focus reduces and the yellowing of the crystalline makes it more difficult to distinguish color, and the solution to overcome this situation is increasing the luminance. The contrast between the artwork and the background is another alternative, whereas the artwork must have the highest luminance than its surroundings. It is essential to eliminate sudden changes in illuminance, especially when we want to reveal the texture and, for achieving this it is better using a non-uniform light. As the eye ages the amount of light scattered in the eye increases and this makes the eye more responsive to disabling glare. The distance between the visitor and the object must, be greater as the age advances. Thus, the space should allow the visitor to approach or move away from it, without physical obstacles that impede it.

To achieve visual comfort we need, at a technical level, attend to the direction of the light, the visual fatigue and luminance level. At a psychological level, we have to avoid glare and provide a pleasant environment. The quality of the light depends on whether it is appropriate to view the object. The main causes of visual discomfort are the luminance uniformity, brightness/glare and shadows. Any luminance adaptation must happen before we enter in a museum display space. The levels of luminance advised are 20/50 lux (50 lux is considered to be the lowest level for clear visibility) in circulation spaces and 200 lux (except for detailed works which needs more luminance) at the most. Direct light creates well-defined patterns of light, but causes glare, and higher heat levels, however it hierarchizes vision, since the eye first is direct towards to the illuminated areas. Furthermore, direct light, also deepens shadows, models objects and accentuates its colors, making it more suitable for lighting three-dimensional objects. Direct sunlight should be blocked through shading systems or by having an automatic adjusting control, particularly in summer, when the light is more harmful. As for the devices like brise-soleil, and light shelves, they can be used to redirect light into locations distant from the windows. Direct sun beams can be reflected, refracted or channeled by light pipes or wells [3–5].

Excessive and/or insufficient light, are responsible for the visual fatigue and by creating a hierarchy of luminance between the artworks this issue is overcome. Surfaces, for instance, must be lighter since it contributes to a better distribution of light, and it should not be a large deviation in the values of luminance between

objects and their background, since it forces the muscles eyes to make constant adaptations which cause eyestrain. The most appropriate light for museums is through openings in ceilings and skylights, since they spread the light more effectively. The dark ceilings generate higher contrast, which affects the view, therefore should be avoided. The ceiling should be high in order to prevent large differential between horizontal and vertical light intensities. If the ceiling is artificially lit, it should be complemented with electric rails or luminous spots. Shadows are another cause of visual discomfort and occur when the light comes from a particular direction that is intercepted by an opaque object. With increasing the light levels, using surfaces with high reflectance, or with the illumination of the shadowed areas, the shadows can be avoided. When the object is smaller than the shadow produced it can cause confusion on the perception, especially if the shade is not static. Nevertheless, it is essential to reveal and enhance the perception of textures of three-dimensional objects. The strongest shadow is produced by a single source in a dark space, while the weaker shadow is created by large light sources and with a high degree of reflection. The higher the lamp efficiency the lower its color rendering. The lamp efficacy is higher when there is more lumens per watt, which is the relation of the ratio of luminous flux (in lumens) and lamp power. While, the efficiency is the lifetime in hours of use. Luminaires should be directional/orientable, have adjustable intensities and the reflectors must be of good quality so they could be targeted, and avoid stains resulting from luminaires (arcs). The shapes of the reflector, the slope, the permission to change the degree of focus in order to be more precise, are also important features. The simple fact that artificial light permit precision and constancy does not seem to be a good thing, as a matter of fact uniformity is not something that we should want. The artificial lighting should be warmer, or colder, depending of geographical location. In the Nordic countries and along the shorelines the light enters more easily through skylights. In areas where the temperature is colder the light, the way it enters in an indoor space, its duration in time, area and orientation are fundamentals. The façades oriented north are more stable over the year, while if it is oriented east or west the variation is considerable. Hence, we cannot ignore this factors. [1, 3, 4].

2.4 Museum

Nowadays, the museum is also seen as equipment that revitalizes the city´s urban area, because it was the way of assigning a new function to an existing building. There are two major types of museums display spaces, the classical and contemporary art. This aspect is crucial, since the luminous needs are different depending on the type of degradation that may affect the artworks exhibited. It's almost a crime jeopardizing the conservation of classical works, but this is not seen in the same way, if we refer to the works of modern art, such as installations that are also artworks. A different perspective is an artwork that is designed to be contemplated

from a certain angle or with a certain light, but this is a difficult goal to achieve. It is known that in Baroque churches the light has to enter on a certain day at a certain time, has an effect in order to captivate believers. Artificial light cannot do that, due to its constancy and accuracy, which are regarded as their major advantages. Therefore, the answer also is not to use, exclusively, artificial light, because this causes damage to the objects exposed. The fact that museums curators wish that the artworks should be exposed in similar conditions to those in which they were conceived in, is something difficult to simulate because the light differs depending on the geographical area. Apart from that, the ink over time eventually oxidize, changing its retinal perception, as Marcel Duchamp demonstrated in the Grand Verre, work where he wanted to immortalize the paint itself. Another interesting question is that some artists claim that the passage of time leave marks on it, Siza Vieira (Portuguese architect awarded the Pritzker), for example, argues that over time his works gain a certain patina and that the feeling of nakedness disappears of his works. Following this reasoning, is the light supposed to have its role, active in the transformation of artwork? But, in reality, what happens is that many of these artworks, for being of a certain artist, are subject to a level of conservation that does not allow them, even, to gain patina. So, visiting a museum is more than a visit to see artworks is an emotional experience, especially if the design of the exhibition has the awareness of this fact and make a and for that it is necessary to careful study of the works to expose how to expose [3, 6, 7]. When we stand before contemporary artworks, under natural lighting, the care of the artwork become less central, as in the work of Tratado de Libré Comer of Abraham Cruz Villegas since it can be easily replaced. In these works there are not so many concerns with the light because they are not considered unique, or irreplaceable, and therefore the guild of visual comfort versus degradation of works is more easily achieved. Conversely, the classic artworks are considered as being unique, so they require a specific care. Unique because of ethical issues and its replication is also technically more complicated to achieve. However, the opinions of museum curators are that the artwork must be preserved. With the use of replicas the original artworks remain protected and continue to be appreciated and contemplated. The museum may consider creating replicas for such purposes, but should be clear that these are the replicas. Even though, sometimes even experts, do not distinguished replicas from the real object at naked eye.

2.5 Inclusive Design

The Louvre Museum, for example, is testing in its Tactile Gallery, regarding the inclusiveness of artworks, and thus make them accessible to visitors with visual impairments or “low vision”, and the way to overcome this issue was, precisely, using replicas, allowing them to be displayed and preferably perceived by the touch. Although, in this example the question is not directly related with light, it sustains

the defense of the replica. Everyone appreciate the fact that is possible to touch in the artwork, and for those you are blind or has some kind of visual impairment this is essential. The seventeen works exhibited in Tactile Gallery (July 2012) were plaster mold, resin and terracotta and all have subtitles in Braille. The fact that they are replicas reinforces the approach of man to the artwork. The eye is an organ that artworks best depending on the distance that found in the artwork. But in order to enjoy an impressionistic work, we need to move away so we can view the whole and at the same time, we need to approach us to realize the technique used, overlapping paint layers in impressionist paintings for instance. The current culture is dominated by the image, particularly appealing to sight, but the touch is the sense that calls for approximation and awakening of other senses. The touch allows us to perceive the texture, weight, density and temperature of matter. Tact returns, to the paintings and sculptures its sensuality and its sensitivity [6]. It is curious that we close our eyes when we want to hear a song more closely, when we need to focus or even for daydreaming. We reinforce the other senses and we are compelled to resort to imagine and memory, which, in a sense, takes us to create an affective bond and therefore more real and more enduring. The new artistic approaches are another aspect to take into consideration, such as Urban Art or Earth Art, or even through the Internet, since they are not affected by the light. The first two are exposed to weather conditions, while the third allows the visit virtually to museums display spaces, without perceiving what types of lighting are artworks under, because it is not something that comes recorded photographically. And there is not any concern with their conservation. Another issue that has a great impact on the artwork conservation displayed relies on the permission to take pictures. And some museums do not allow us to take pictures, even without flash. The flash not only damages the artwork but also creates glares, shadows, and reflexes due to the glass that protects the pictures. And when the pictures are protected by acrylic the yellowing that appears as time goes by, also modifies the colors of it. Interesting, is the fact that the permission of taking, or not, photographs is based on the museum politics and not on the type of artwork that is displayed. At the Guggenheim is not allowed to take photos on the display spaces, with or without flash. At Kunsten, and Tate, is not forbidden to take photos, even with flash. And, we noticed that this permission is not the best for the paintings displayed since some of them have visible damages. This could be all diminished if the artworks were replicas. Even though, the replicas should have a value as artworks (although they are not the originals), and is this way we all could see, and touch the various artworks displayed and awake our senses, not only vision, in order to appreciate the art itself. But, it should be clear that they are replicas of the originals and an explanation for it would be nice, too. Does the art only serves our visual curiosity and does it exist merely for being contemplated? According to Pierre Cabane (apud Marcel Duchamp, 2002), no, the important is to induce imagination. Another issue is that the replica makes the artwork accessible to all, since there are no barriers, geographically speaking, and cultural. It is a way to globalize art itself to all mankind.

3 Case Studies

3.1 Solomon R. Guggenheim Museum, New York, United States of America, 1943–56, Frank Lloyd Wright (1867–1959)

At Guggenheim Museum (Fig. 1), in the summer (Figs. 2 and 3), the solar rays enter the central skylight with greater intensity and longer, since the solar pathway happens to NE-NW and the angle of solar incidence is 80°, which does not reach the artworks exhibited, since the rays, due to the angle, are directed to the ground floor and not to the perimeter walls of the large roundabout. While in winter the sun's rays, with 35° inclination, are intercepted by the built environment, the SE-SW. Daylight, when we are inside the Guggenheim, both in central skylight as Annex Thannhauser are always present. We have the opportunity to observe the exposed opposite the ramp and thus allows a different, more dynamic interpretation works. However, it also causes distractions and figures, which does not contribute to a good contemplation of the works. The lateral grooves turn out to be purely decorative, since, typically, are covered. Its angle, almost flat, also complicates the entry of light inside and even though the light to enter the effect function as backlight. The artificial lighting is guaranteed mainly by spots of different sizes, shapes and placed in electrical rails, allowing its adaptation. Concerning multimedia spaces, which are on the upper floors (where the ramp is wider) they do not always have an area of adaptation between the different luminous intensities passing from spaces with quite a lot of light to spaces with practically no light at all. The spots on the desk cases, causes reflections in the artworks because they are misdirected. The glass serves to protect the artworks and not to hinder the observation of them. Acrylic does not jeopardize the preservation and does not cause glare and/or reflections. The artificial light, should be directed laterally in relation to the artworks and be further from it to avoid causing reflections and shadows.

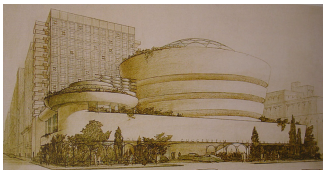

Fig. 1 Exterior perspetive of Guggenheim Museum [8]

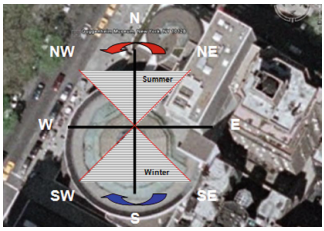

Fig. 2 Aerial view, Guggenheim Museum, New York [9]

Fig. 3 Solomon R. Guggenheim Museum section. (Drawings of Michael Gabellibi based on the drawings of Gwathmey Siegel Associates Architect's. figure de Tom Powers, Ivy League of Artists) [10]

3.2 Nordjyllands Kunstmuseum, Aalborg, Denmark, 1968–72, Alvar Aalto (1898–1976), Elissa Aalto (1922–1994) and Jean-Jacques Barüel (1923–)

As for the Nordjyllands Kunstmuseum (Fig. 4), which is referred as Kunsten in the present paper, in the summer (Figs. 5 and 6), the sun's rays came in mainly in the central hall, and sculpture hall, since the solar pathway is from NNE to NNW and has an angle of incidence of 60°. While, in winter, rays of 10° are intercepted on the hillside that lies on the south side. There are natural light in all display spaces, which gives an idea of the weather, and what part of the day (morning, afternoon and evening) are we in. Spite of the sloping skylights and the curved reflectors solar rays can enter the display spaces, however the intensity is already dimmed since it has been projected several times until it falls on the artworks. In the Galleries I-VII

Fig. 4 Aerial view of Nordjyllands Kunstmuseum [11]

Fig. 5 Exterior view of Central Hall from the sculpture park (Aalborg, Denmark) [12]

Fig. 6 Solar exposition, Kunsten [9]

the sun does not enter because in the winter the slope function as a barrier, but even if that happens it would suffice to have blinds that block them. Whereas in Central Hall and Sculpture Hall it does not happens. A surprising fact is that in winter the southern slop offers a protection from the solar rays but there is no need of it since they are almost inexistent and weak, while, in the summer, the solar pathway is from NE to NW and has no obstacle whatsoever in order to offer protection. The movable panels in mate and light color shows to be a good solution, since they have similar illuminances. Nevertheless, the floor has areas with polished finish, which is no longer a good example. There are several types of artificial light, with lots of lamps with different color temperatures, however during the winter sunlight is scarce. The fixtures are sometimes lit when it is not necessary and cause discomfort glare. The placement of sensors allows the adaptation of existing fixtures in the various display spaces. The luminaires in the exhibition spaces are cooler that is seen as comfortable in the Nordic countries. The existence of several configurations of fixtures is commendable, because these are essential in the winter. Alvar Aalto sought many forms of sunlight entering the interior. However, direct sunlight enters the interior and degrade the works exhibited and there is shutters only to protect the works in Galleries I-VII (side spans). One of the most troubling points in Kunsten is that some, though few, artworks exhibited are damaged.

3.3 Tate Modern (Improvement), London, United Kingdom, 2000, Herzog (1950–) and de Meuron (1950–)

At Tate Modern (Fig. 7), in the summer (Figs. 8 and 9), the sun rays do not enter directly in the display spaces, since that solar pathway goes from SE to SW and has an angle of incidence of 70°. And, in the winter, the angle is 15° and is projected on the main façade that has windows. Thus, in the summer the artworks do not suffer the consequences of the heat and of the sun rays. In most of the display spaces we are stand before natural light, which gives us the notion of the climate state of the weather, time, if it is morning, afternoon or night, through the vertical windows across the main façade which can be found on the northern and western façades. Although, the turbine hall is on the west façade and there are not artworks displayed there. At the display spaces located on eastern and southern façades the sun does

Fig. 7 Tate Modern (London, U.K.) [13]

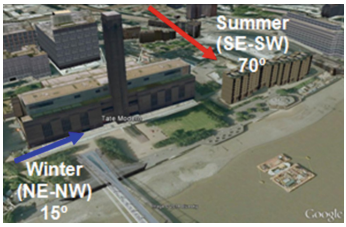

Fig. 8 Sun exposition [9]

Fig. 9 Solar pathway [9]

not enter since there are not any windows. So, in those areas the artworks are, only, illuminated by artificial light. Thus, the sun rays do not damage the artworks displayed, but the artificial light does. It is not possible for the art to be immune to light, they always suffer the consequences from the heat and from the light rays. As for the artificial light, which is in electric/lighting rails on the ceiling, enables flexible location on the room, quantity and the lamp type should be directional/orientable. And there is another kind of artificial lighting, through false windows that have artificial light in its interior. However, both causes discomfort glare. The light intensity on the false windows should be rethought. And, if the luminaires on the electric rails have accessories and diffusers that hide the lamps the discomfort glare would be avoided. At the display spaces which are near the northern façade, the natural light on the winter season is spread all over the vertical windows, which makes the light to reach far away from them.

4 Comparison Between the Case Studies

See Tables 1 and 2.

Table 1 Solar pathway's comparison between case studies [14]

Season	Guggenheim	Kunsten	Tate Modern
Summer	15 h per day of natural light Solar path NE-NW Insolation and average clarity **Artworks protected Visual Comfort median**	18 h per day of natural light Solar pathway of NNW-NNE Insolation and average clarity **Artworks moderately protected Visual Comfort**	16 h per day of natural light Solar pathway of SE-SW Insolation and average clarity **Artworks protected Visual Comfort median**
Equinox	12h30 daily natural light Solar Pathway E-W Insolation little below half average (sun is weaker) **Artworks protected Visual Comfort**	11 h daily natural light Solar Pathway E-W Insolation about 1/4 and average (sun is much weaker) **Artworks protected Visual Comfort**	12 h daily natural light Solar Pathway E-W Insolation above half average clarity in September and below half average in March. **Artworks moderately protected Visual Comfort**
Winter	9h30. daily natural light Solar path SE-SW Very low insolation. (weak sun) **Artworks protected Visual Comfort**	6h30. daily natural night Solar path SSE-SSW Practically zero (weak insolation) **Artworks protected Visual Comfort**	9h30. daily natural light Solar path NE-NW Low insolation and clarity **Artworks protected Visual Comfort**

Table 2 Visual comfort and artwork integrity's comparison between case studies [15]

	Guggenheim	Kunsten	Tate Modern
Visual comfort	+ −	+	+ −
Degradation of artworks	–	+	+
Natural light	+ −	+	+
Artificial light	+	+ −	+ −

5 Conclusions

Despite the works on display at Kunsten have showed damage, due to its exposure to light, visual comfort is achieved more efficiently. Interesting is also the fact that glare at the Guggenheim is due to artificial light, while at the Kunsten is a consequence of natural light. As for the Tate Modern some of the spotlights could induce discomfort glare and many of the artworks exposed are installations, which it is possible to replace parts of it. Kunsten in terms of visual comfort is a better example. In turn, the works exhibited in the Guggenheim exhibit less damage than in Guggenheim and Tate Modern. There are many museums in which certain works are exposed for only a certain few number of hours per day, so that your exposure to light, artificial and natural, do not reduce its life expectancy. The replica is a way to reactivate and/or enhance the other senses, broaden access to works of art for blind visitors, make inclusive space and protect the works of harm from natural light so necessary to man. Using replicas both objectives, are achieved, the preservation of artworks and visual comfort. The arguments supporting this view are many, includes the fact that there is almost no kind of light, natural or artificial, which does not cause irreparable damage to the artworks, whether classical, contemporary or modern.

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Developing a Social Capability Model of Inclusive Public Facilities: A Case Study of Play Space in Hong Kong

Yi Lin Wong, Kin Wai Michael Siu and Mei Seung Lam

Abstract Through a case study of Hong Kong, the paper presents how the Inclusive Design Cube (IDC) can be referenced to develop and evaluate inclusive play space in practice. While social activities take place frequently in play space, the paper advocates that it is essential to include social aspect in public design. Consequently, based on the IDC, the paper develops a model of Socially Inclusive Design Cube (SIDC) to investigate and identify the relationship among social, motion, cognitive and sensory capabilities in the context of play space. Through the development of the SIDC model, the paper raises a question about inclusive design approach. It is hoped that the further development and the application of the SIDC model will contribute to the discipline of inclusive design with social concerns.

Keywords Inclusive design cube (IDC) · Socially inclusive design cube (SIDC) · Play space · Public design · Children · Hong Kong

1 Introduction

Since few decades ago, researchers had already noticed the problem of defining play. There is no distinct definition to describe and explain its nature [1]. Sutton-Smith [2] claimed that this is the ambiguity of play. Some researchers were still attempting to resolve the issue. Scarlett et al. [3] concluded from the

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perspective of children that play is "about having fun, being outdoors, being with friends, choosing freely, not working, pretending, enacting fantasy and drama, and playing games" (p. 3). It is also central to children's physical, social, emotional and cognitive development that children often learn through play at home, school, playgrounds and outdoor playgrounds [4]. In order to protect children from bad play that is unsafe and threatening and facilitate them learning the skills and abilities, it is essential to provide suitable play facilities or objects for children.

Play facilities in public space provided by government are one of the most common play facilities that most children can come to contact with. In the recent years, their designs have been drawing more attention of designers and architects. As society advances and the concept of inclusiveness develops among the members, it is unsurprising to find that more inclusive facilities are provided for users with different abilities. The same should have happened for play facilities; however, this is not the case of Hong Kong, as well as many cities which claim that they have invested a lot of money and other efforts and resources on play facilities.

Despite the growth of other inclusive facilities, for example, most of the current play facilities in the play space of Hong Kong do not cater the needs of the disabled children. Based on the deficiency in Hong Kong, the paper presents how the Inclusive Design Cube (IDC) can be applied to develop and evaluate play space in practice. Based on the IDC model, it also develops a model of social capability, namely Socially Inclusive Design Cube (SIDC), for understanding the social aspect in play space. The SIDC model seeks to identify the relationship among social, motion, cognitive and sensory capabilities in the context of play space.

2 Inclusive Design Cube and Its Application in Play Space

2.1 Inclusive Design Cube (IDC)

Considering the needs and preferences of the end-users is imperative for a successful design [5]. The IDC is one of the well-developed model focusing on the users. It advocates designing for the whole population [6]. The whole population means all users with different sensory, cognitive and motion capability (Fig. 1). The cube itself is used to explain how the population is divided into groups with different capability.

The axes of the cube represent the motion, cognitive and sensory capabilities. The front corner of the cube represents the fully able user. In the illustration of Clarkson et al. [6], the cube is divided into different parts to represent populations using different designs: special purpose design, modular/customizable design and user aware design. The user aware design is widely accessible to the majority of the population. The special purpose design is catered for users with special needs and severe impairment. The modular/customizable design, which is in between the two designs, features adjustable parts to make adaptation for some users. Apart from

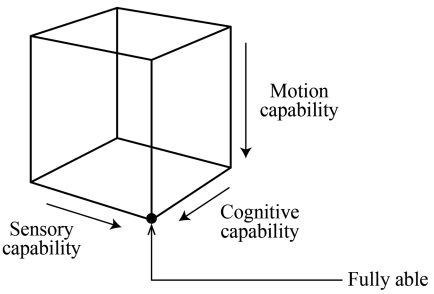


Fig. 1 The inclusive design cube (a simplified diagram modified from the version of Clarkson et al.) (by authors)

these three kinds of populations and their corresponding designs, the cube also includes population who need to be assisted by caretakers.

The IDC model suggests that people with different motion, sensory and cognitive capabilities may be served by different design approaches. Potential market can be identified and designs which suit a wider range of users may be developed. Inclusive designers can also make use of the cube to evaluate products' usability for different groups of population. They can use the cube with other quantitative data such as demographic and ergonomic data so that a more inclusive design can be produced.

It is noted that not only is the inclusiveness addressed, the exclusiveness of designs is also highlighted in the model of IDC. As the model illustrates the whole population, it is easy to identify which groups of population of end-users are being excluded. The IDC provides perspectives on the exclusion of end-users and addresses why some users are excluded [7].

2.2 Application of IDC in Public Play Space

In the example given by Clarkson et al. [6], a product (i.e., a kettle) was used to explain the application of IDC. Apparently, the IDC model is applicable across various design disciplines, as it is not designated in any specific contexts. Any designers dealing with inclusiveness and exclusiveness can apply the model. The IDC can be applied in any public play space attempting to be inclusive for children with different capabilities.

A possible way to apply the IDC in play space is to use it as a method of idea development (see Fig. 1). Designers can select the population with lower capabilities as end-users in the cube and design customizable/modular designs for them. For instance, in order to create play space allowing wheelchair users with lower motion capability, the width of the pathways may need to be wider. A play space that is able to cater children with exceptionally high cognitive capability may need to include some adventurous or creative problem solving elements in the play facilities. Being inclusive for children with sensory disability may need to choose colors carefully or introduce auditory elements in the play space. Using the IDC as

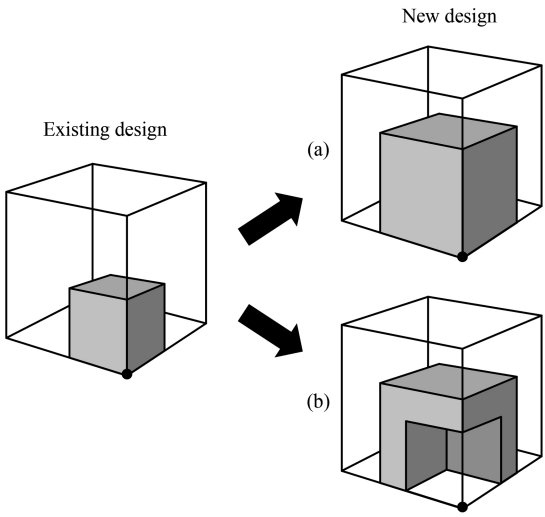


Fig. 2 **a** Increasing the population of end-users by including more end-users in the IDC model, **b** designing for a specific population of end-users (the *grey cubes* present the end-users of whom a play space is designed for) (by authors)

a method of design development is to focus on the inclusiveness. This increases the accessibility of the play space for a specific population of end-users, or includes more end-users in different populations, depending on the level of its design inclusiveness.

The IDC can also be a method of evaluation. Instead of focusing on inclusiveness, exclusiveness is the emphasis (see Fig. 2). In other words, populations who are excluded by a design are of concern [7]. For instance, play facilities of a certain play space may be unable to cater the needs of armless children, and children with this kind of disability are being excluded in the design of the play space. It may be primarily because climbing is a major play activity in the play space, and children without arms cannot play well. Children's with Down syndrome may be unable to play in a certain maze park individually. This group of children is excluded, and adult companion must be needed because the cognitive ability needed to solve the maze is too high for the children. Children with disability in spatial awareness may be unable to jump from one stump to another one with different heights in play space. Play space with this kind of stumps design excludes children from enjoying play (Fig. 3).

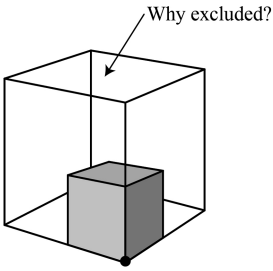


Fig. 3 Identifying the reasons of exclusion by focusing on the excluded end-users in the IDC model (the *grey cubes* present the end-users whom a play space is not designed for) (by authors)

From the above examples, design inclusion is the usual method used by designers to develop inclusive design for end-users, while design exclusion is able to understand why a population of end-users is excluded [7].

2.3 *The Complication of IDC in the Case of Hong Kong Play Space*

A joint-institutional and interdisciplinary research project has been implemented to explore the inclusiveness of public design. The research team attempted to apply the IDC model to understand Hong Kong (public) play space. Among all 18 districts in Hong Kong, the Kwun Tong district has the highest population density of children below 12 years old in 2011 [8]. The researchers then chose the play space in the Kwun Tong district for the investigation. There are 105 play spaces in total. These play spaces are actually playgrounds with play facilities and rubber safety mat on the ground. Figure 4a, b shows two examples of typical playgrounds and facilities in the Kwun Tong district of Hong Kong. The most popular facilities and structures include slides, swings, climbing frames, rocking chairs and seesaws.

The research team visited the 105 playgrounds and studied the play facilities by using the IDC model. The process of preliminary observation revealed that the application of the model in playgrounds of Hong Kong is not as direct as it seems. The context of play space is more complicated, as it not only concerns a single design aspect but more than one.

Play space is one of the public facilities which covers the aspects of product (play facilities) and environment. When the IDC is applied in the context of play space, both play facilities and the environment may have to be studied separately. The level of accessibility of the two may be different, as the populations the play facilities and the environment served may not be identical. This mismatch is possible in the context of public play space. Figure 5 illustrates an example of mismatch of accessible populations using play facilities and environment.

Fig. 4 Typical playgrounds in the Kwun Tong district of Hong Kong (by authors)

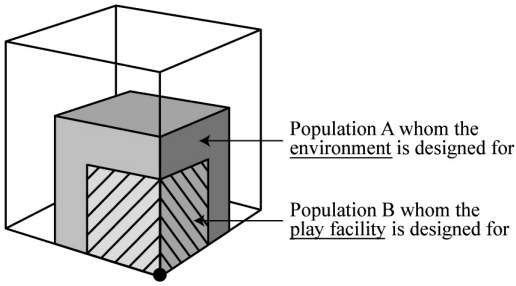


Fig. 5 An example of mismatch of the accessible populations using play facilities and environment (by authors)

In the example of Fig. 5, end-users in Population A have higher capabilities than those in Population B. A play space's environment is often able to cater the needs of Population A with the installation of lift or wheelchair path. However, the play facilities in the same play space may be unable to address the needs of Population A, and they can only serve the end-users of Population B. For instance, although a wheelchair path is built at the entrance of a play space, no play facility is provided accordingly. This kind of mismatch is common in playgrounds of Hong Kong.

In other words, while designing inclusive play space by using the IDC model, it is essential to consider the play facilities and the environment separately. It is undoubtedly the most preferable to synchronize the two accessible populations of play facilities and the environment and consider how to increase the population in the IDC model simultaneously. In addition, in the evaluation of play space, consideration should be taken for any populations which are excluded by either play facilities or environment. The evaluation should focus on both to get a more precise assessment outcome.

Apart from the mismatch issue discussed above, the research team, based on the preliminary observation, found that social activity is an important aspect in children's play in a play space [9]. After examining the environment and the play facilities of a playground, the research team would observe children's play. It is found that most children would play the play facilities and enjoy the fun that the structure could provide them but soon they would develop their own games with their peers or other children with similar age. Almost no children would play alone, and no children with disability appeared in the playgrounds. Apparently, social activities are essential. The interactions identified in the play space are not limited to child and playstructure but also child and child.

Consequently, inclusive play in this regard is not limited to motion, cognitive and sensory capability. The social aspect should also be considered. The IDC model should also include social capability, i.e., whether children is able to play with other children, in the context of play space. This calls for an inclusive design model through a social approach.

3 Developing a Social Capability Model of Inclusive Design

A social capability model of inclusive design is developed from the IDC model of Clarkson et al. In order to explain the possible interaction among the end-users in the IDC, each end-user of the population in the IDC model is illustrated by a small molecule (a sphere) in Fig. 6. Each molecule represents an end-user in the population analogically. The end-users are arranged in sequence based on their capabilities, and the front corner of the cube represents the fully able user (same as the IDC model described above in Fig. 1). The IDC model is used to develop the social capability model because the three capabilities in IDC are dispensable elements in considering inclusive design.

The social capability of an end-user is not represented by the three-dimensions as the three capabilities do. It is illustrated through the mobility of the molecules inside the cube. It is argued that being socially inclusive means that children with different capabilities can play together and engage in various activities. For instance, wheelchair children, children with Down syndrome, and visually impaired children can play with other children through some specially-designed games or facilities in a play space. The possibility of assimilating into other end-users groups with different capability becomes the key measurement of social capability.

The concept of Socially Inclusive Design Cube (SIDC) is thus developed to include social capability. The social capability is independent from the motion, cognitive and sensory capabilities. It is regarded as another type of capability that it depends on various extrinsic factors such as environmental settings, and attitudes and responses of other end-users. Sometimes the caretakers may also create an impact to children's social capability [10]. The social capability is about the relationship between the end-users; therefore, it is measured by mobility and flexibility, and it is not norm-referenced.

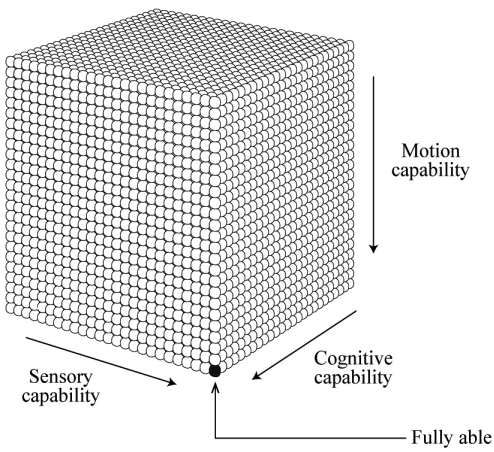


Fig. 6 The IDC model with individual end-users illustrated (a molecule represents an end-user) (by authors)

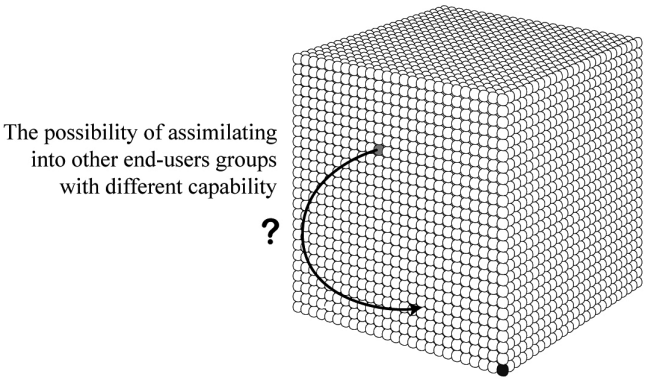
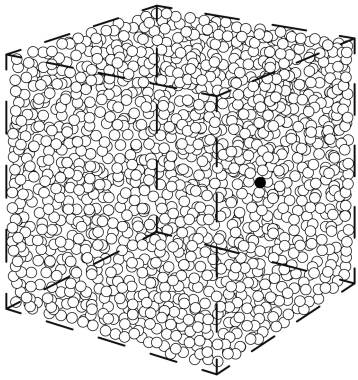


Fig. 7 The rigid and solid state of the socially inclusive design cube (SIDC) (by authors)

Fig. 8 The 100 % flexible and 'fluid' state of the SIDC (by authors)



The current rigid and solid state of the SIDC illustrated in Fig. 7 is unable to facilitate mobility and flexibility. Even the fully-able person may not have this kind of mobility. The molecules in Fig. 7 should have a certain level of mobility in order to assimilate into other groups. Ideally, *perfect social inclusiveness* occurs when the end-users use a *super design*. It disregards the motion, cognitive and sensory capabilities, and the *super design* allows the end-users with different capabilities (including the fully-able person) socially mixing together. This forms a 100 % flexible and 'fluid' state of the SIDC (Fig. 8). The molecules are able to move around so that the end-users with different capability can mix and socialize with each other by using the *super design*.

However, the state of the SIDC in Fig. 8 does not currently exist. Designs nowadays are still limited by the technology, and at the moment we are still unable to overcome the disabilities perfectly. In other words, *super design* is now just an imagination and does not exist also. The *perfect social inclusiveness* shown in Fig. 8 is not yet realized. In reality, the state may be 'viscous' or between 'solid' and 'fluid'. Different states may exist simultaneously in the cube. For instance, the

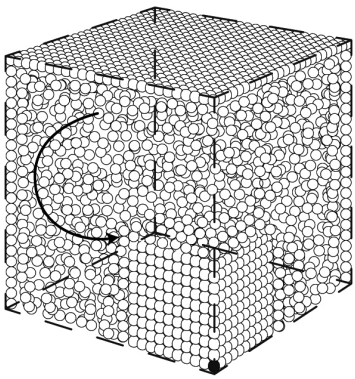


Fig. 9 An example of the SIDC with different states (by authors)

molecules near the front corner are arranged orderly, while other molecules far from the front corner are more loosen and flexible to move (Fig. 9). This discourse of reality raises a question: what approach should designers take to attain social inclusiveness and at the same time retaining the capabilities of the end-users? The response to this question is central to any inclusive design with social concerns.

4 Conclusions

The IDC model is one of the well-developed models to develop and evaluate inclusive design. This paper does not have any intention to devaluate or underrate the original IDC model. Instead, it is a study focusing on the social inclusiveness based on the conception of the IDC model.

Through applying the IDC model into the playgrounds in the Kwun Tong district of Hong Kong, it is found that its application in play space is not straight forward as in other design disciplines. The public design nature of play space complicates the application of the IDC model, as public design is a discipline concerning product, environmental, and sometimes architectural designs. This paper also suggests that when public design is concerned, researchers may need to develop specific approaches to investigate into the topic.

The SIDC model suggested in this paper grounds a fundamental perspective to understand the relationships among the end-users in socially inclusive design. The different states of the model express the level of mobility and flexibility among the end-users. The model also addresses the issue of balancing the needs of socially inclusiveness and the concerns of capabilities. In order to put the SIDC model into real practice, practical application of the model is needed. Further adjustment and modification are needed afterwards.

Designing for social inclusion is exceptionally important in play space. Researchers and designers should shift the inclusive design approach from capability to diversity [11], so that children not only can use the facilities but also enjoy

and share the real joy of play with others in public play space. Again, this paper does not any intention to provide a perfect or well-mature model for design application—at least up to the current research position. Instead, this paper wants to raise a critical question as abovementioned for researchers and designers to have more exploration and discussion.

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Analysis of Parent-Child Interaction at Various Space and Furniture of Reading Environment—Take Parent-Child Reading Areas in Taipei Public Libraries as an Example

Jo-Han Chang and Jun-Yu Wang

Abstract Different reading environment affects parent-child interaction, joint reading time and reading posture. The research is based on the example of parent-child reading areas in Taipei public libraries. We visited eight Taipei public libraries in person, analyzing pros and cons of space and furniture arrangement with mandatory of "Learning Environments for Young Children" as well as recording parent-child reading behavior at varied environments with Nonparticipant Observation Method. After evaluation and analysis of the research, we found two aspects to be improved which are library space and furniture arrangement—furniture lack of containing space and space lack of artistic display and decoration. Through parent-child reading interaction, the result of analyzing relations between environment and behavior is that the design of soundproof space is too confined and that massive bookshelves cause pressure on children attracting no child to enter the area. Diversified reading chairs may increase intention of parent-child reading. Making good use of children-related subject in interior design helps arouse parents and children's interests in coming. Switching to different reading environments and books every 10 min may prolong the duration of reading. The common parent-child reading posture is sideways sitting. The seating designed especially for parent-child reading may increase the comfort of reading and duration of reading.

Keywords Library · Reading environment · Parent-child reading

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1 Introduction

Parent-child shared reading facilitates children's abilities in story comprehension [1], and language expression [2] as well as strengthens parent-child relationships [3]. Children's reading rooms or parent-child shared reading areas at libraries are some of the places where parents and children often go for reading together [4]. However, reading environments are closely related to children's reading comfort and concentration [5]. Based on the above, this study intends to apply the Nonparticipation Observation Method to analyze parent-child behavior in terms of space and furniture in different reading environments. Next, the results from the observation will be organized so as to identify the relationships between the environments, furniture and parent-child interactions.

2 Literature

2.1 Parent-Child Reading Environment

The space planning at libraries is mainly based on the needs of users and for the purpose of creating a good reading environment [6]. In a reading area, over crowded space reduces users' intention to enter for reading [7]. In addition, comfortable furniture or soft materials such as mats, rugs or pillows being placed on the ground can increase physical interactions and intimacy between users [8].

2.2 Reading Concentration and Comfort

The use of appropriate furniture is crucial to the health development of young children. Well-designed chairs help them to keep focused in a reading environment [9]. "Dialogues" during parent-child shared reading not only help intensify parent-child interactions but also expand reading content and improve concentration of young children [10]. Meanwhile, long-time reading can easily cause distraction of young children and reduce reading quality [11].

Posture can affect users' comfort [12]. Accurate sitting posture is able to increase the balance and stability of young children's upper limbs so that their body feels comfortable for reading [13]. On the contrary, young children's heels hang off the ground while sitting on a higher chair. This can cause a backache, eye strain and discomfort when children are reading [14].

3 Research Methods

3.1 Field Study

The researcher visited eight public libraries in Taipei City from December 1–16, 2015 in order to record and analyze the current conditions in relation to space planning for parent-child shared reading [15]. In this study, the table of Learning Environments for Young Children was revised and omitted. The items evaluating a reading environment in "Organization of early childhood area" (Table 1), "Accommodations for range of ages and families" (Table 2) and "Displays" (Table 3) are described as follows.

3.2 Observation Survey

The research [16] classified the children's reading rooms and parent-child shared reading areas at public libraries in Taipei City into eight types (Table 4). For

Table 1 Items of organization of early childhood area

Number	Item
1	Organization of the environment is clear
2	Activity and learning centers are easily recognizable
3	Activity areas provide space for children and adults to stand, sit, or work next to each other
4	Activity areas provide space for young children to move, practice large motor activities, and learn with entire body
5	Young children can access a portion of collections
6	Low shelves, open bins (without lids or covers), and/or low hooks or hangers hold materials that children can access themselves
7	Furniture and seating is available for small groups of two to four people to gather in face-to-face interactions
8	Quiet and noisy activities are separated.
9	Activity centers can been seen with unobstructed views from more than one section in the children's area
10	A separate room is available for special programs
11	Noise levels are minimized by design considerations
12	Lighting, including windows and natural lighting, enhances the environment

Table 2 Items of accommodations for range of ages and families

Number	Item
1	Furniture scaled to the needs of young children is adequate to meet demand
2	An area with soft furnishings for adults and children to share is available
3	Adult size chairs for parents/caregivers are available
4	Separate places to put equipment and outerwear are available

Table 3 Items of displays

Number	Item
1	Sense of family place and messages of welcome are established through use of design features and/or hanging decorations and displays
2	Color, light, and design elements are used to create cheerful decorations of interest
3	Displays, exhibits, and activity/learning areas are of interest to young children
4	Pictorial symbols and letters are used to assist in communicating organization of area
5	Displays, exhibits, and interest areas encourage ethnic pride and the recognition of cultural diversity
6	Children's projects and artwork are displayed
7	Children's projects and artwork are displayed at eye level for young children

Table 4 Types of children's reading rooms and parent-child shared reading areas

Parent-child reading areas	Types
	Seats _A library
	Tables _B library
	Floor _C library
	Floor with seats _D library

(continued)

Table 4 (continued)

Parent-child reading areas	Types
	Floor with tables _E library
	The floor has a hole _F library
	The floor has a hole with seats _G library
	The floor has a hole with tables _H library

carrying out this study, visits were paid to the public libraries representing these eight types in Taipei City.

4 Results

4.1 Assessment Results of Space Planning for Parent-Child Shared Reading at Taipei Public Library

In this study, the following items are assessed in terms of the three categories: "achieved rate", "failure rate" and "to be improved rate". The results evaluating a

reading environment in "Organization of early childhood area" (Table 5), "Accommodations for range of ages and families" (Table 6) and "Displays" (Table 7) are described as follows.

Table 5 Results of organization of early childhood area

Number	Item	Achieved rate (%)	Failure rate	To be improved rate
1	Organization of the environment is clear	100	0 %	0 %
2	Activity and learning centers are easily recognizable	75	0 %	25 % (B, F)
3	Activity areas provide space for children and adults to stand, sit, or work next to each other	100	0 %	0 %
4	Activity areas provide space for young children to move, practice large motor activities, and learn with entire body	87.5	12.5 % (B)	0 %
5	Young children can access a portion of collections	100	0 %	0 %
6	Low shelves, open bins (without lids or covers), and/or low hooks or hangers hold materials that children can access themselves	100	0 %	0 %
7	Furniture and seating is available for small groups of two to four people to gather in face-to-face interactions	100	0 %	0 %
8	Quiet and noisy activities are separated	100	0 %	0 %
9	Activity centers can been seen with unobstructed views from more than one section in the children's area	75	12.5 % (B)	12.5 % (E)
10	A separate room is available for special programs	100	0 %	0 %
11	Noise levels are minimized by design considerations	37.5	0	62.5 % (A, C, E, G, H)
12	Lighting, including windows and natural lighting, enhances the environment	75	12.5 % (B)	12.5 % (C)

Table 6 Results of accommodations for range of ages and families

Number	Item	Achieved rate (%)	Failure rate	To be improved rate
1	Furniture scaled to the needs of young children is adequate to meet demand	75	25 % (E, F)	0 %
2	An area with soft furnishings for adults and children to share is available	62.5	37.5 % (B, C, E)	0 %
3	Adult size chairs for parents/caregivers are available	62.5	37.5 % (F, G, H)	0 %
4	Separate places to put equipment and outerwear are available	25	75 % (B, C. D. E, F, H)	0 %

Table 7 Results of displays

Number	Item	Achieved rate (%)	Failure rate	To be improved rate
1	Sense of family place and messages of welcome are established through use of design features and/or hanging decorations and displays	75	25 % (E, F)	0 %
2	Color, light, and design elements are used to create cheerful decorations of interest	62.5	37.5 % (B, C, F)	0 %
3	Displays, exhibits, and activity/learning areas are of interest to young children	50	50 % (A, C, E, F)	0 %
4	Pictorial symbols and letters are used to assist in communicating organization of area	75	25 % (C, E)	0 %
5	Displays, exhibits, and interest areas encourage ethnic pride and the recognition of cultural diversity	0	100 %	0 %
6	Children's projects and artwork are displayed	12.5	75 % (A, B, C, D, F, G)	12.5 % (H)
7	Children's projects and artwork are displayed at eye level for young children	12.5	75 % (A, B, C, D, E, F)	12.5 % (H)

4.2 Assessment Results of the Relationships Between the Environments, Furniture and Parent-Child Interactions

The results from the observation will be organized so as to identify the relationships between the environments, furniture and parent-child interactions. For carrying out this study, visits were paid to the public libraries representing these eight types in Taipei City. The results in "the environments, furniture and parent-child interactions in eight reading areas" (Table 8) are described as follows.

Table 8 Results of the relationships between the environments, furniture and parent-child interactions in eight reading areas, including the below results are marked a-m as referred to table

Library	A library	B library	C library	D library	E library	F library	G library	H library
Physical contact	a.(9) b.(1)	a.(1)	a.(1)	a.(6)	a.(2)	a.(1)	a.(2) b.(1)	a.(7)
Shared reading/time (concentration)	c.(2) d.(8)	f.(1)	c.(1)	c.(2) d.(4)	c.(1) e.(1)	c.(1)	d.(3)	d.(4) e.(3)
Child performance during shared reading (concentration)	g.(9) l.(1)	g.(1)	i.(1)	g.(5) h.(1)	g.(1) h.(1)	i.(1)	g.(2) h.(1)	g.(5) h.(1) i.(1)
Posture of parent-child shared reading (comfort)	j.(10) k.(6) l.(10)	j.(1) m.(1)	j.(1) k.(1)	j.(6) k.(3) m.(1)	j.(1) m.(1)	j.(1)	j.(2)	j.(2)

a. Sideways sitting. b. Embracing. c. 3–5 min. d. 5–10 min. e. 10–15 min. f. Beyond 20 min. g. Child interacting with a parent upon story telling.. h. While the parents were telling stories, the children listened to them quietly. i. While the parents were telling stories, the children ran hither and thither. j. The parents and children bent their neck. k. The parents and children bent their trunk. l. The parents bent their hand. m. The parents bent their legs

5 Conclusions and Discussions

5.1 *The Design of Soundproof Space Is Too Confined and that Massive Bookshelves Cause Pressure on Children Attracting no Child to Enter the Area*

By referring to Table 5, only B Library had better noise reduction compared with the designs in the libraries of other types. The reading space is dedicated to children and isolated from other areas. In addition, the space was embraced by big and tall bookshelves. Consequently, sound proofing reached a better level. However, this space was more enclosed and these big tall bookshelves imposed mental stress on children. These factors diminished children's intention to read in this area. In addition, most parent-child shared reading areas were set in a children reading room. Though the space was encircled by bookshelves or distinguished by using different floor materials, running or jumping young children in the shared reading area could still influence other users in the children reading room.

5.2 *Diversified Reading Chairs May Increase Intention of Parent-Child Reading*

Take A Library for example, four types of reading carriers such as "Seats", "Floor with Tables", "Table" and "The floor has a hole with tables" were included. The observations showed that light chairs could be moved freely upon parent-child shared reading. This diversified the choices to sit in different directions and parent-child interactions upon shared reading. Additionally, young children could select different reading environments based on their preferences so as to create various reading atmospheres and increase the frequency of parent-child shared reading.

5.3 *Making Good Use of Children-Related Subject in Interior Design Helps Arouse Parents and Children's Interests in Coming*

It is learned from Table 7 that tables in various geometric shapes can be applied to display the diversity of a reading area while integrating symbols into designs (B Library). Regarding space design, balloons in different cartoon characters could help create reading atmospheres so as to enhance parents' and children's intention

to enter into this area for reading (D Library). However, few libraries achieved the three conditions including "displays, exhibits, and interest areas encourage ethnic pride and the recognition of cultural diversity", "children's projects and artwork are displayed" as well as "children's projects and artwork are displayed at eye level for young children" while being examined. Therefore, this result of this study can serve as a reference for different types of libraries to make improvements. For example, displaying photos which help promote reading activities such as "story telling" can boost the intention of parents and children to walk into this area for shared reading (H Library).

5.4 Switching to Different Reading Environments and Books Every Ten Minutes May Prolong the Duration of Reading

By means of the "observation method", it is learned that shared reading behavior and users distinguishingly varied in different environments. There are two strategies to extend reading duration for young children. One is to have shared reading in an enclosed environment which is free from noise interference and isolated from other areas. Young children can experience higher concentration for reading in such an area. The other strategy is to have shared reading within ten minutes each time. After each shared reading activity, parents can have their young children to pick up a book they are interested in before parents start story telling again. By doing so, the times of parent-child shared reading can be increased. This also avoids young children from losing concentration.

5.5 The Common Parent-Child Reading Posture Is Sideways Sitting

By means of the "observation method", most parents and children had their physical contact through "side-sitting" while reading or chatting. The advantage of such posture is that it's convenient for both to read. "Embracing" posture can increase the intimacy between parents and children but inconvenience may occur because the sight of parents may be blocked by children while reading. On the other hand, parents and children sitting face to face usually denote the condition that parents are reading their own books while children are writing their homework. Hence, fewer interactions between parents and children are observed.

5.6 The Seating Designed Especially for Parent-Child Reading May Increase the Comfort of Reading and Duration of Reading

By means of the "observation method", the arrangements of chairs and tables in adults' sizes in children's reading areas or parent-child shared reading areas attract adolescents and the elderly for study or reading instead. Parents and children usually use these chairs and tables for the purpose of writing homework and reading separately. While using chairs in adults' sizes, children's heels are usually off the ground or they have to tiptoe or change their sitting postures from time to time. On the contrary, the tables and chairs designed for children are apparently different from others in size. Users can realize at the first glance that these chairs and tables are for children or parent-child. Parents sitting here do not feel comfortable. Their necks, bodies and legs are bending. Thus some parents choose to sit on the floor while having shared reading. However, there is no proper position to put a book. Books can only be put on the floor or a parent's legs and both places are not appropriate for reading. As a result, most parents bend their necks forward to a significant degree while sitting and reading on the floor. Moreover, parents who sit on the floor usually choose a corner close to a bookshelf or wall so as to reduce the degree of bending forward their bodies. Based on the above observations, it is suggested to design chairs suitable for parent-child shared reading in a parent-child shared reading environment. The seat height should fulfill both parents' and children's needs. In addition, an appropriate angle of back support is able to improve comfort during parent-child shared reading.

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Firing of a Cannon: Psychophysical Evaluation of Ergonomic Hazards

Theresa Stack, Daniel Autenrieth and Lee Ostrom

Abstract Musculoskeletal-related occupational illnesses and injuries comprise a majority of military medical encounters resulting in decreased combat readiness and degraded human performance. An artillery company performing a live fire exercise was observed for two days along with the collection of perceived exertion, fatigue and pain data. Twenty-five U.S. Marines were involved in the study. Sixteen (64 %) reported becoming injured after returning from combat during a "Call for Fire" exercise and four (16 %) were on limited duty at the time of the study. Their perceptions of exertion, fatigue, and pain increased over the course of both days. In addition, human error also increased over the course of the day and moral decreased as well. The study uncovered that the exposure profile during the support of the "Call for Fire" exercise is leading to degradations in physical performance and increased exposure to physical work place risk factors resulting in various soft tissue injuries.

Keywords Human factors · Human-Systems integration · Psychophysical · Borg scale · Crew fatigue · M198 155-mm howitzer · Ergonomic · Health hazards · Back injury · Exertion · Military · Manual material handling

1 Introduction

Artillery is a class of large military weapons built to fire munitions far beyond the range and power of infantry's small arms. Modern artillery vehicles are highly mobile weapons of great versatility providing the largest share of an army's total ground based firepower. Heavy artillery is arguably the most lethal form of

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land-based armament currently employed and includes the Howitzer. The M198 Howitzer is a medium-sized, towed 155 mm artillery piece, developed for service with the United States Army and Marine Corps. The crew size for the M198 Howitzer is optimal at nine [1].

Gunner in the armed forces is the term for the personnel with the primary function of using artillery. The gunners' proximity to and participation in direct combat against attacks by aircraft and land forces make it a notoriously dangerous position while in combat. There are multiple examples of weapons systems employed by military forces with minimal consideration to their impact on the Soldier because the development was during a time when occupational health was not a major concern or the impacts of exposure was not well understood. The Textbook of Military Medicine describes multiple examples of the lack of information available during equipment development that exposed personnel to unnecessary health risks. For example, the M198 155-mm Howitzer was found to cause chest wall pain and blood in the sputum of the crew, which was later attributed to a primary blast injury caused by the physical properties of the blast wave following firing. Limiting the number of round fired in a designed time period controlled was considered a control for this injury type [2–4]. However, there is a paucity of published studies that address the occupational health risks encountered by gunners during routine training activities.

Much of the published literature has focused on artillery occupational exposures related to noise and hearing loss prevention. Additional occupational risks for gunners include non-auditory effects of excess noise, lead, and work-related stress [5, 6]. There are no known studies that have examined physical work place risk factors associated with heavy artillery.

It has, however, been established that heavy exertion can increase the risk of developing work-related musculoskeletal disorders (WMSDs) [7]. Further, WMSDs are often precipitated by symptoms of fatigue and pain, which can be measured and used to identify work tasks that result in an increased risk of injury [8]. The symptoms of fatigue and pain associated with heavy exertion can also decrease worker morale and lead to increased errors and reduced work quality [8].

In response to anecdotal reports of personnel becoming injured during routine training activities, The U.S. Marine Corps requested the present study to assess three questions about the "Call for Fire" training exercise: (1) What are the injury experiences of gunners during non-combat training activities; (2) what are the perceived levels of exertion, fatigue, and pain of gunners during these activities; and (3) are these symptoms leading to increased errors and decreased morale of the artillery crews? The goal of the study was to quantify factors influencing musculoskeletal injuries during repeated live fire exercises and recommend remediation measures based on the findings.

2 Methods

2.1 Interviews

Each member of a Marine Corps artillery company was interviewed to determine their injury experience during non-combat training activities. Each soldier was asked their name, stature, weight, age, months in the military, months at this assignment, number of two day shoots. Anthropometric data for shoulder to mid-hand length and shoulder width was taken during the interviews. All interviews were conducted prior to assessing the 'Call for Fire' training exercise.

2.2 Call for Fire

Following the conclusion of the personnel interviews, the crew set up the three M198 155-mm Towed Howitzer guns and firing supplies to prepare for the training exercise. A 'Call for Fire' training exercise was evaluated on the following two days by the research team to assess gunners' perceived exertion, fatigue, and pain as well as worker moral and work errors. The 'Call for Fire' from field artillery exercise is conducted approximately every 45 days. New Second Lieutenants determine what type of artillery support they need for a scenario and call in the coordinates into a fire support center. This initiates the following steps by the gunnery crew.

1. The fire instructions are radioed to the recorder
2. The recorder announces the fire order
3. The powder man adjusts the propellant
4. The type of round to be fired is verified
5. A round is removed from the ready board and laid into the loading tray
6. The two loaders pick up the round
7. The rammer places the ram at the back of the round
8. The breach is opened
9. The loaders bring the round up to the breach
10. The rammer pushes the round in the breach
11. The loader on the right side of the loading tray releases his grip
12. The other loader steps back and to the left of the gun
13. The powder man brings up the powder and hands it to the A-gunner
14. The A-gunner verifies the amount of powder (propellant) and places it in the breach
15. The A-gunner closes the breach and places a primer in the priming hole
16. The lanyard is attached and then pulled
17. The gun fires
18. The A-gunner opens the breach and swabs the breach and breach plug

The process is repeated a number of times depending on the orders from the field and the specifics of that exercise. Between one and six rounds can be fired during a 'Call for Fire' and should be done in rapid succession. The firing procedure used by the artillery crews is standardized and the detailed standard operating procedures (SOPs) provided to the research team prior to the assessment [9].

The artillery crew size is variable to allow for completion of the work without a full crew. However, the optimal crew size for this job is nine people, organized as follows:

- Chief of the Gun
- Gunner
- A-Gunner
- Recorder
- Powder Man
- Ammo Team Chief
- Two Ammo Handlers
- Rammer

The work of the artillery crew includes some high and low-risk tasks in terms of manual handling of materials and exertion. In terms of physical stress, low-risk tasks include operating the radio, calling out instructions, and handling the powder. Higher risk tasks involving manual handling the rounds included moving, hoisting, loading, and ramming. On average, each round weighs more than 98 lb. Artillery crews lifting a round on the loading tray and ramming a round into the barrel shown in Figs. 1 and 2, respectively.

Fig. 1 Crew lifts 98 lb round and loading tray to position it in front of the barrel

Fig. 2 Two handlers position the tray in front of the barrel as the rammer forces the round into the barrel

2.3 Psychophysical

Minimally invasive methods were used to collect crewmembers' perceived fatigue, exertion and pain ratings during the live fire drill. There are variety of methods for determining work intensity levels, including heart rate, oxygen consumption, time motion studies, and the Borg Rating of Perceived Exertion (RPE). The RPE method was the chosen for this study due to its non-invasive nature and validity for the measurement of work intensity, fatigue, and pain.

The RPE has been validated for use in occupational exposure studies [10]. The exertion scale ranges from six to twenty, as shown in Table 1. This exertion scale is used because it has been shown to correlate well with the heart rate. In physically demanding tasks, heart rate is correlated to exertion [8]. For example, if a subject reports a perceived exertion level of 17 (very heavy exertion), the subjects heart rate should be approximately 170 beats per minute. In contrast to the exertion scale, the fatigue and pain ratings of the RPE range from zero to 11, as shown in Table 1.

As with all psychophysical measures, an individual's response is based on their personal perception. For accurate and precise data collection using rating scales, the calibration of the participants is imperative. Therefore, prior to and during data collection, every participant in the study was repeatedly briefed as to what the scales meant and how to interpret their fatigue, pain, or exertion. Exertion, fatigue, and pain data were collected at random intervals every 8–12 min during the live fire exercise. However, data were not collected from every participant at every interval.

Table 1 Exertion, fatigue and pain anchored scale

Exertion		Fatigue		Pain	
6	No exertion	0	Nothing at all	0	Nothing at all
7		0.3		0.3	
8	Extremely light	0.5	Extremely weak	0.5	Extremely weak
9	Very light	1	Very weak	1	Very weak
10		1.5		1.5	
11	Light	2	Weak	2	Weak
12		2.5		2.5	
13	Somewhat hard	3	Moderate	3	Moderate
14		4		4	
15	Hard	5	Strong	5	Strong
16		6		6	
17	Very heavy	7	Very strong	7	Very strong
18		8		8	
19	Extremely hard	9		9	
20	Max. exertion	10	Extremely strong	10	Extremely strong
		11	Absolute max.	11	Absolute max.

The crew received the following directions:

"At intermittent times during the shoot, the ergonomists will ask you to gauge your feeling of exertion. This feeling should reflect how heavy and strenuous the activity feels, combining all sensations and feelings of physical stress, effort, and fatigue. Do not concern yourself with any one factor such as leg pain or shortness of breath, but try to focus on your total feeling of exertion.

Look at the rating scale below, Table 1, while engaging in an activity; it ranges from 6 to 20, where 6 means "no exertion at all" and 20 means "maximal exertion." Choose the number from below that best describes the level of exertion you feel at this time. This is a good indication of the intensity level of the activity.

Try to appraise the feeling of exertion as honestly as possible, without thinking about what the actual physical load is."

2.4 Observational Methods for Evaluating Morale and Errors

Three researchers were on site for three days during a live drill from 0645 to 1850 and observed the daily actives from set-up of the Howitzers on day one to final cleanup of the dunnage on day three. Set-up included staging of armament supplies (fuse, projectile, primer and propellant) and assembly of temporary facilities that included shelter for the command center, portable bathrooms, and overhead

camouflage netting. Cleanup included readying the guns for transport and consolidating expendables. The crew set-up four guns but only three were used for the exercise. Each researcher remained with one of three crews who each operated one cannon. Researchers defined the cycle time for work analysis as the time between two recurring events:

1. Fire instruction radioed to recorder or recorder announcing the fire order
2. The last round fired.

The work of each crew was directly observed by a researcher and compared to the SOPs. Errors in the procedure were noted by the researchers, as was the time they occurred. Morale was also assessed through observation during the live fire drill. Morale was rated by the researchers on a scale of 1—working well together to 10—infighting. Other general data was collected during each drill including the effective crew size, the number of rounds per fire order, changes in crew size, and comments.

In addition to direct observation, a military videographer recorded the 'Call to Fire' exercise. The videos were then assessed by the research team after the conclusion of the exercise and the video content was compared to field notes and artillery task SOPs. Morale ratings were not modified based on the subsequent video analysis. Video analysis was used for a bio-mechanical assessment not addressed in this paper.

3 Results

3.1 Artillery Crew Injury Experience

All of the artillery crewmembers were male with an age ranging from 23 to 31 years, (mean 24—STD 1.9). Sixteen of 25 (64 %) reported becoming injured during a routine training exercise after returning home from deployment, and four (16 %) were on limited duty during our study because of an injury suffered since returning home from combat. Of the sixteen previously injured personnel, nine (56 %) reported injuries that were related to their back. Ten of the sixteen (62 %) previously injured personnel recalled becoming injured while lifting or moving cannon rounds.

Most back injuries were related to the loading tasks of lifting, loading, and ramming rounds. These tasks are illustrated in Figs. 1 and 2. The average number of months in the Marines was 70 (STD 11), the average months at this assignment was found to be 16 (STD 7). The 25 service members on average had performed 26 prior two-day shoots. The elapsed time between when the Marine returned from overseas and the interviews was approximately 50 months.

Table 2 Means response for exertion, fatigue, and pain ratings on day 1

	Time of day								
	8:00	9:00	10:00	11:00	12:00	13:00	15:30	17:00	18:00
Exertion	6.14	6.14	8.4	14	9.4	11.88	13.8	14.25	15.53
Fatigue	3.14	3.2	2.0	6.0	3.7	5.85	6.9	7.34	8.37
Pain	1.0	0.71	1.4	1.0	2.83	2.88	3.95	5.42	6.5

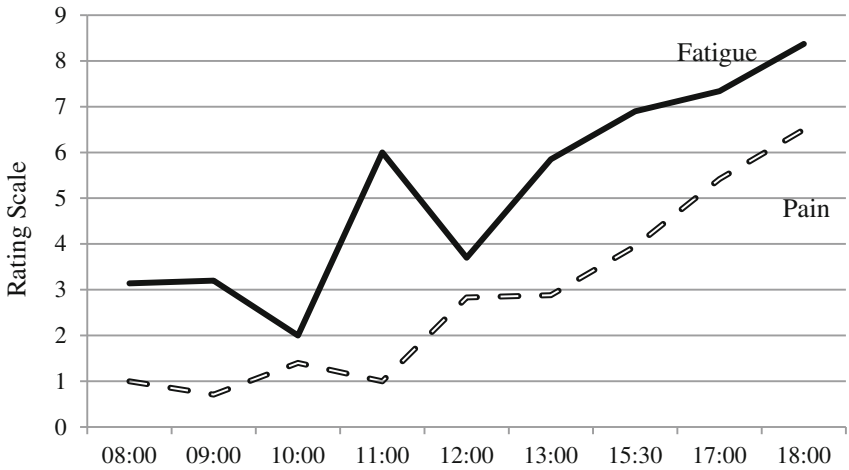

Fig. 3 Mean fatigue and pain levels, day one

3.2 Psychophysical

Crewmember rating using the three psychophysical scales in Table 1 are summarized in Table 2. Note the mean ratings increased throughout the day for all three scales, pain, exertion and fatigue. The mean values of fatigue and pain shown as a trend over time is provided in Fig. 3. The time trend for exertion ratings is shown in Fig. 4. Only data from the first day of the 'Call for Fire' exercise are presented here, but similar upward trends in time were observed on both days with apparent recovery after rest.

3.3 Errors and Crew Morale

Table 3 summarizes the errors in procedures that were noted by researchers for one of the three active cannons. These errors were deviations from the SOPs observed during the 'Call for Fire' exercise or the subsequent video analysis. As fatigue, pain

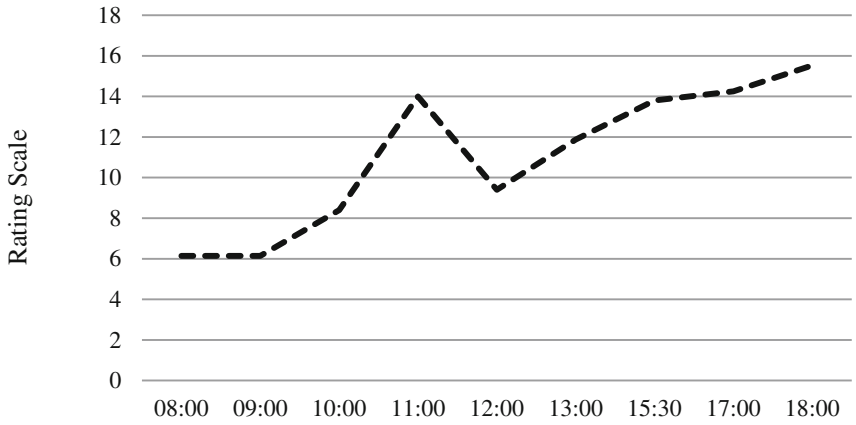

Fig. 4 Mean exertion levels, day one

Table 3 Time and major errors noted on day one for gun one

Time	Comment or observation
1036	The sweat in one of the gunners eyes was so bad he jammed his finger during a load because he could not see
1300	They missed ramming the round
1311	The crew put a pallet down on the ground to set the loading tray on to make it a little easier for them to lift
1440	A projectile was placed backwards onto the cradle
1500	The A-gunner did not swab the breach between each projectile anymore.
1510	The powder man does not wait for confirmation before loading the barrel with the propellant
1630	Fuse was not secured to projectile properly
1735	A projectile was dropped from the pallet
1745	Everyone announces being maxed out and one was very dizzy. The recorder started transposing numbers and then caught himself later The crew answered back to the radio and began to in-fight with each other about who is carrying the burden of the weight
1805	594 rounds completed for day one across three guns (approximately 200 rounds per gun or 16 rounds per hour)

and exertion increased throughout the day, so did the number of errors. A decrease in crew morale throughout the day was also observed, as evidenced by the in-fighting, swearing and rough handling of equipment.

4 Discussion and Conclusions

The injury experience of the artillery company after returning home from combat was exceptionally high, with 64 percent of gunners reporting an injury during non-combat training exercises.

The vast majority of injuries suffered by gunners in our study involved the spine. These injuries are not surprising given the amount of lifting that was required during the live fire drill and the average weight per round of over 98 lb. The presence of injured gunners on limited duty during our study exacerbated the problem by reducing the crew size per gun from nine (optimal) to six to seven. Loading and ramming tasks were not rotated when crew sizes were below optimal. The rounds are moved a minimum of two times during a single fire order. With an average of 200 rounds per day at 98 lb each, primarily three gunners lifted the combined weight of 39,200 lb per day; or each gunner lifted 13,000 lb.

Observations made in real time by the research team or in subsequent video analysis indicated that errors increased and morale decreased as each day of the 'Call for Fire' progressed. Therefore, it is believed that the increasing exertion, fatigue, and pain experienced by gunners in our study throughout the day resulted in these decrements of performance and morale.

The self-reported levels of exertion, pain, and fatigue reported by gunners in this study all increased throughout the day with time, as shown in Figs. 3 and 4. Only during rest and lunch breaks was there a leveling off, but none of the average ratings returned to early morning levels. Following rest periods, the increasing trend continued throughout the remainder of the day. Exertion and fatigue trended closely, peaking before lunch and then again at the end of the day, indicating a relatively fast recovery time. These ratings were not superimposed because they were measured using a different scale. Pain levels on the other hand rose more slowly but increased throughout the day. The recovery observed in exertion and fatigue ratings during lunch was not apparent in the pain ratings.

One of the major limitations of this study was the focus on only a single artillery company and a single 'Call for Fire' exercise. The focus was limited as such because our objective was to investigate the experiences and exposures relative to this particular company. Thus, projecting these findings to other Howitzer gunnery crews should be done cautiously. However, it is believed that the study procedures presented here could aid in the assessment manual material handling jobs or tasks.

Another limitation of this study is that no statistical analyses were conducted on this convenience sample of gunners, and thus no statistical conclusions would be influenced by any unintentional and unaccounted biases.

The gunners in this study were exposed to many physical work place risk factors, including heavy lifting and carrying; awkward body positions; temperature extremes; and a fast work pace. These risk factors contributed to the remarkably high number of injuries suffered by gunners during routine out-of-combat exercises. The high number of injuries resulted in increased risk due to sub-optimal crew sizes

and limited task rotation. This negative feedback loop places everyone at increased risk by degrading performance and morale.

Following the conclusion of the study, several recommendations were provided to the artillery commanders to reduce the risk of injury and errors. To limit the amount of weight handled and allow for task rotation, the crew size should be increased by either Howitzer crew members or the use of Second Lieutenants. The Second Lieutenants can be utilized to supplement the crew and clean up the dunnage. In addition, recommendations on the design of lift tray were also provided. The Basic School was briefed at the conclusion of the study and supporting the decision to utilize additional help. Follow-up studies assessing the biomechanics of the highest risk job tasks are underway and will be presented in a separate paper.

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Color in Glossolalia: Much Ado About Blue

Leonor Ferrão

Abstract The aim of this article is to present the Glossolalia project in the aspects that deal with color. Since color is intrinsic to the creation of any designed product and is essential in the process of recognition, perception and communication, it determines the semantics of a given object. In establishing the meanings of color, the aspects that are addressed encompass a broad gamut that include neurology, vision and illumination and the interactions of light and color in the understanding of the nature of design at stake as well as the cultural context. A multidisciplinary approach allows other qualities to be addressed, such as synesthetic reactions to color, communicative variables, color terminology, aesthetics as well as historic and cultural embedding. This essay will address some of these dimensions on the color blue in Western culture.

Keywords Human factors · Product design · Key concepts · Western culture · Color

1 Introduction

All meanings of the word "glossolalia" (from the Greek words *glossa*, meaning tongue or language, and *laleō*, meaning to speak, talk, chat, or to make a sound) raise a knowing smile because they can be applied to what is happening with words that circulate in the design discourse. We do not intend to dismantle any ambi-

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guities associated with the language of design, but to simply clarify a list of "keywords" that help us find our way through the labyrinth of the disciplinary terrain. We are motivated by a love of the fragmented and the detail—the French say *Le bon Dieu est dans le detail* (God is in the details), but the Italians prefer *il diavolo è nei dettagli* (Devil is in details). This is why we will distance ourselves from the concise well-behaved and systematic style. For this purpose, the Glossolalia project will identify the terms of the key concepts, their genealogy and the contextualization of their use (historical, philosophical, critical, theoretical, social, cultural, political, ideological…) and will present a critical review of what is capable of producing meaning when applied to design [1].

We wish to contribute to the Glossolalia project in the aspects that deal with color. We chose one color—BLUE—to scan and emphasize some important characteristics and issues, considering the different contexts and dimensions regarding the use of this color in Western culture.

2 The Odyssey of Blue

Some languages do not have a word to designate the color *blue*, and use others that either correspond to the color blue or the color green, or even colors that have nothing to do with what we nowadays designate as *blue*. The most ancient natural pigment known to us comes from an herbaceous plant, *Isatis tinctoria* (*woad* in English), until others where discovered, extracted from *Indigofera tinctoria*, from lapis lazuli and, well understood, from artificial pigments, namely cobalt, of Persian origin, used in Chinese porcelain from Yongle Emperor's kingdom onwards (1403–1424) [2, 3].

Going back to the foundations of western civilization, in the Homeric poems, the color of the sea is referred to using analogies with wine (Homer, *Odyssey*, XIII, 418; XIX, 172), or terms that were also used to designate the color gray (V, 410; IX, 132, 564) or purple (II, 427; XIII, 84–85). All these terms and analogies were not mere poetic devices but rather expeditious ways to deal with the absence of a word to designate the color *blue*. The «dark» sea (V, 388–389) is another formula that is found in the *Odyssey* every time that the author intends to establish an association with the maximum danger inherent in the dimension of Ulysses' endeavor and the unpredictability of the Elements at sea, which has not favored the positive reception of the color *blue* [4].[1] In fact, the Mediterranean Sea presents a vast richness of blue tones and it is not as serene as it may seem, justifying the Poet's options to characterize it.

For the Romans, the color blue also had a negative connotation by being associated with the face and body paintings wore by the «barbarian» people during battle. Caesar, in a fragment of the testimony on the Gallic Wars (dated 54 B.C.),

[1]We have used the translation by Frederico Lourenço (b.1963), who has reconstituted in the Portuguese language and in hexameters the poem on the Return of Ulysses to Ithaca.

left a reference to this habit: «Omnes vero se Britanni vitro inficiunt, quod caeruleum efficit colorem» (*De Bello Gallico,* V, 14), which means: «All the British, indeed, dye themselves with wood, which occasions a cerulean color, and thereby have a more terrible appearance in fight» [5]. The translation of the term "vitrum" used by Caesar in the quoted passage is controversial; the English translators that we quote have translated it as «wood», which may not be an error (could they be referring to "Celtic wood"?), although the majority translates it as "woad" (i.e. *Isatis tinctoria*), the herbaceous plant known in Western and Northern Europe since the Iron Age, of whose leafs a blue pigment is extracted. Independently of the substance used by several people of Celtic ethnicity to tattoo and paint their body,[2] what matters to us is the negative connotation of this "vitreous" color for the Romans. In another passage, we find a very impressive reference to the stature of the Germans and to the ferociousness of their eyes, another argument in favor of the Latin's feeling of strong repulse for the color blue: «the Germans were men of huge stature, of incredible valor and practice in arms-that oftentimes they, on encountering them, could not bear even their countenance, and the fierceness of their eyes» (*De Bello Gallico,* 1, 39). Pliny the Elder dedicates a chapter to the plants that were used to stain the body, making a direct reference to the barbarian habit of tattooing and painting the body in blue: «I remark, in the first place, that there are some foreign nations which, in obedience to long-established usage, employ certain plants for the embellishment of the person. That, among some barbarous peoples, the females stain the face by means of various plants, there can be little doubt, and among the Daci and the Sarmatæ we find the men even marking [tattooing] their bodies. There is a plant in Gaul, similar to the plantago in appearance, and known there by the name of "glastum:" with it both matrons and girls among the people of Britain are in tile habit of staining the body all over, when taking part in the performance of certain sacred rites; rivaling hereby tile swarthy hue of the Æthiopians, they go in a state of nature» (Pliny the Elder, *NH*, XXII, 2) [6]. The translators of Pliny that we have researched consider that «glastum» is *Isatis tinctoria*, «the root of this Celtic wood is probably "glas," "blue," whence also our word "glass;" and it is not improbable that the name of glass was given to it from the blue tints which it presented. Julius Cæsar and Pomponius Mela translate this word "glastum," by the Latin "vitrum" "glass."» In these it is possible to associate the chromatic characteristics of the Roman glass, between blue and green, and with transparency, to the bodies of the barbarians painted in blue, the latter becoming as if "transparent" (and, thus, scary).

At the end of the 12th Century an extraordinary change occurred, when, suddenly, the color blue began to dispute the prestige of the color red. It became *the* color of divine light and from then on new symbolic and aesthetic hues appeared that transformed what was formerly despicable or horrible into something beautiful

[2]Some (non academic) authors refer as impossible the use of woad to tattoo and paint the body (and the hair), arguing that this pigment, although natural, produces serious skin burns (that are in no way blue). They suggest that the Celtic used copper and iron to produce blue and black, respectively, and not woad.

and divine. From there to becoming an "aristocratic" color was a small step (maybe —but only maybe—this is why one says "blue blood" meaning any member of a noble family). Pastoureau situates this "revolution" in the kingdoms of the French kings Phillipe Auguste (1180–1223) and Louis IX, Saint Louis (1226–1270) and refers the difficulties of the Romance languages to keep up with it. It was necessary to borrow from the German the word *blau*—adopted by several Romance languages (*blau* in Catalan, *bleu* in French, *blu* in Italian)—and from the Arab (*lazurd*), which originated *azul* (in Portuguese and Spanish) and *azzuro* (in Italian). It wasn't possible to assert if it appeared in the Virgin's vestment in the first place and from then on in the royal robes (namely the robe of the Kings of France), or if in stained glass and illumination, then in heraldry and then, by association, in the robes of the aristocracy. The contribution of abbot Suger (1081–1151) to this change is undeniable and to the invention of a new (gothic) spatiality (gothic) "made" of blue light. Once again, the technique followed the ambition to raise the height of the naves and to slim the thickness of the walls, allowing the tearing of big windows entirely covered in stained glass, where cobalt blue ruled all the other colors. This blue, celebrated by the stained glasses of the Cathedral of Chartres (France), came to be known as "Chartres blue" [7].

This brand new taste for a color without a name in the Greek language and unloved by the Latin people was encouraged by some technological advances. The search for obtaining more beautiful and stable results justified the need to discover new pigments and processes to obtain them. In the Late Middle Ages, or yet, from the 12th Century onwards, up to the Renaissance, the blue color conquered a very different symbolic meaning from the current one. In those days it was warmer than the color red. For that reason, in the episode of the Fall of the Rebel Angels to hell, in the sumptuous book of hours of the Duke of Berry, the Limbourg Brothers used blue in the robes of the angels fallen in disgrace (the larger angel, the Devil, also dresses in blue) and the Hell is painted in subtle hues of bluish gray and golden. The same intense blue, possibly extracted from lapis lazuli (a semi-precious stone of Asian origin and high market value), is used in the rich clothes of the prince who ordered this book of hours (in the *folio* concerning the month of January).

The same profound blue tinges the clothes of the Virgin in the *Deposition* by Rogier van der Weyden (*c.* 1435) [8]. When alternatives to woad appeared, more effective and durable, some European states prohibited its import to protect their national producers. In Toulouse, Jean de Bernuy, a rich Jewish merchant of woad, of Spanish origin, erected the highest tower in the city where he resided and his fortune served as rescue bail for the King of France, François I^{er}, made prisoner by the troops faithful to the Holy Roman Emperor Carlos V, following the victory in the battle of Pavia (1529), which really accounts for the commercial importance of a pigment that made possible the production of the color blue [9].

The association of the color blue with the sky and with the "celestial" (divine) figures, corresponds to a giant step in the codes in use in Medieval European painting—it should be noted that the skies used to be covered in golden leaf, an option clearly anti-naturalist (because both the Romanesque and Gothic paintings were situated in the antipodes of reality). Giotto (1266–1337) painted blue skies

(splashed, evenly, as if a pattern, of stars painted gold), in an aesthetic era that can only be considered as proto-renaissance (because mathematical perspective had not yet been invented to replace the empirical perspective that was still practiced by Giotto and his contemporaries). Raffaello Sanzio (1483–1520), among other painters, handed down to posterity the dress code of the Virgin (blue robe and red dress) [10]. Albert Dürer (1471–1528) chose blue primed paper for his study of the *Praying hands* to achieve the *plus ultra* in Drawing (Fig. 1) [11].

The association of the color blue to water is a late one: in ancient cartography, the sea, the lakes and the rivers were represented in green and only came to be represented in blue from the 15th Century onwards. Pastoureau relates this option to the increasing "cooling" of the color blue, until it became the "coldest" of all colors in Romanticism [7]. For Goethe, «blue still brings a principle of darkness with it» and «gives us an impression of cold, and thus again, reminds us of shade» [12].

The French Language is very rich in the use of the term blue in idiomatic expressions; it is curious to note that when in French one says *blue* in other Romance languages the purple, the yellow or the red occur (e.g. in Portuguese one says *purple with cold* and *red with fury*, which corresponds to the French *bleu de froid* and *bleu de rage*). In the same way, whereas in Portuguese the state of drunkenness is associated with red, in German one says *blau* (blue) to designate the loss of consciousness for excess of alcohol. The same allusion to the blue color occurs in the expression *heure bleu* or *blue time*. There are other expressions that include the word *blue*. For example, *Blue time* (in French *heure bleue*), is the moment of the day that alludes to the thirty minutes that precede nightfall. In the English language, *to be blue* means to be sad or melancholic—*blues* is a musical genre that is rooted in the chanting of African black slaves, in somber and hurtful tones. The French expression *je n'y vois que du bleu* means *I can't see anything*, which addresses another characteristic of the color blue—the capacity to dematerialize the surfaces in that color (the origin of this belief is, for sure, the Latin legacy

Fig. 1 Albrecht Dürer's study, c. 1508 (brush drawing on *blue* primed paper, 290 × 197 mm), Graphische Sammlung Albertina, Vienna. Source: http://www.wga.hu/

about the "invisibility" of the surfaces painted blue). The association of the color blue to melancholy is another aspect of the "cooling" it suffered along the 19th Century, in the Romantic sensibility and culture. But way before Romanticism there was another substantial alteration, following the divide between Catholics and Protestants. One may ask in what sense the religion had to do with color and, in particular, with the color blue. If we compare the color palette of the painters of the European Catholic states with that of the Protestant sates we can observe that the latter have adopted a somber and more reduced palette, whereas the first used a festive palette. Pastoureau refers that the blue won with the Protestant Reform because it was considered a morally correct color, like the tones of white-beige-brown and of white-gray-black. This "moral" dimension, associated to prestige—aristocratic and, therefore, conservative—of the color blue, justifies that until today the Anglo-Saxon countries (largely Protestants), use it for anything and everything, in national flags (although not just in Protestant countries, as is the case of the French flag). It also rules in the color palette of center-right-political parties (the Republican Party and the Democratic Party of the USA both use the color blue). Blue is also present in the uniforms of the peacekeeping troops, known as Blue Berets (or Blue Helmets), in numerous police uniforms, airline companies (PANAM stewardesses' uniforms were famous and glamorous), in many national flags, as referred, and in the flags of the United Nations and of the European Union. It is, according to Pastoureau, the favorite color of Europeans; for the French it is *the* color [7, 13]. In the disciplinary field of product design it is possible to find echoes of the Catholic and Protestant "moral" in the use of color: if in Swiss and German *good design* the palette is pretty restrict, in Italian *good design* the coloring is intense. Some authors, as an outcome of experiencing other cultures, end up radically altering their color palette. It was the case of Finnish designer Tapio Wirkkala (1915–1985), after having working in Murano [14]. His decorative glasses denote the profound impression that the intense coloring of the crystal and of the Venetian painting provoked on his "icy" sensitivity of a northern man (however, from a strictly formal point of view, he maintained the white landscape imaginary as well as the geometry of ice mountains).

Pre-Colombian cultures elaborated beautiful color palettes very rich in blue (and green), namely in objects of adornment, using semi-precious stones, whether in a funerary context or in a religious one and therefore it is not surprising that they have remained that way after the Spanish conquest and colonization. The intensely colorful palette of Charles (1907–1978) and Ray Eames (1912–1988), among other Northern-American designers of their time, like Alexander Girard (1907–1993), is un-dissociable from his aesthetic research of Mexican Pre-Columbian and vernacular cultures (an extraordinary mix of pagan and Catholic spirituality). They are examples of the fusion of very contrasting spiritual frameworks, with a very significant impact in the choices of colors. In Europe, in spite of societies' de-sacredness (even in the most conservative), the differences are more clearly defined; one need only to compare the objects of the German radical design, harsh-faced (and even aggressive in their critique of consumerism), with the Italian radical design—good-humored and intensely colorful [15].

3 Chinese Porcelain and Dutch Tile of Portuguese Commission

The passion of the Portuguese for blue Chinese porcelain goes back to the first commissions coming from the Orient through the Indian Route and is at the basis of a profound transformation in the taste of the European elites in the social rituals at the table. In the kingdom of the Emperor Jiajing (1522–1566) the first commissions were executed with Portuguese motives or Portuguese quotes (royal weapons, armillary sphere, heraldry of aristocratic families and inscriptions). In 1552, the regulation of the port of the city of Lisbon was authorizing that 1/3 of the cargo of the ships of the *Carreira da Índia* (Armada of India) was constituted by porcelain imported from China, which gives a very good idea of the importance of these tableware of a sumptuous nature in the Portuguese court. It is also a symptom that the Portuguese market could not absorb so much porcelain and therefore the exportation of Chinese porcelain to Europe became an advantageous business for the Portuguese; the risks of wreck and piracy were very high and thus the price (of resale) had to compensate for that. Just to have an idea of the quantities loaded by each vessel, in 1603, the Dutch imprisoned a Portuguese carrack originating from Macau (on the route to Goa and destined to Lisbon) that transported 200,000 pieces —the precious cargo was sold in Amsterdam, with a big profit for the burglars. Due to circumstances of various natures, the importation of Chinese porcelain to Europe became a monopoly of the Dutch West India Company (WIC), from 1623 [3]. The thinness and whiteness of the clays, the quality of the glazes and the novelty of the colors, namely cobalt blue, the most appreciated color by the Portuguese (but not only), had no rival for almost two centuries, until the secret of porcelain fabrication was discovered (in Germany, in the first decade of the 18th Century)—the *Palácio de Santos* (current Embassy of France in Portugal) has a golden carved ceiling with a Chinese porcelain tableware (largely blue and white, of the Ming dynasty), possibly executed in the building campaign of 1667 and 1687 (Fig. 2). It is not composed of fragments of plates but whole pieces (over 250) and may have a commemorative meaning.

The title of the recent exhibition at the *Museu Nacional de Arte Antiga* (National Museum of Ancient Art, Portugal) addresses an expression that is used when a thing or a situation reaches perfection: it is no more than the survival of a taste that existed in Portugal between the 17th and 18th Centuries and that united the golden carving with the blue painted tiles [16].

There are many other evidences of the Portuguese taste for blue and white ceramics. The numerous panels of blue and white *azulejos* (tiles) that covered wainscots, walls and ceilings of many churches and aristocratic residencies in Portugal along the 17th and 18th Centuries are echoes of the high prestige that Chinese porcelain achieved in Portugal [17]. It should be noted that the word *azulejo* has its origin in the Arab word *az-zuléij* (which is justified because the first Portuguese orders of tiles were executed in the South of Spain, in Seville and in Talavera, until the local production started). In Portuguese, the verb *azulejar* means

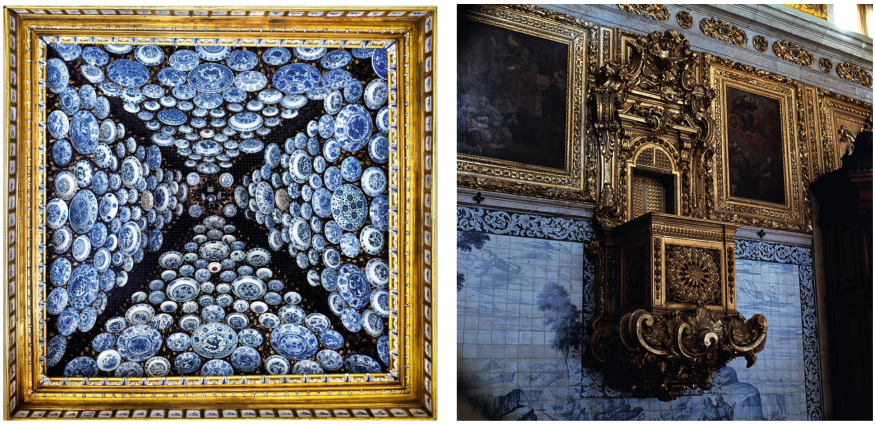

Fig. 2 Ceiling in golden and Chinese porcelain (*Palácio de Santos*, Lisbon), 3rd quarter of the 17th Century. Source: http://www.ambafrance-pt.org/Exposicao-das-porcelanas-do; Nave of *Madre de Deus* Church (Xabregas, Lisbon), pulpit sculpted by Félix Adaústo da Cunha in 1759, gilded by painter Joaquim José, Dutch tiles painted by Willem van der Kloet (?) in early 18th Century. Photo by Carlos Calvet

to cover in tiles or *to make blue* [18]. Around 1665, Portugal was the biggest market in Europe in decorative ceramics. The Dutch, who were interested in some Portuguese commodities, saw in this taste for tiles, on the one hand, and for the color blue, on the other hand, an excellent business opportunity. The exportation of Dutch tiles was initiated on a scale that was economically very interesting for both manufacturers and merchants, in spite of the protests of the Portuguese manufacturers.

The first examples began to arrive around 1650. Smaller and lighter than the tiles produced in Portugal, the first Dutch *tegels* were single figure tiles (*enkele tegels*), painted in a beautiful cobalt blue and with an exquisite transparent and ultra-shiny glaze, that were a success in the Portuguese court. Then, came the big panels adorned in blue and white, also of Portuguese commission and taste, at least until the end of the first decade of the 18th Century, a time when the national producers started to meet all the demands—even the more prestigious ones, although the influences of the Dutch *tegels* were clearly visible. The Lisbon Earthquake of 1 November 1755 was responsible for the destruction of the majority of the Dutch panels, but some subsist (in places that were, at the time, the outskirts of the capital), as in the *Madre de Deus* church (in Xabregas) (Fig. 2 above) and in the *quinta de recreio* of the Marquis of Fronteira (his villa in S. Domingos de Benfica) [19].

More recently, the blue of Dutch tiles, and of the ceramic and porcelain of Delft, has inspired the designer Hella Jongerius (b. 1963). Her Delft Blue B-Set is an excellent example of how to deal with history in Product Design without nostalgia or revivalism (Fig. 3).

Fig. 3 "Delft Blue B-Set" by Hella Jongerius (porcelain hand painted Delft blue, 2001). Source: http://www.jongeriuslab.com/work/delft-blue-b-set

4 It Varies

The Wedgwood factory (namely at Etruria, since 1769) instituted the taste for a new shade of blue (close to that of lavender flowers), commercializing successfully the products in this color, whether in tableware or in cameos of highly variable dimensions for personal use and adornment (boxes, rings, bracelets, necklaces, etc.). Wedgwood, an English entrepreneur, recovered, in unglazed stoneware, a tradition that goes back to the Roman carved cameos in semi-precious stones and the denominated *terra sigillata*—red ceramic of thin walls produced in *Aretium* (currently Arezzo) and after that in the south of Gallia, pieces very appreciated by the social elites of the Empire. Wedgwood jasperware constitutes an example of neoclassic good taste and quality (by then emergent) applied to large scale Industry.

Before Wedgwood, the workshop of the Della Robbia was inspired in the Roman cameos. One of the most famous works of Andrea Della Robbia (1435–1525) is the beautiful series of blue and white terracotta medallions (*tondi*) on the main facade of the *Ospedale degli Innocenti* (Florence) (Fig. 4).

The color blue was also present in Romantic poetry and literature (in Goethe and Novalis) and was one of the selected colors by the impressionists and post-impressionists. The *Café Terrace on the Place du Forum, Arles, at Night* (1888), *Starry Night over the* Rhône (1888), *Road with Cypress and a Star* (1890) and *The Large Bathers* (1900–1905), among many others, are examples of the use of blue with a very different function from the one used in Romantic (Academic) painting. *Blue* gave the name to one of the expressionist groups and their periodical publication—*Der blaue Reiter* (The Blue Rider)—where Franz Marc (1880–1916) and Wassily Kandinsky (1866–1944), among many others stood out.

The color blue is also associated with death—as in *Camille Monet on her Deathbed* (1879)—and an integral color in the painting of Yves Klein (1928–1962) (known as the International Klein Blue). Furthermore, it is integral in the working outfit created by Levi Strauss in 1873 (blue jeans) and, allegedly, and ideal color for hospital environments, thanks to its calming effect (Pastoureau *dixit*). Blue is also the

Fig. 4 One of eight glazed terracotta *tondi* depicting infants in swaddling bands, which were set in the spandrels between the arches of the main façade of the *Ospedale degli Innocenti* (Florence). Source: https://www.flickr.com/photos/edk7/8448070873

name of the most famous Jazz Club of New York and of its record label (The Blue Note). Also in the Jazz territory, it is part of the title of an album by Miles Davis (1926–1991), with the stamp of Columbia Records, released in 1959 (*A kind of blue*).

Blue is not the most used color in seating objects, but Room 606 at the Radisson SAS Royal Hotel (Copenhagen), which is preserved as in the opening of 1960, is a "rhapsody in blue" (Fig. 5, below). Because blue is the color of dream

Fig. 5 Radisson SAS Royal Hotel in Copenhagen, room 606 (Suite Arne Jacobsen), 1960. Source: http://www.elusivemagazine.com/14043/

and evasion it is only by mere ignorance, bad taste or irony that it was possible to propose (and approved by the decision maker of the Portuguese State) the color blue for the national office that regulates taxes. It seems that both authors and decision makers passed through the looking-glass (as Alice did) and nobody noticed it.

The color blue is also used in the context of creative thinking as a metaphor for a certain attitude. In De Bono's Six Thinking Hats, which is a pragmatic approach to creativity, the blue hat ends the process (and comes immediately after the green one). Acting as a reviewer, «the blue hat is for thinking about thinking» [20], and this is why it may be regarded both as a thinker that controls the results achieved by one creative process (and this is why it stimulates the convergent thinking), and as a thinker that opens new possibilities, exploring divergent thinking. We can also apply in this (creative) context the famous saying "the sky is the limit", because the blue hat is the one that evaluates the final results and decides if it is necessary, or not, to restart the process.

5 Epilogue

In music, light blue is like a flute, dark blue is like a cello, and when still darker, it becomes a wonderful double bass. The deepest and most serene form of blue may be compared to the deep notes of an organ [21].

Sound does have color. Some individuals when they experience a certain color they feel other sensations as if experiencing them simultaneously. Thus, it is possible to *see* blue and *hear* a certain sound without it being played, or to feel the scent of a perfume without having smelled it. The problem is that none of this is voluntary, and therefore it is not always as beautiful as it seems when we read Kandinsky's remarks about sound and color. Furthermore, it is bizarre, as bizarre as passing through the looking-glass, again like Alice.

By the way, the Caterpillar is blue and likes to ask: « Who are you? », a question to which the color blue wouldn't know how to answer because it can be everything and it can be nothing (Fig. 6).

Fig. 6 Alice speaking with Caterpillar. *Alice's Adventures in Wonderland* by Lewis Carroll, illustrated by Arthur Rackam (1907). Source: http://www.artpassions.net/rackham/alice5.html

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GlanceID: A Usable, Single, and Yet Strong Optical Authentication Method

Christina Braz and Ahmed Seffah

Abstract Biometric authentication is being viewed to a greater extent as a credible option to knowledge or key based security systems. GlanceID is a usable, single optical authentication method with strong authentication capability. It captures and processes eyes gaze direction, and object positioning in real-time with the aim of granting access to users for physical access control. GlanceID is the only existing single biometric authentication method which provides a two-factor authentication. Additionally, GlanceID makes use of the rising "slippy" user experience which is all about glance-ability and focuses less on engagement but more on quick task-based user requirements.

Keywords Biometrics · User authentication · Usability · "Slippy" user experience · Physical security · Access control · Task-Based requirements

1 Introduction

Biometric authentication is being viewed to a greater extent as a credible option to knowledge or key based security systems. It is increasingly getting acceptance as a technology for user authentication to computerized systems. An example is the Touch ID [1], a fingerprint recognition feature released, and currently available on certain versions of iPhone and iPad. Touch ID allows users to unlock their device, as well as make purchases in the Apple digital media stores, and to authenticate Apple Pay online or in apps. Biometrics is defined as: "*automatically recognizing a person using distinguishing traits*" [2].

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Biometrics techniques can be mostly divided into classical and soft biometrics. Whereas classical biometrics deals with *physical characteristics* which are unique to a specific subject (e.g., fingerprints, retina/iris, face, hand/palm, voice, odor, ear) [3] and *behavioural characteristics* (e.g. keystroke, signature, gait, etc.) [4], soft biometric traits refer to physical and behavioural traits, such as gender, height and weight, which are not unique to a specific subject, but are useful for identification, verification, and description of human subjects. Among advanced biometric solutions, an innovative user authentication method is AuthenLink [5], an implantable mobile Radio Frequency Identification (RFID)-based authentication system which makes use of a new approach to distinguishing characteristics to authenticate people (authentication factor): something you CONVEY. Biometric authentication is typically viewed as a powerful single-factor user authentication method. However, it is not flawless, and certain vulnerabilities lead to important security breaches given that existing biometric methods cannot provide strong authentication by their own; they require one or more authentication methods, biometric or not, in order to offer a higher level of security (i.e. strong authentication). Strong authentication combines at least two authentication factors of different types to enhance the security of the verification of the identity. Using two factors of different types as opposed to one delivers a higher level of authentication assurance. In many real-world applications, unimodal biometric systems often are confronted by significant limitations due to sensitivity to noise, non-universality, physical characteristics, etc. Multibiometric systems (e.g. fingerprint and face recognition) in turn seek to alleviate some of these problems by providing multiple pieces of evidence of the same identity providing therefore more accuracy when compared to unimodal system. However it can be very expensive to implement. Therefore, to provide this level of security using a single optical authentication, we propose the "GlanceID, a glance-based and "two-factor" optical authentication method with strong authentication capability. This method comprises of something you ARE (eyes gaze) and something you HAVE (objects positioning) in a single biometric authentication method. It captures and processes eyes gaze direction and objects positioning in real-time with the aim of granting access to users for physical access control. Moreover, if we consider that "objects" and "positioning" are two different entities which they are so that we may claim that GlanceID is a multi-factor authentication: something you ARE (eyes gaze), something you HAVE (objects), and something you KNOW (positioning).

1.1 "Slippy" User Experience—The Glance-Ability Factor

"Slippy" user experience (UX) is about glance-ability and focuses less on engagement but more on quick task-based user requirements. It describes a natural evolution from sticky user experiences, for which the design goal is to get a user to notice, then stick around and keep using your Web site, application, or product. On the contrary, the goal when designing a "slippy" UX is for it to catch a user's eye,

then seamlessly integrate with that person's life, and support whatever he or she needs [6]. This type of experience lets people get on with their life while it does useful things for them. Think for example of user interfaces for an airplane, a nuclear reactor, or a military application. *This type of experience should enhance, not interfere with what a user is doing; nor should it consume too much of a user's attention*. For example, an Apple Watch by Apple will often be a task-based operation it would particularly require a slippy UX. Additionally, with the lack of real estate, means that *glance-ability and scannability become crucial.* With its health and fitness integration the Apple Watch is a good example of how just "glancing" at the screen can provide you with all the information you need in a snapshot. Another relevant example is the GlanceID the main topic of this paper, and described in the next paragraphs.

2 State-of-the-Art of Optical Methods for Biometric Authentication

To tie identity more closely to an individual and have a more appropriate authorization, the use of optical methods for biometric authentication are increasingly gaining user acceptance. Currently, the most widespread types of optical authentication methods are the retina and iris recognition. Retina Recognition (RR) aims to identify a person by comparing images of the blood vessels in the back of the eyes, the choroidal vasculature. On the other hand, Iris Recognition (IR) takes an infrared picture of the iris, the colored part of the eyes. This is considered by users to be less intrusive. These two types of biometrics have come a long way in recent years allowing the individual to be scanned even through their glasses or contact lenses. Iris authentication systems are produced by Panasonic[1] and Iris ID Systems,[2] and retinal systems by EyeVerify.[3] RR and IR authentication methods may be employed alone or integrated with other technologies such as smart cards, encryption keys and digital signatures [7, 8]. Biometric technology is commonly rated against a set of performance standards or performance metrics: the False Acceptance Rate (FAR), and the False Reject Rate (FRR). FAR is the percentage of times a system generates a false accept, which occurs when an individual is incorrectly matched to another individual's existing biometric. FRR in turn is the percentage of times the system generates a false reject, which occurs when an individual is not matched to her own existing biometric template. The accuracy of these methods can vary between a False Recognition Rate of 2–10 % and a FAR ≥0.001 %. Two drawbacks to these devices nevertheless are that they have trouble reading images of those people who are blind or have cataracts, and that

[1] ftp://ftp.panasonic.com/pub/Panasonic/cctv/SpecSheets/IrisReaderBrochureFinal11105.pdf.

[2] http://www.irisid.com/productssolutions/irisaccesssystem.

[3] http://www.eyeverify.com/product-technology/products.

Table 1 Comparison of optical biometric characteristics [7]

Biometric characteristic	Universality	Distinctiveness	Permanence	Collectability	Performance	Acceptability	Circumvention
Retina	H	H	M	L	H	L	L
Iris	H	H	H	M	H	L	L

H = High; M = Medium; L = Low

they presently are cumbersome to use especially if the a legitimate user is rejected access affecting thus the usability of these systems. The associated costs make them unappealing for network users, but as these technologies become more standardized and accepted so then costs will drop and remove any costs related obstacle in the decision making process.

2.1 Measurement Requirements

A biometric system to be useful and trustworthy should meet specific standard requirements and characteristics. What biological measurements qualify as biometrics? Any human physiological or behavioural trait can serve as a biometric characteristic as long as it satisfies the following requirements [9]: *Universality* (availability) states that each person should have the characteristic. Availability is measured by the "failure to enroll" rate. *Distinctiveness* declares that any two people should sufficiently have different characteristics, and it is measured by the False Match Rate (FMR), also known as "Type (II) error". *Permanence* (robustness) states that the characteristic should be stable (with respect to the matching features) over a period of time (i.e., stability over age). *Robustness* is measured by the False Non-Match Rate (FNMR), also known as "Type (I) error". *Collectability* (accessible) affirms that the characteristic can be measured quantitatively and easy to image using electronic sensors. *Accessibility* can be quantified by the "throughput rate" of the system. *Performance* means to achieve recognition accuracy, speed, and the resources required to the application. *Acceptability* relates to the particular user population and the public, in general, should have no (strong) objections to the measuring/collection of the biometric characteristic. Acceptability is measured by polling the device users. Resistance to *Circumvention* tests and proofs how the system resists fraudulent methods easily. Table 1 shows a brief comparison of the iris and retina biometric techniques based on above factors.

Which biometric characteristic is best? Each biometric feature has its own strengths and weaknesses and the choice typically depends on the application. Accordingly, each one could be used in authentication and/or identification applications. Predicting the FARs and FRRs, system throughput, user acceptance, and cost savings for operational systems from test data, is a surprisingly difficult task.

3 GlanceID Recognition

In this section, we present our GlanceID system by defining it, demonstrating how it works, presenting a comparative analysis among the three existing optical authentication methods such as GlanceID, Retina Recognition and Iris Recognition, and finally describing the security and usability aspects of our system.

3.1 Definition

GlanceID is an optical authentication method with a strong authentication capability that uses *eyes gaze direction* and *object positioning* in real-time in order to grant access to users for physical access control. As mentioned, this represents a two-factor authentication such as something you ARE (eyes gaze) and something you HAVE (object and positioning) in a single biometric authentication method. With a wide field of view provided by GlanceID, users are free to demonstrate natural human behaviour (i.e., *eyes gaze*), and not to be forced to act in certain ways with the purpose to authenticate themselves to a system (e.g., Google authenticator: users first need to install the Authenticator app on their smartphone; to log into a site or service that uses two-factor authentication, they provide user name and password to the site and run the Authenticator app which produces an additional six-digit one-time password; then users provide this to the site, the site checks it for correctness and authenticates users). The *object positioning* can be realized by the precision tracking mode, with the screen calibrated. Within one second and a half a user is reliably authenticated providing a quite secure and easy-to-use optical authentication method. It is especially recommended to physical access entry for high security facilities such as military installations, nuclear facilities, laboratories, research centers, and so on. For example, military and security organizations are more likely than civilian organizations to have more stringent security needs. Our system works with all eyes types, with or without contact lenses and with most eyes glasses from a distance up to one meter without compromising system accuracy. Work in bright sunlight or at night time. We illustrate the physical access control scenario in the next section.

3.2 How Does GlanceID Work?

In the enrollment process, a "sight point" (and its location) is chosen by the user at a specified and authorized door perimeter. It might be a light switch or a decorative iron details on the wall next to the door, or it can be anything that is successfully identifiable by the user. The sight point is her credential which is presented to the system through the eyes gaze direction reading at the moment of the verification process. The following describes an example of GlanceID system in a physical access control scenario (Fig. 1): Bob needs to authenticate to a high security military facility. (1) Bob approaches to the operational range (e.g. a marked area on the floor) of the authentication unit (camera and sensors) next to the sliding door; (2) Proximity sensors detect Bob and trigger a small digital stereo camera pair (i.e. acquisition device) to precisely capture her eyes gaze direction; (3) Then the proximity sensors detect her object positioning (i.e., sight point) which is then

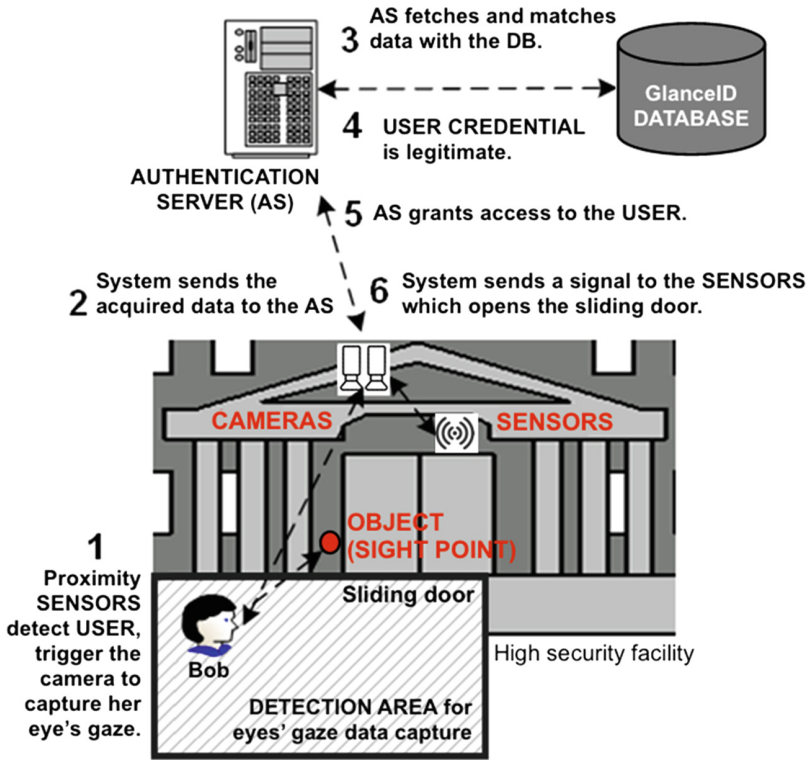

Fig. 1 GlanceID: optical authentication method architecture

streamed over the network to the Authentication Server (AS); (4) Next, the AS proceeds with the authentication process finding Bob's sight point stored in the database; (5) The AS compares the trial template versus Bob's reference template; (6) If the parameters of template correspond (Bob's eyes gaze direction and sight point positioning), the AS successfully authenticates Bob to the system which makes the sensors unlock the sliding door granting her access to the high security facility.

GlanceID is not a multi-modal authentication method since it makes use of a single authentication mechanism. Although multi-modal biometric authentication can also increase the level of security achieved by the system, GlanceID provide relatively the same high level of security without the corresponding high implementation costs while "acting" as a multimodal authentication. GlanceID platform incorporates properly into existing security systems or operates as a standalone. Although GlanceID has not been implemented, its feasibility has been demonstrated theoretically and the results have been validated experimentally.

4 Comparative Analysis of the Optical Biometrics Authentication Systems

The accuracy of biometric systems is commonly measured from two statistical measurements: 1. The False Acceptance Rate (FAR) is a measure of the readings that the system erroneously matches to its database. The lower the FAR, better a system's security is. For example, a highly secure system may involve constant human intervention to allow access to authorized users not recognized by the device; 2. The False Rejection Rate (FRR) is a measure of the readings that the system erroneously fails to match to its database. The lower the FRR, the easy-to-use system will be. For example, an easy-to-use system, meaning convenient for both user and system administrator, may allow unauthorized access to a secure area. The FAR and the FRR are reciprocally proportional, forcing a trade-off between security and convenience when using biometric systems [10]. One important advantage of GlanceID is that if the FRR is set up high, users will not be

Table 2 The main benefits and drawbacks of each of the optical mechanisms

Acquisition device/description	Retina recognition (RR)	Iris recognition (IR)	GlanceID recognition (GIDR)
Definition	Identify people by comparing images of the blood vessels in the back of the eyes, the choroidal vasculature	Take an infrared picture of the iris, the colored part of the eyes. Less intrusive	Identify people by capturing, processing eyes gaze direction and object positioning in real-time. No intrusive
Data acquisition distance	Usually from a distance of 0.05–0.20 m (depending on the type of camera). Users must focus their eyes at an extremely close range to the lens	Usually from a distance of 0.07–0.25 m (depending on the type of camera). Not affected by contact lenses or glasses	Distance from 0.5 to 0.8 meters. Don't require users to position their eyes within the field of view of a single narrow angle camera
Usability	Personal knowledge is unnecessary. Significant user cooperation in order to obtain a retina image	Personal knowledge is unnecessary. Significant user cooperation although in a less extent than RR	Requires minimal user cooperation and minimal personal knowledge
Security	Forgery almost impossible. Single-factor authentication: RR does not constitute strong authentication used on its own [12]	Forgery almost impossible. Accurate biometric. Forgery almost impossible. Single-factor authentication: IR does not constitute strong authentication used on its own [12]	Forgery almost impossible, and more difficult than IR, and RR. 2-factor authentication on its own: GIDR doesn't need to be coupled with another method in order to provide strong authentication

denied access due to the fact that the system first checks out for the object positioning, sight point, matching the captured data with the database (i.e. user identification). This provides not only high usability to the system but definitely higher security. Most existing biometrics systems today are based on verification rather than identification. Biometric templates usually require a lot of memory, and our system provides here three-fold advantage: (i) It is cheaper to assume the costs of its storage; ii) It is simpler than to settle a smart card infrastructure; (iii) It provides strong authentication on its own and does not incur additional authentication method and implementation costs. We describe the main benefits and drawbacks of each of the optical mechanisms according to the Table 2.

5 Security and Usability Aspects

The main security advantage with biometric authentication is that the credentials are truly unique to the user and are often difficult to forge. They cannot be lost, stolen or forgotten eliminating threats like guessing, social engineering, brute force and point of entry attacks. However, capture and replay attacks of the digital code are possible when traveling over the network; the same kind of attack is also possible with GlanceID. Nevertheless, the main differentiation compared to the other optical authentication systems is that the object positioning (sight point) mechanism provides additional information (i.e. something user KNOWS which is a user credential) which represents in fact a two-authentication factor. A security flaw of GlanceID just as with biometrics in general is that if someone succeeds in forgery or replay, there is no way to disable the credential and issue a new one. You can simply not replace someone's eyes with a new one. It is also likely that many threats to optical biometrics, that are not yet known, will become apparent once there are more large scale applications using biometrics and thus a greater reason for attack. Biometrics systems usually are subjected to three categories of attacks: (i) Trial-and-error attack: It is a classic way of measuring biometric strength [11]; (ii) Digital spoofing: An attacker transmits a digital pattern that mimics that of a legitimate user's biometric signature) which is equivalent to password sniffing and replay. Biometrics can't prevent such attacks by themselves (Smith 2001); (iii) Physical spoofing: It presents a biometric sensor with an image that mimics the appearance of a legitimate user. But how GlanceID copes with these attacks and protect the system? With regard to Attack (i): Although the attacker might be able to get the right biometric pattern s/he cannot disclosure the sight point "secret"; Attack (ii): Even if the attacker transmits a digital pattern s/he is not able to transmit the sight point "secret" over the "network" since it is intangible and cannot be copied; Attack (iii): The attacker is not able to present exactly the same user's eyes gaze direction.

Organizations may diverge in the capabilities they need for their security and usability requirements. Figure 2 shows a model of a potential scale of authentication factors characteristics from lowest security to highest security and from lowest

usability to highest usability. As indicated, the usability of the authentication method is likely to decrease in proportion to increasing security requirements. In addition, interoperability requirements (e.g., storing multiple certificates in a smart card) will impact the capability, size, and cost of the card. Extremely difficult to undertake Man-In-The-Middle attacks given that all data transmission from the camera to the object, and from the object to the camera to the sensors, and to the authentication server are all encrypted. Another way the sight point can be revealed is when the user shares it with another person. No need to create or store digital templates (i.e., pictures) of the eyes, so eyes gaze direction or object positioning cannot be reconstituted to generate any sort of visual image. Moreover, GlanceID can record the duration of fixation on the sight point object and serves as another layer of strong authentication. Another security advantage of GlanceID is against the well-known trial and error attack which is in fact a cognitive safeguard and not related to commonly hardware and logical ones. Consider this attack scenario: an attacker tries to figure out the sight point secret; attacker looks at every square inch first close to the door entry which is the first attempt to find the object position; however looking at every inch is tremendously tiresome from a cognitive

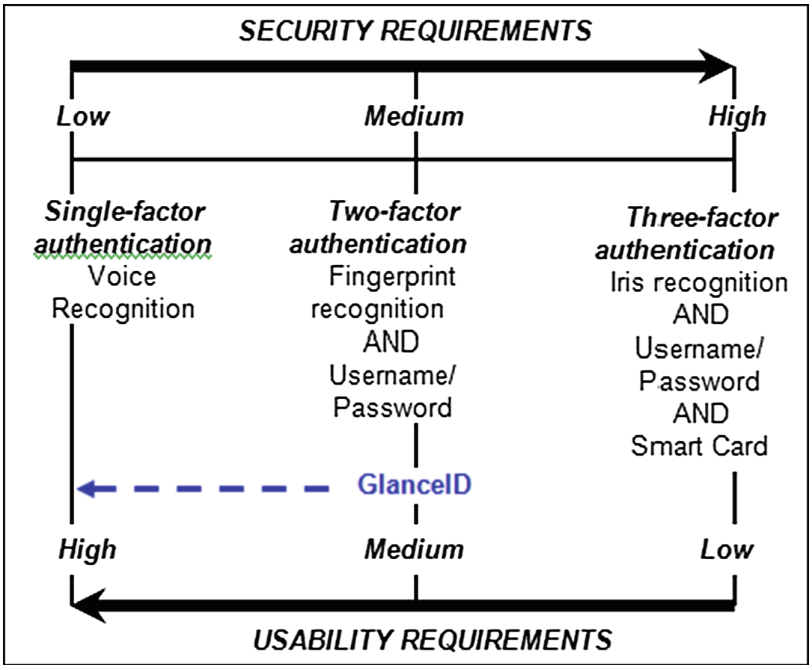

Fig. 2 The security and usability requirements scale shows the different authentication factors characteristics from lowest security to highest security (*upper arrow*) as well as from lowest usability to highest usability (*lower arrow*)

standpoint, and even doing a small chunk of five inches by five can be considered an extremely strenuous task.

As Fig. 2 points out, the usability of the authentication methods are likely to decrease in proportion to increasing security requirements. Combining different approaches such as single-factor authentication to multifactor (two or more) authentication to achieve a higher level of security is feasible. "GlanceID" is positioned in the Security and Usability Requirements scale as a strong authentication method (i.e., Medium Security Requirements) even though it presents a single-factor authentication and because of that GlanceID presents in fact Low Usability Requirements. Another interesting point is that our optical system does not require re-enrolment (e.g., changes in voice tone may trigger re-enrolment process) providing thus suitable user convenience.

6 A Concluding Remark

In this work, we have taken the first step toward meeting the challenge of providing a usable and single-factor optical authentication system with strong authentication capability (i.e., two-factor authentication). GlanceID uses eyes gaze direction and object positioning in order to grant access to users for physical access control. GlanceID is the only single-factor optical authentication method that provides strong authentication on its own. Organizations therefore are able to make the most of a simple and cost-effective optical authentication system for their biometric user authentication needs.

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Innovation of Modern Architecture—Expressionist Tendencies

Nina Juzwa, Adam Gil and Katarzyna Ujma-Wasowicz

Abstract The subject of this work are reflections and comments on the architecture of recent years, and in particular of objects that are examples of a search for originality and expressiveness of form. Examples that, by using modern technical possibilities, are representations of ideas—architectural concepts, which up to now most frequently remained only in the form of drawings. This concerns the architecture of recent years—objects that are a continuous subject of the interest of our team. Objects in which evolution and development of technical and technological options in architectural design lets "placing" a large building "at the corner" in a way that it still gives the impression of stability and durability.

Keywords Contemporary architecture · Avant-garde · Innovation · Expressionist tendencies · Geometric form · Material solutions · Human factors

1 Introduction

Since the Antiquity, each historical epoch introduced to the architecture features characteristic for its culture, but also possible to implement in that period. Today, adapting to the needs of society—to the changeability or liquidity of needs—also in architecture we observe the increasing ability to freely combine various types of content: functional, aesthetic, familiarity and identity, display of prestige. The

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acknowledgement of technique and technology is important as well. Today, the human factor remains an immanent element of design.

Contemporary architecture, especially since the end of the last century, is a constant search for novelty. Dariusz Kozłowski talks about the search for novelty and weariness: "*(….) the recipient may be weary, but rather the impatience of a bored artist is the powerhouse of change in the subsequent objects*" [1]. When talking about irony and ecstasy that govern the imagination of the architects, Charles Jencks introduced for this movement the term "*ecstatic architecture*" [2]. When referring to the famous Mies van der Rohe's "*less is more*" and his pavilion at the World Exhibition in Barcelona (1929), Hans Poelzig's "*We build modestly and it may cost as much as it has to*" [3] is perfectly fitting. To demonstrate the irony of the context and the loftiness of the form Ewa Rewers uses the example of the Louvre pyramid by I. Ming Pei. The clash of cultures and styles, the historic façade of the palace with the transparent building of the Pyramid constitutes also a transition from yesterday's to tomorrow's reality.

The current paper's authors' study travels to the USA and Japan allowed to deepen the exploration and research of world architecture. Our comments and reflections generally apply to objects erected in the USA and in Japan using them as the background for architecture realized in Poland. We stress the global importance of creating around us a new, innovative space, and a new culture of the place. The innovation (also in architecture) as an immanent characteristics of modern times overlaps with aspirations and expectations of the recipient—user and observer of the objects being erected. The authors are convinced that the presented formal transformations will contain more than a mere record of the changing architectural geometry, embodying the expressionistic tendencies in architecture.

The discussed problems are presented in three groups-functions of objects: higher education and science establishments, museum objects, housing developments. The chosen thematic groups affect the perception of the architectural geometry.

The inclusion of the subject of housing objects into the research that normally concerns larger scale objects and of functionality that goes beyond individual needs of the user is:

- on the one hand a testament to the fascination with this architecture, mainly gained during the study trip to Japan (although not exclusively)
- on the other hand, the emerging belief that objects of this function usually undergo a faster transformation into new architectural standards that are also socially acceptable.

The selection of the presented objects stems from the belief that some contents contained in the architectural structure are more amiable to the innovation of form than others. In the past, these were monumental buildings: churches or town halls. Currently, these are public or commercial buildings. Thus the choice is connected with the question of social acceptance of new standards, which in the authors' analysis are conveyed by the choice of prime examples. As a result, the selection of objects is a very personal consideration of the presentation of the modern architectural thought.

The public utility objects, like museums and some higher education or research objects, thanks to their architectural aesthetics become symbols of the place; they become its abstract image. We discuss them with respect to:

- shaping of their geometric form,
- innovation of material and constructional solutions.

2 Challenges in the Creation of Modern Architecture

Architecture is always a child of its time. Ever since Vitruvius, its basic material was a thought—an idea. Although a thought alone does not constitute architecture. Architectural design, in the form of a drawing or a model is still only a thought necessary to be transformed into the form of a real object. The relationship between the thought content and the material shape of the created work depends on the time, as well as on the place where the object is being erected. Increasingly often, the designed object from the outset is created as a three-dimensional computer model. Thanks to computerization, the human thought soars ever higher, and increasingly often: impossible—becomes possible. In addition, project documentation is being created faster; the scope and manner of cooperation with specialists has changed as well. In other words, computerization enabled the design process to become shorter, and sometimes facilitates the creation of the form.

Still however, the importance of freehand drawings, mock-ups, understood as the first materialization of an architectural idea, does not decrease. Drawing or a working mock-up, which are sketchy presentations of an idea, create a balance between the manifestation of a dream contained in the drawing, and the process of erecting an object. Dynamic, as-if-carved, forms of contemporary architecture refer to expressionist tendencies. Ewa Gyurkovich calls these buildings new expressionism, where their inspiration is often in the decomposition trends in the visual arts [4]. "*Images of architecture, a fragment of the creative act preceding the formation of the object, or simply part of a specific project (…)*". The role of such images lies in their explanation of the author's thoughts, persuasion and convincing the audience or customer to accept a vision or an idea [5].

Drawing stood at the origins of Expressionism in the 1920s. The creation of the Mendelsohn's observatory Einsteinturm in Potsdam (1917–1921) was preceded by other drawings. Le Corbusier, when designing the chapel Notre Dame du Haut in Ronchamp in the 1950s, was fascinated by the beauty of soft lines and he diverted from the regularity and rigidity of line characteristic for his work. The modernists contemporary to him perceived his new vision difficult to explain [6]. And yet, nowadays, the chapel in Ronchamp is one of the iconic places for architecture.

The extremely dynamic form of the hyperbolic paraboloid and steel masts of the cover of the Olympiapark in Munich by Gunther Behnisch and Otto Frei (1972) is till original and remains an excellent model of fusion of architecture of fleeting forms with innovation engineering, visible in the material concept and its spatial

structure. Without such amalgamation of the thoughts of the architect and the engineer, it would be difficult to realize the concept of the UFA Cinema Centre in Dresden by Coop Himmelb(l)au. However, also a drawing—"*a line spontaneously captured on paper without thinking*" [7] marked the beginning of the idea that materialized in the building of the Cinema Center.

When talking about the importance of drawings, the concept presented by Zaha Hadid at the competition The Peak Club in Hong Kong (1982) cannot remain without being mentioned. The dynamic, full of beauty, sketches reveal a certain disintegration of the landscape and an architectural concept of objects. This visual disorder, Hadid transforms into a program and metaphysics of "tidied up" picture. The project, remaining within the art of decomposition still inspires by the explosion of an isomeric presentation, despite remaining in the realm of dreams.

The objects described above are important for the understanding of the works of the most recent years—the examples presented below, when the introduction of computer graphics enabled a "painless transition" from drawing dreams to the real world. This constitutes a symbolic transition in time and space.

3 Examples of World Architecture (Polish, American and Japanese)

3.1 Higher Education Objects

3.1.1 Sciences Building of Cooper Union College, New York, USA/Thom Mayne, Morphosis Architects, 2009 (Fig. 1a)

Sciences Building of Cooper Union College in New York (2009) has been authored by Tom Mayne from the Morphosis Architects group (winner of the Pritzker Prize) and it is the building cited at the introduction to this article.

The building is an extension of the Cooper College complex existing since 1859. It houses the faculties of engineering, arts and architecture. The idea of the new building was creating a "connector" for the cultural and intellectual environment.

Situated in Manhattan, at the edge of the East Village, near the Washington Square Park, surrounded by the quiet residential buildings, filled with bookshops, galleries and cafes, it seems to participate in creation of the environment. The idea of a "connector" that guided the authors is clear and positively introduced into the architectural solutions. On the photos from the construction period (2006–2007), a 9-floor, compact building with orthogonal divisions of the interiors can be seen. It is not however a plain cuboid. The leaning solid with cut-outs, supported at the entrance on v-shaped columns evokes the impression of a large sculpture with a torn-apart smooth surface. The full of expression form is not however controversial.

The geometric form is the effect of the envelope—a semi transparent double skin, which surrounds the spatial-functional interior structure creating the sculptural

Fig. 1 **a** Sciences Building of Cooper Union College, New York, USA/Thom Mayne, Morphosis Architects, 2009 [Photo: D. Zielezniak]. B. KAIT—Kanagawa Institute of Technology, Kanagawa, Japan/Junya Ishigami and Associates, 2007 (Photo: A. Gil)

character and expression of the form. The plan of the projection is compact and organized—the only extravagance is the central patio extending through the whole height of the building. It is surrounded by the galleries, auditorium and the main staircase connecting the floors; 1st, 5th and 8th in a "skip—stop" system. The green roof and terrace crown the last, 9th floor. The stainless steel panels offset from the glass and aluminum window wall ensure the transparency of the interior and the comfort of its use, reducing the heating of the building in the summer and ensuring the access of sunlight during winter.

3.1.2 KAIT—Kanagawa Institute of Technology, Kanagawa, Japan/Junya Ishigami and Associates, 2007 (Fig. 1b)

This remarkable in its tectonics object came to existence in the imagination of the Japanese architect Junya Ishigami. The building has been erected in the suburbs of Tokyo.

KAT Workshop constitutes a modern vision of the moving boundary between materiality and visibility in architecture. When working inside the building, we have the impression of being in the open air. This accessibility, white matter, sunrays entering from all directions give the impression of elegance and weightlessness of the building. The localisation allows a free view from all sides, the panoptical principle of shaping the elevation (fully glassed windows) and interiors (lack of divisions inside), along its unconventional construction, allow to consider the Kanagawa Institute of Technology as an object innovative in form and contents. A flavor to the design is added by the, seemingly unfitting, arrangement of the interior and the furnishings (furniture), bringing about associations with a flea market and spatial chaos rather than with the principle of crystal clarity of the whole object.

The basic idea of the author was to evoke in the user the impression of being in the middle of a forest. Designing the grid of 305 fragile and delicate columns of varying diameters and "planted" in a way that would seem quite random, which support the flat, filled with skylights roof, demonstrates the great knowledge, as well as imagination and courage of the architect. The seemingly random arrangement of the columns constitutes a conscious idea of zoning the interior depending on the changing needs of the students, a possibility of its easy arrangement.

> Junya Ishigami says, that he tries to combine architecture, artificial things and natural environments to make a new criterion for human activities. He further explores these ideas by conceiving pieces from a child's point of view on the world and natural phenomena. His work balances poetics and technical engineering as he tries to learn from thermodynamics and physics. [8].

3.2 Museum Objects

3.2.1 Cricoteka—Centre for the Documentation of the Art. of Tadeusz Kantor, Kraków, Poland, IQ2 Konsorcjum (Stanisław Deńko, Piotr Nawara, Agnieszka Szultk), 2014 (Fig. 2a)

Centre for the documentation of the art of Tadeusz Kantor has been localised in Kraków at the banks of the river Vistula at Nadwiślańska Street. Cricoteka is a public utility building and it has been conceived as an accent, a dominant in the panorama of the city. Its genesis is a result of the revitalisation of the buildings of the power plant located in the city district Podgórze; it is an expression of the architectural tribute to the artist whose art has gained international acclaim.

Fig. 2 **a** Cricoteka—Centre for the Documentation of the Art. Of Tadeusz Kantor Kraków, Poland, IQ2 Konsorcjum (Stanisław Deńko, Piotr Nawara, Agnieszka Szulik), 2014 [Photo: A. Gil]. **b** New Museum, New York, USA/SANAA: Kazuyo Sejima + Ryue Nishizawa, 2007 [Courtesy: N. Kowalski]

The building of the museum, according to the creative thoughts of Kantor is not integrated with the surroundings, and the existing historic building does not define its function through identification with its original function, but through a conscious juxtaposition of its form and contents. The aim of the creative process of the designers was not the identification of the shape as a form, but rather its influence on the surroundings [9].

This unique structure that combines elements of a museum, theatre and cinema, is a combination of the old building with a completely new, almost abstract form. The designers spanned a kind of a "bridge" above the historic building of the power plant. The facades of this geometric form are covered with openwork elements made of corten steel and they bring about associations with the post-industrial heritage of the place, lending it, both, an abstract and modern expression. This tone is also highlighted by the mirror cover located under the mentioned "bridge"—when standing at the foot of the building, one can see one's own reflection when looking up. The construction of the building, in its character reminiscent of the design of a bridge, had to solve a number of difficult and inconvenient issues. Its development required creative thinking and familiarity with modern digital techniques to solve complex static problems. Large reach of the cantilever of the spans constituting the functional spaces while reducing the size of the support elements create dynamic relationships from the level of the passer-by standing on the river bank. The object is supported at three points, two of which define the internal vertical communication.

The co-author of the project, Stanisaw Deńko said "Kantor's vision envisaged theatre as an experiment in the sphere of abstraction, stimulation of imagination – a connection of the actor with a prop, with any object. The Centre for The Documentation Of The Art is a mirror – a reflection of the active part of the city at the Vistula River that becomes a "prop" and in an abstract way participates in the awareness of the passer-by …" [10].

3.2.2 Muzeum Śląskie (Silesian Museum), Katowice, Poland/Riegler Riewe Architekten, 2014

Just like many Silesian cities, Katowice is historically strongly connected with the heavy industry and mining, which form the cultural and historic backbone of the region. The competition for designing the Silesian Museum was announced in 2006. It can be said that the Silesian Museum designed by the Austrian architects Riegler Riewe Architekten was the starting point for the long-term, sustainable revitalization of the large, centrally located urban area that only a few years ago was heavily degraded. This object, similarly to other investments forming the so-called "Culture Zone of Katowice", was erected in the heart of the city, within the localization axis of the famous in the region, as well as in the sports and cultural world, hall "Spodek" (1971), the gaining prestige headquarters of the National Polish Radio Symphony Orchestra (2014) and the completely new International Congress Centre (2015). The University campus (of the University of Silesia and

the University of Economics) is located in its direct proximity. Thus, this object, together with the mentioned buildings, forms a complex of public buildings attracting large numbers of people and is an important spot on the cultural and educational map of the region.

What seems particularly interesting for thinking about innovative shaping of contemporary architecture is the concept of a minimalist museum, based on programming the extensive space for declared functions with only a slight interference with the surroundings. It is an object of a form and scale deliberately inadequate to its rank, breaking away from the traditional role of a museum often considered to be a temple of art. The authors suggested hiding the exhibition space up to 14 meters underground to exhibit the post-mining monuments and create a public space around them. The placement of the main exhibition space underground can be regarded as a romantic reference to the mining tradition. Only the monumental internal ramp leading from the entrance area to the main exhibition space laid out over three floors below has a representative character. On the surface, only a raw in expression public establishment is seen, which offers a view of the constantly changing panorama of Katowice.

The authors stated that the greatest challenge for them was to design the elevation. They were on the one hand anxious to ensure that the structures located on the ground would not obtrude the existing buildings that are precious from the conservation point of view, on the other hand, they would interest and intrigue the passer-by. Thus is seems logical that they chose abstract, translucent, "milky" boxes reminiscent of minimalist lanterns that sprout from the post-industrial landscape. The entire object is dominated by the silhouette of the headframe of the mine shaft —perhaps the most distinctive symbol of the Silesian landscape.

3.2.3 New Museum, New York, USA/SANAA: Kazuyo Sejima + Ryue Nishizawa, 2007 (Fig. 2b)

This original in its form building is located at the frontage of the Bowery Street in lower Manhattan. The interplay of 7 boxes (nonchalantly stack one upon another) suggested by the architects is reminiscent of an abstract sculpture, or in a more critical view, an irregular and overblown pyramid. Further, the buildings surrounding the object, which constitute typical quarters of downtown development, form a compact background for the museum. It is very well visible from various directions, also thank to its massive, much higher spatial structure than the neighboring buildings.

For such a prestige function, the designers nearly always look for originality (vide Guggenheim Museum in NYC by F.L. Wright, 1959 or the Guggenheim Museum in Bilbao by F. Gehry, 1997) because it is obviously connected with raising the prestige of the place, founders and designers. In 2008, the New Museum has been declared by Condé Nast Traveler (luxury and lifestyle travel magazine) one of the "New Seven Wonders of the World". The architects stated that "*...the New Museum is a combination of the elegant and urban. We were determined to*

make a building that felt like that". It was quickly seen that the presence of the building "*redefines Manhattan downtown architecture for a new generation*" [11].

The arrangement of white, displaced with respect one to another, boxes reaches a height of 50 m. The structure built from steel and concrete is surrounded by a 4.5 m tall glass wall on the ground floor, and above, each box is surrounded by a façade made from aluminum net without any visible connections (the endings of adjoining panels overlap by 2.5 cm creating the impression of a uniform surface). Such intelligent application of the elevation material combined with decisive displacement of the boxes created an impression of an object that is like a strong body in a delicate, firmly and softly shining skin.

3.3 Residential Objects

3.3.1 Casa Olajossy Ossia Villa in Fortezza, Detached House, Lublin, Poland/Dariusz Kozłowski, Tomasz Kozłowski, 2010 (Fig. 3a)

Today, the worldwide most recognizable Polish designer of detached houses is Robert Konieczny, but in this text we would like to draw attention of the reader to a house designed by another outstanding Polish architect—Prof. Dariusz Kozłowski. In 2009, in Lublin (a city in eastern Poland with 350 thousand inhabitants) he designed a house uniting various currents, conventions and periods in a coherent form. D. Kozłowski is a designer who has the postmodern ability to unite threads, especially in the formal layer of architecture, while maintaining a multifaceted interplay of meanings, relationships and symbols.

The house is located on the outskirts of Lublin and it stands out from the surrounding pragmatic, and rather devoid of architectural values, spatial background. A cuboid inscribed into a perforated concrete cylinder has been erected on a plot of a shape close to a trapezoid. The interior of the cuboid contains the main housing

Fig. 3 **a** Casa Olajossy Ossia Villa in Fortezza, Detached House, Lublin, Poland/Dariusz Kozłowski, Tomasz Kozłowski, 2010 [Courtesy: T.Kozłowski]. **b** Okurayama Apartments, Yokohama, Japan/Kazuyo Sejima & Associates, 2009 [Photo: A.Gil]

function while the cylinder is a kind of a sculpture surrounding the house. The distribution of functions of this house is not typical. The ground floor houses mainly technical functions. The daytime zone is located on the 1st floor, bedrooms—on the 2nd, and studios on the last. The whole structure is intersected by "freely" distributed staircases. However, the housing function is not the most important here. The key element is the play with form thanks to which a sculpture consisting of matter and light has been created.

The relationship between the cuboid and cylinder is far from indifferent: the reinforced concrete cylinder lets in streaks of light through an arrangement of incisions, which create theatrical effects in the interiors. The interiors make a surprising use of the subtractive space between the outline of the cuboid and the cylinder. Funnily, this postmodern interplay was achieved with the use of modernist and brutalist elements. A cube chequered in Mondrian colours reminds of De Stijl buildings. The reinforced concrete cylinder is executed according to the "Béton brut" principles with imprinted wooden framework texture. The composition of incisions is reminiscent of late work by Le Corbusier. The perforations in both elements that fail to meet ensure the "*play of masses brought together in light*" [12].

When analyzed pragmatically, the object can be easily criticized. The arbitrary concept does not make a good use of the plot; the stiff form restricts the functional layout leading to an increase of the number of floors and odd functional reshuffling, and the intended theatrical character of staircases to an excess of communication.

These shortcomings, however, do not seem to exist in a direct contact with the object's architecture. The user readily "incurs the cost" for them, similarly as in the buildings of SANAA or F.O. Gehry. The user agrees to the mundane nuisances, gaining in return the everyday possibility of communing with space stimulating their sensitivity, feelings, emotions, with a non-obvious space that is coherent and beautiful—with a piece of art.

3.3.2 Okurayama Apartments, Yokohama, Japan/Kazuyo Sejima & Associates, 2009 (Fig. 3b)

Okurayama Apartments is one of the most iconic Japanese housing developments. The author is Kazuyo Sejima, a member of the best-known Japanese architectural duo—SANAA. However, this object was created as her independent work in the in the studio Kazuyo Sejima & Associates.

The object is built in a residential district of Yokohama, on the border with Tokyo, directly at the train station Okurayama. It consists of 9 residential units, each of an area of approx. 50 m^2. (this is slightly above the average area of an apartment in Tokyo) intended for occupation by 2 persons. In a top projection the building looks as if it was the result of 'subtraction' of an organic shape (of another object designed by the duo SANAA—Serpentine Pavilion) from a rectangle.

This subtractive space forms an irregular arrangement of ribbon atria of apartments and terraces which are intertwined at different levels. What is characteristic

for the Japanese avant-garde architecture—the boundary between interior and exterior, the private and public spaces, becomes blurred.

> "By cutting this strip-shaped plan randomly, some spaces become interior terraces, while others become exterior terraces. We tried to create a condition where interiors and exteriors are intermingled comfortably and continuously" the author writes in her essay about her work [13].

While conceptually the building is reminiscent of the Moebius strip—a place where traveling on one side we move to the other without noticing it, it clearly spatially distinguishes itself from the environment. In a manner characteristic of Japanese buildings, organic shapes of the building and the atriums are brutally "cropped" to the boundary of the plot. This anchoring in reality is also emphasized by the unadorned concrete façade—a characteristic element of Japanese construction fashion.

A great weight has been attached to the social organization of space and to ensuring privacy of the individual apartments. An emphasis was also put on the increase of contact with nature by creating additional outer space and precise framing of views. On the other hand, functional requirements on the micro-scale were treated with negligence (from the perspective of a European)—the interiors generally have a width no greater than 2.5 m, locally narrowed by staircases; the interiors are winding; intentionally no rooms are defined; and on each level "each space has two straight walls" which according to the belief of the designer should suffice to ensure comfortable interior design. Such approach to functionality is characteristic of the duo SANAA.

The building, like many examples of Japanese avant-garde architecture created over the last 15 years seems to be composed of opposites. On the one hand, it is introverted—on the other this is a reaction to the context. The spatial arrangement of curvature and perforations is random—but the frames which are created are precisely designed. The key project premise was the mental contentment of the user—however the object seems to ignore the daily annoyances arising from its form. The interior creates a maze—however it does not induce anxiety. Finally, the monolithic, reinforced concrete shell—creates the impression of transience and sublimity close to experiencing natural forms—canyons cut by rivers.

Buildings following a similar concept of an interplay of contradictions are also seen outside Japan. Within the European avant-garde architecture, works by MVRDV, BIG or Rem Koolhaas can be mentioned. They are based on a similar approach, but the strength of their architecture lies in a contrast, while the contrasts in Japanese architecture are bonded into a single integral gentleness.

Certainly, this is such a type of expression of form that is not connected with domination over the recipient but with evoking a sense of lightness and sublime; an expression whose marks can be found in western architecture in the Sydney Opera House by Jørn Utzon or in the Fallingwater House by F.L. Wright.

3.3.3 Beekman Tower (8 Spruce Street), New York, USA/Gehry Partners LLP, 2010 (Fig. 4a)

In the immediate vicinity of the outposts of the Brooklyn Bridge and the Woolworth Building in the lower Manhattan, a new residential building by Frank Gehry studio has been located. It is a 76-storey residential tower with apartments for rent. The projection of the building, at the height of the first 7 stories, is trapezoidal and reflects the shape of the plot fitted between four streets, filling it completely. Above, the tower assumes the shape of the letter T. The interior of the building is surprisingly conservative, repeatable floors are based on a corridor system oriented along the axes of the wings of the building. Small apartments of the scale and spatial distribution similar to hotel rooms are connected to the corridors. The standard of interior fittings goes beyond that of a standard hotel room of course —this is one of the most expensive residential buildings in NYC. The exterior however surprises. The building dominates the surroundings—is the tallest residential building in the northern hemisphere, but it is not its size that makes the greatest impression. The façade seems to flow as if the building was wrapped by a wavy surface of a lake. New Yorkers call it the "Rippling Building".

The façade is made of individually shaped stainless steel panels with characteristic 'wrinkles'. The panels include not only the cladding—in fact they are entire ventilated outer walls with installed panoramic windows. The wavy

Fig. 4 **a** Beekman Tower (8 Spruce Street), New York, USA/Gehry Partners LLP, 2010 [Photo: D. Zielezniak]. **b** Fifth Avenue Apple Store, New York, USA/Bohlin Cywinski Jackson, [Photo: K. Ujuma-Wasowicz]

skyscraper—surprisingly—fits perfectly into the historic context of the lower Manhattan (its immediate neighbors are buildings from the early 20th century). Both, the stepped composition and the sculptured façade refer to the character of the context, despite the use of completely different materials.

The key to success is in the inspiration by a baroque "folding" to fascination, to which Gehry admits directly: "I've always been fascinated with folds. All artists through the ages have spent time on the fold. Michelangelo had stacks of drawings of fabric. At 8 Spruce, we're using Bernini's folds to inspire the façade. I look for ways to express feeling in a building without using historic decoration." [14]

To create this building (and in particular it envelope) Gehry used, as in the case of his previous works, the software of Catia Dassault Systèmes modified for his needs. The number of types and shape of the panels was repeatedly verified and changed, both, at the stage of design, and at the pre-production to optimize costs (the construction of the building took place at the time of crisis). Despite this, the developers managed to maintain the expression of form, which is particularly strongly affective when the building emerges cropped through the narrow streets of Manhattan. This is undoubtedly an example of a classic "technological terror" which, thanks to the sensitivity of the artists, has been tamed and used to obtain a unique and monumental artistic impression.

4 Summary

In our contribution we have tried to indicate the global importance of creating an innovative space around us and new culture of a place. It seems that the buildings discussed in the article are very expressive, they are a reflection of the search for emotions and excitement. On the other hand, they are objects with a "class", which respect the surroundings and are not pretentious (see Fifth Ave Apple Store in New York Fig. 4b).

It should be stressed that innovation (also in architecture), is an immanent characteristics of modern times, which overlaps with the aspirations and expectations of the user and the observer of the constructed buildings. In the current time, the human factor remains an inseparable element of design.

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A Study of e-Picture Books and Traditional Picture Books on Children's Reading Attention

Tien-Ling Yeh and Chun-Ching Chen

Abstract In the recent years, the rapid development of multi-media assistive technology and teaching aids has led to the increasing variety of children's reading devices. This study aimed to explore the influences of e-picture books and traditional picture books on children's reading concentration. There were two phases in this study: (1) the literature review, which illustrated different forms of picture books and psychological and physiological cognitive processes of concentration; and (2) the experiment, in which participants were asked to read traditional picture books and e-picture books. Their concentration was then measured using an EEG. The experiment was performed in June, 2015, with the participants being 42 first-grade students from an elementary school in Xindian District. The results are summarized below: (1) the EEG results showed that the concentration of those reading the traditional picture books was higher than those reading the e-picture books. (2) The form of the picture book had a significant influence on children's understanding of the story content. Due to the short duration of the experiment, the form of the picture book had no significant influence on children's attention level. (3) According to the observations, it was found that the children were easily distracted when they were not interacting with any e-media.

Keywords HCI and children · Traditional picture book · e-picture book · Attention

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1 Introduction

With the rapid and continuous development of the Internet and multimedia technology assistive devices, the focus of the educational circles has moved from promotions of computer assisted instruction and integration of information in instruction to recent promotions of flipped classrooms. In the recent years, in the educational circles, more and more attention has been paid to constructionism-related learning concepts and research on information processing based on cognitive neuropsychology, resulting in researchers in the fields of multimedia learning and digital curriculum development broadly designing instruction models and learning activities based on constructionism and information processing [9]. By the end of 2013, the growth of e-books for children was 200 %. The output value of e-books for children was 21 and 13 %of that of books for adults and books for children, respectively. It is estimated that there were 65 % of children in the US having a tablet PC [2]. Digital reading and integration of e-picture books in curriculums have become one of the highly valued reading instruction styles in the elementary school education [6]. Elements of e-picture books include text, dynamic images, sound effects, colors, etc. Story plots are integrated with animation-like images to get children's attention, so that children can firmly memorize the content of the stories in a short time. Although there have been a lot of studies on e-picture book related issues, the researcher of this study found that there have also been scholars suggesting special effects such as sound and light effect of e-picture books would result in children being addicted to sense stimulation, which can obstruct their development of imagination and creativity. Thus, based on the above-mentioned background and motivation, this study aimed to explore the types of picture books, as a reference for teachers and parents when choosing reading media. The purpose of this study is to explore the relationships of non-interactive e-picture books and traditional picture books with children's reading attention.

2 Literature Review

2.1 Traditional Picture Books and e-Picture Books

Illustrated books or picture books for children combine images and text to delivery ideas and knowledge. There can be both daily language and literal language in picture books. Picture books are projections of children's own experiences. E-picture books are different from traditional paper picture books. Every page of e-picture books is designed with dynamic e-information. E-books can be considered as a type of interactive and lively multimedia with multiple pages (including

information in the form of text, pictures, or sounds) [1]. E-books can be categorized into "interactive" and "non-interactive" e-books based on reading methods. An interactive e-book contains the story of the original picture book and a series of games which users can enter by mouse clicking. With the feature of interactions of computer animation, it can develop different viewpoints for the story and enrich the originally one-way story structure. As for "non-interactive" e-books based on picture books, they present stories through animation films. They are so-called "e-books for children". The stories of this kind of e-books for children are still linear, following the timeline of the corresponding films.

2.2 Attention

Attention means we actively process limited information which comes from our sense organs, memories, and other cognitive processes. Lewis et al. [8] suggested that attention is a type of limited general cognitive processing resource. Coull [4] indicated that attention is a cognitive distributing and processing resource generated simulations from locations, subjects, or time. However, Lefrancois [7] believed that learning is involved in changes in abilities and images, and attention is the arousal of psychological concepts, as well as the degree of being clear-headed. Its main source is the hearing and vision of the distance receptor. The most effective learning is achieved when the arousal level was the most appropriate. There is no doubt that only special stimulation can give rise to learning attention (translated by Li 1998: 464). Attention contains several psychological and physiological processes. Its functions include: (1) to receive external stimulations; (2) to analyze and cognize received stimulations; (3) to assign priorities to external stimulations received at the same time; (4) to focus concentration on one of the things; and (5) to arrange priorities and responses (such as memorizing something). All these processes are chained together instead of independent [5]. Children's attention would be influenced as long as one of the processes goes wrong.

3 Research Methods

3.1 Experiment

1. Subjects: First-grade students from the normal grouped classes of Ankeng Elementary School aged 6–8. 20 students were sampled from each of the 2

Table 1 Samples for the experiment

E-picture book	Tradition picture book

classes for between-group comparisons. There were both male students and female ones.
2. Duration: 2015/6/24 and 2015/6/26
3. Location: A classroom in Ankeng Elementary School
4. Samples for the experiment: One of the New York Times Best Children's Books 2011: I Want My Hat Back, in the forms of the e-picture book released by Children's Cultural Center, Ministry of Culture and the tradition picture book for the purpose of comparisons Table 1.

3.2 *Experiment Procedure*

1. Set up equipments for the experiment: cameras and EEG (attention);
2. Explain to the subjects about how the process of the experiment and ask them to sign the letter of consent with their parents' and teacher's approval;
3. Perform the experiment in two different classes with the subjects in class A reading the e-picture book and those in class B reading the traditional picture book;
4. Record the subjects' attention based on their brain waves;
5. Ask the subjects to answer the questions related to the story after the previous task is completed; and
6. Summarize and analyze the recorded data.

3.3 Statistical Analyses

3.3.1 Descriptive Statistics

1. Results of attention based on brain waves with the e-picture book and the traditional picture book.

3.3.2 Descriptive Statistics and Independent Sample Test

1. Whether there is a significant influence of the form of picture books on children's reading attention
2. Whether there is a significant influence of the form of picture books on children's correctness of answers to the questions related to the story.

4 Experiment Results

4.1 Descriptive Statistics

This study measured attention using EEG. The levels of attention included low, normal, and high and levels of relaxation included nervous, relaxed, very relaxed Table 2.

4.2 Results of Independent Sample Test

The result of the homogeneity test showed no significant difference ($P > 0.05$) and the result of the ANOVA showed a significant difference ($P < 0.05$*). Table 3 shows the items with a significant difference.

Table 2 The averages of levels of attention and relaxation

EEG	Form of picture book	N	Min.	Max.	Average	S.D.
Attention	Tradition picture book	20	10.00	88.00	44.3500	22.50912
	E-book picture book	20	13.00	89.00	41.9000	21.64766
Relaxation	Tradition picture book	20	22.00	93.00	51.0000	19.95521
	E-book picture book	20	19.00	92.00	51.4000	22.40630

Table 3 The test results regarding the influences of the forms of picture books on children's reading attention and story content

		Levene variance homogeneity test		T-test to compare means						
		F	Significance	T	d.f.	Significance (two-tailed)	Mean difference	Standard error	Lower bound	Upper bound
Attention	Using equal variance	11.608	0.002	−1.729	40	.091	−0.3809	0.2202	−0.82617	−0.0642
	Not using equal variance			−1.729	32.120	.093	−0.38095	0.22029	−0.82960	−0.06769
Story Content	Using equal variance	17.778	0.000	2.108	40	0.041*	0.28571	0.13553	0.01181	0.55962
	Not using equal variance			2.108	36.000	0.042*	0.28571	0.13553	0.01085	0.56057

4.3 Results of Observation

Traditional picture book	e-Picture book
• Children flipped through the pages based on their own reading speed • Some children would go back a few pages sometimes to confirm certain content information • Children read in silence • Children would use a finger to point at the word they were reading based on their reading speed • Some children read text first and then enjoy the illustrations later • Children sit up straight with the book placed on the desk in front of them and read flipped through it • A few children skimmed through their book quickly as they wanted to finish the experiment sooner • Children were rather nervous during the experiment	• Because the speed of the e-picture book could not be controlled by users, a few children attempted to pause the animation • A few children were rather impatient and asked questions such as "is it going to finish any time soon?" • Because iPads were used, some children sit and leaned against the back of their chair with a rather sluggish posture • Children were excited when see the iPads and were thus more relaxed • The animation of the picture book was rather long and children were easily distracted while watching it

5 Conclusion and Discussion

1. According to the EEG results, the attention level of the students reading the traditional picture book was higher than the e-picture book, and the students reading the traditional picture book could answer the questions more correctly.
2. The levels of relaxation between the students reading the picture book of two different forms were not significantly different.
3. The form of the picture book had a significant influence on children's understanding of the story content. Due to the short duration of the experiment, the form of the picture book had no significant influence on children's attention level.
4. It was found through observation that the students reading the e-picture book had no interaction with their iPad while reading. They could not concentrate and spent a rather longer time reading. Those reading the traditional picture book could control their reading speed as they turned the pages themselves. A few of them would sometimes go back a few pages to read the details more carefully.
5. According to the definition of attention proposed by a scholar, Fang-Chu Hsu, children can only focus on one single thing at a time. When they read an e-picture book with dynamic images and sounds, in their cognition, they have to make responses or arrange priorities. For small children, it would be difficult to focus on the story and the plot of the book.

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Portable on Orbit Printer 3D: 1st European Additive Manufacturing Machine on International Space Station

Giorgio Musso, Giuseppe Lentini, Luca Enrietti, Costantino Volpe, Elisa Paola Ambrosio, Massimo Lorusso, Gabriele Mascetti and Giovanni Valentini

Abstract Additive Manufacturing (AM) technologies represent a solution for enabling astronauts to manufacture parts in situ, as needed, starting from feedstock material. The importance of these capabilities are particularly evident in manned space exploration missions, e.g. on human Mars missions, for which cargo capacity is paramount key factor in order to supply the astronauts with everything they may need during the mission, but at the same time is a severely constrained resource. Also, AM technologies enhance freedom of shape optimization for mass savings, compared to conventional manufacturing processes, thus helping in reducing overall mass at launch. The capability to make parts in space, during the mission, would allow a dramatic reduction of the mass transported to the destination site and would also help astronauts in solving any unexpected problems that may occur during a space mission: if the Apollo had been equipped with a 3d printer, the filter housing with a suitable interface could have been easily manufactured by astronauts using Additive Manufacturing technology. The Portable on-Orbit Printer 3D represents the first European additive manufacturing experiment in space. The Printer implements the Fused Deposition Modelling (FDM) process for the fabrication of parts using PLA, a biocompatible thermoplastic polymer. The objective of the experiment is to validate the 3D printing technology in microgravity and to pave the way for an Italian and European development of the additive manufacturing technology on board the ISS and, more in general, in space. This paper will present the results of the demonstration activities performed with "Portable on-Orbit Printer 3D" while its permanence on board the International Space Station. It also presents

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the analysis performed on the on orbit "printed" part, in comparison with the same part "printed" on ground.

Keywords ISS-International space station · Additive manufacturing · Portable on-Orbit printer 3D · FDM-Fused deposition modeling

1 Introduction

Space systems working on orbit around Earth (today means on ISS, in the next future probably on Cis-lunar orbit) need regular resupply from ground with very high delivery/launch costs estimated in the order of thousand dollars per kilo (http://www.nasa.gov/centers/marshall/news/background/facts/astp.html_prt.htm).

In case of space exploration mission, e.g. a mission to Mars, where no resupply services could be envisaged, the astronauts would have to carry all the needed items with them.

The reduction of the space mission costs related to logistics and launch, one of the main goals of space agencies, and it can be achieved by improving the space launch vehicles and decreasing mass and volume of the items to launch.

The approaches to follow for minimizing impacts to total mission mass, stowage volume requirements, and cost can tentatively proceed through the following actions:

- maximize commonality of hardware at all levels: increased commonality reduces the number of unique spares that must be carried and increases the opportunities for exchange of hardware as the need arises.
- pursue repair at the lowest possible level: typically, when a complex hardware assembly fails, the failure is attributable to a very limited number of small internal components rather than massive failure of the assembly at a gross level. The replacement of single components instead of the entire equipment represents the attempt of the designers to overtake the ORU concept (on-orbit replacement unit) on which the maintenance of the ISS has been based so far.
- provide the capability to manufacture replacement components in situ as required. A very significant advantage of this capability is that it reduces the need to carry specific, unique replacement components and selected parts are generated as needed from feedstock material. Furthermore, in situ fabrication of replacement components reduces the chance that a required component will not be available and, also, reduces the chance that components are carried that will not be needed [1]. The advantages deriving from having an in situ manufacturing facility should allow to reduce the mass and volume of spare parts to be resupplied or, in case of space exploration, to solve one of the problems deriving from the impossibility to resupply.

Additive Manufacturing (AM) technologies represent a solution for enabling astronauts to manufacture parts in situ, as needed, starting from feedstock material. Also, AM technologies provide the capability to produce complex parts as well as geometrical complex shape, not otherwise obtainable by traditional subtractive manufacturing technologies. Although many individual assemblies have quite simple configurations (e.g. washers, seals), many others are equally complex, composed by many parts to be assembled in the post manufacturing phase. Any AM process is capable of producing geometrically complex components that can be manufactured without the need of post manufacturing assembly or reworking.

Another advantage of manufacturing parts in situ, since parts are built and delivered only when needed, it is that is not necessary to maintain a large inventory. This aspect becomes important when parts are manufactured in small production runs and when the availability of the parts has to be ensured for long time. The inventory reduction is a significant cost savings, because whether it is kept at the supplier or the end user, it is still a cost that must be accounted for. Further, when changes are made, the inventory becomes scrap or, at the very least, the parts will have to be reworked.

2 Experiment and Hardware Description

2.1 Experiment Description

The goal of the investigation is to help demonstrate that Fused Deposition Modeling (FDM) or Fused Filament Fabrication (FFF) process, which is well established for commercial applications in both prototyping and manufacturing fields, is viable for making plastic objects on-board the ISS.

Space application of the available AM technologies is dependent on the technology itself and their compatibility with the space environments. Liquid based and Powder based AM technologies are g-sensitive while the Solid based ones (like FDM) can theoretically be compatible with the microgravity environment.

The experiment focuses on some specific aspects of FDM technology transfer, namely the compatibility with ISS manned environment in terms of contamination potential and the optimization of the process aimed at making it essentially independent from the gravity vector orientation on ground.

The high compatibility with the confined ISS environment was achieved by adopting an extremely “clean” polymer, the polylactic acid, PLA, combined with a suitable isolation of the build volume aimed at protecting the ISS atmosphere from hazardous solid phase contamination.

Concerning the other objective, the minimized sensitivity of the additive build process to the orientation of the printer relative to gravity vector is a way to achieving the best results reproducibility when the gravity magnitude becomes negligible, as it is on ISS.

The experiment nominally consists in performing FDM printing of a single object in the ISS microgravity environment. The full payload is thereafter brought to ground, where the object made is examined and compared to the object built on ground to investigate the differences with respect to the most significant aspects of the manufacturing quality.

Even though the payload is not designed and certified to allow the crew to remove the object and to perform the setup for another print run, such additional print run is technically feasible and the filament stock is sufficient to perform the manufacturing of at least 10 objects of the same size.

The object geometry was selected based on the following criteria:

1. To be suited to highlight differences between 1 g and microgravity FDM
2. To be as close as possible to a shape having a potential practical use onboard the ISS
3. To be compatible with the over-temperature controls and inhibits implemented in the payload in terms of print phase duration
4. To be compatible with the 50 × 50 × 45 mm build volume of the printer.

Several shapes were tested for manufacturing and eventually the selection short list included a hexagonal socket, a small box, a bend pipe Joiner, and a Stax finger split Fig. 1.

The object chosen for being produced during the nominal experimental run is the Y pipe joiner.

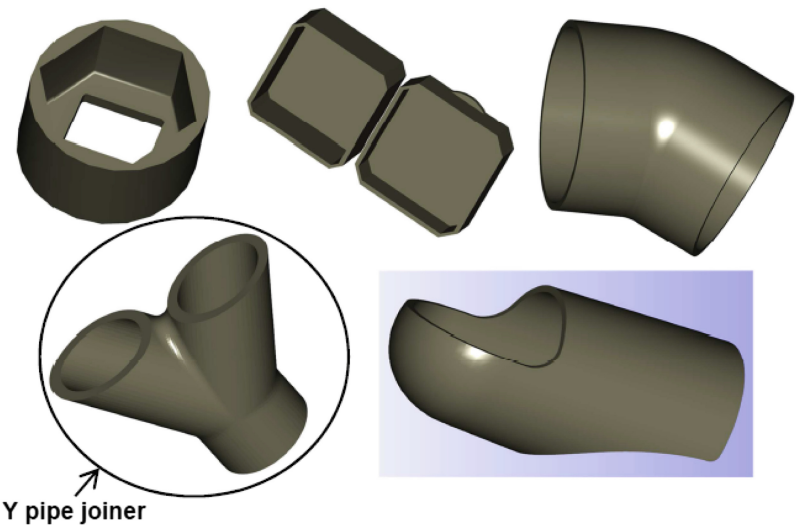

Fig. 1 Short list for selection of object to be manufactured in space

2.2 Payload Description

The P3DP (Portable on Board 3D Printer) is a 3D printing unit enclosed inside its external 250 mm-side cubic case having a total mass of 5.4 kg. The payload implements the Fused Deposition Modeling (FDM) or Fused Filament Fabrication (FFF) process, well established for industrial applications in both prototyping and manufacturing fields to make parts out of thermoplastic polymers. The P3DP is conceived to be independent from the interfaces provided by ISS class I facilities to the most degree. It is a self-contained compact "central aisle payload" interfacing uniquely with electric power source available for portable loads and using only a hand-held onboard camera with HD live downlink, to film the forming process through the transparent observation window and allow assistance from ground.

P3DP uses COTS components as far as possible, mostly with standard industrial quality level. This choice was made to cope with project constraints, also in consideration of the extremely short nominal operation lifetime. However a considerable set of features were designed and implemented in order to make sure that the payload is compliant with safety requirements, in particular to allow the management of potential failures.

The P3DP is composed of four subsystems: the enclosure, the extrusion system, the positioning system and the electronic unit.

2.3 Enclosure

The enclosure is a vented structural housing dedicated to protect the FDM machine and the electronics and to isolate with the appropriate containment level the habitable environment from potentially hazardous released substances. Transparent window and internal illumination allow observation of fabrication process and filtered venting openings allow for internal-external pressure equalization.

2.4 Extrusion System

Extrusion head and material filament feeding device, dedicated to produce the melted polymer filament at the required flow rate and temperature. Includes a cartridge for storing and dispensing feedstock material in the shape of PLA filament.

2.5 Positioning System

A 3 axis Cartesian positioning system, dedicated to realize the relative motion between the extrusion nozzle and the deposition plate: in plane for layer deposition and orthogonal for layer to layer stepping.

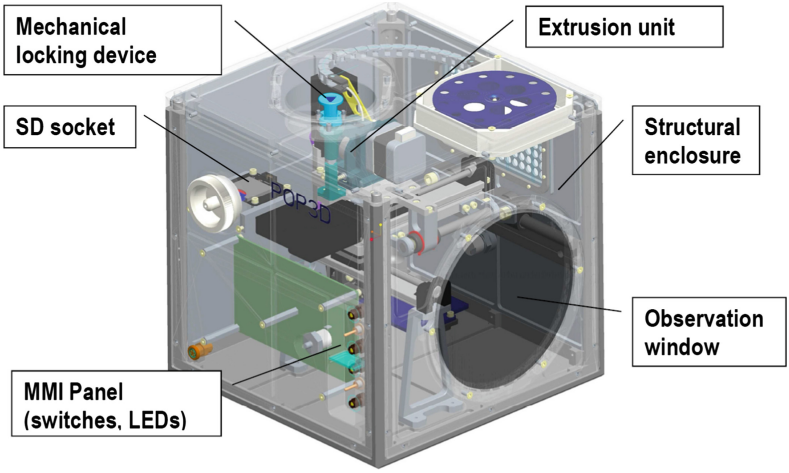

Fig. 2 P3DP—overall architecture

2.6 *Electronic Unit and Firmware*

Consists of an individual board, on which are implemented the control microcircuit, the motor driving electronics and the protection circuitry. The control microcircuit, hosts the firmware, which manages the FDM fabrication process and performs all other software based functions such as failure detection and isolation, safety switches, crew user interface management, self-diagnostic test Fig. 2.

2.7 *Interfaces*

Most of P3DP interfaces are grouped on a dedicated panel, named HMI panel, which is mounted on one of the side faces of the enclosure.

The following interface elements on the HMI panel are for the crew to operate the printer and monitor the automated processes: power switch and operation start switch (both three positions manual switches) plus a set of 4 visual indication LEDs (see picture below) Fig. 3.

Another hardware interface on the HMI panel is dedicated to an off nominal operation task, is a Secure Digital card socket, that can be used to perform a change of the CAM (Computer Aided Manufacturing) file initially residing on the SD mass memory support in the frame of a potential off-nominal recovery activity.

Another crew interface is the knob for release of mechanical locking device, located on the top side panel of the payload. The mechanical locking device is implemented to prevent the extruder from moving along its 2 translational Degrees Of Freedom under the action of transport (ground transport and launch) accelerations.

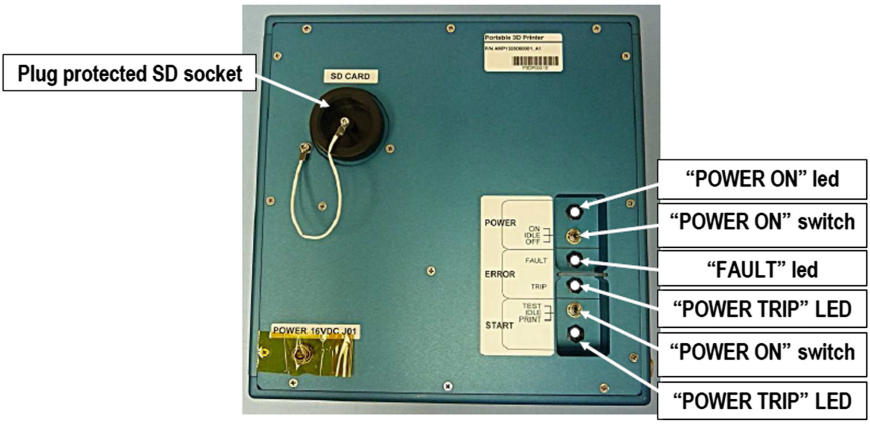

Fig. 3 HMI—interface panel

The locking device actuation (release) has to be performed manually by the crew. Locking release operation consists of pulling up, rotating 90° and release down the dedicated knob Fig. 4.

The HMI panel and locking mechanism actuation design have been carefully developed to meet all NASA HFE requirements. In particular controls sizing and spacing requirements drove the design of toggle switches layout on HMI panel: minimum separation distance between adjacent (from center to center) is 19 mm; and optimal distance is 50 mm.

Accidental actuation of the manual command switches controls is then prevented by the location in a recessed area and by separating the recessed volumes of the two switches with a transparent (polycarbonate) partition element, so that LEDs for Fault indication and Power trip indication remain visible from any view angle.

In addition the dimensions of the recessed area opening where chosen such that the fingers accessibility to the toggle switched is ensured Fig. 5.

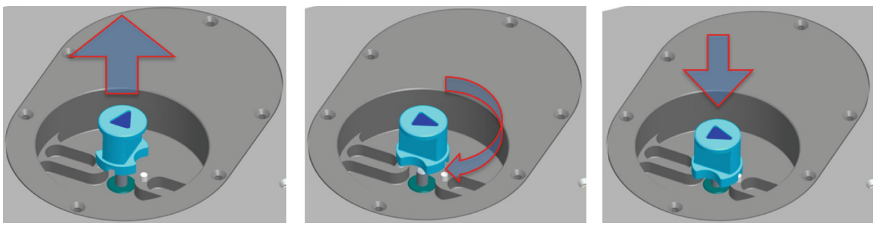

Fig. 4 Phases of locking release

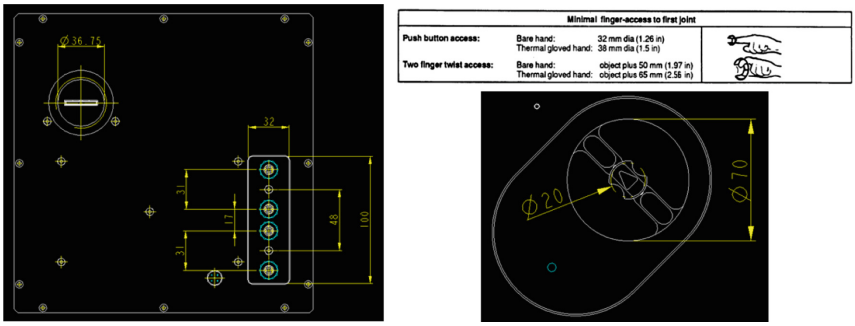

Fig. 5 HMI panel and locking mechanism actuation layout

Similarly, also the knob for locking mechanism actuation is located in a recessed cup shaped volume, and knob size, shape and surrounding clearance distances were submitted to NASA HFE authority and approved.

Indication LEDs colors were also chosen based on NASA requirements for ISS harmonization.

2.8 Thermal Design

The P3DP draws electrical energy from ISS power resource (the maximum rated power does not exceed 70 W) and uses it to feed electric motors (actuators), heater, control electronics and an illumination device. The entire amount of electrical energy supplied to the payload is eventually converted into heat, so that payload external surfaces, initially in equilibrium with cabin air temperature, are subject to increase their temperature in a thermal warming transient that starts when P3DP operations phase is started.

The payload must meet the following two classes of thermal requirements/constraints: Crew Safety driven and Payload Functionality driven. The Crew safety requirement states that external temperature of payload surfaces shall not exceed 45 °C at any point.

The thermal requirements/constraints were met by limiting the duration of the operations phase, which keeps the thermal transient evolution far from reaching the critical threshold temperatures, thus avoiding the implementation of an active thermal management system.

In order to prevent over-temperature anomalies for enclosure external temperature (touch temperature potential hazard) and for the extruder hot end temperature, dedicated protection and inhibits are implemented.

Two separate controls are implemented, one on the extruder and one on the enclosure walls. For the touch temperature at the container there are two fully redundant controls. One is a thermal switch A, in series on the power line (the 16

VDC power coming from the power brick). The second control is based on a temperature sensor whose signal is conditioned by dedicated electronics and processed in a comparator which can eventually trigger the circuit breaker wired in series on the power line. Both sensing devices are placed at the hot spot, as identified by thermal analysis. One additional thermal switch B, located on the HMI panel, behind the electronic board is wired in series to thermal switch A, aimed at controlling potential overtemperature on that area too.

For the over-temperature control of the extruder hot end two (for redundancy) additional temperature sensors monitor the temperature at the hottest area of the extruder (nozzle and surrounding block) and are hard-wired to the comparator which can trigger the circuit breaker.

2.9 Structural Design

P3DP is designed to guarantee structural integrity (e.g. no fractures and no permanent deformations), in particular containment function, with positive margins of safety after exposure to all loading conditions specified for ground handling, launch/return and on orbit operations environments

2.10 Contamination Control

The P3DP performs extrusion of a thermoplastic polymer (PLA, Polylactic acid) according to FDM technique. The polymer is melted and extruded in a continuous fashion, producing a circular section filament about 0,4 mm thick with an average flow rate ranging from 1 to 10 mm^3/s. The extrusion temperature for PLA ranges between 160 and 180 °C and once extruded, the filament solidifies and cools down in stirred air at 23°÷ 40 °C. During the extrusion two types of contaminant emissions are expected: gaseous emission and solid debris.

2.10.1 Ad Hoc Offgassing Test for PLA Extrusion

In order to assess the compliance of PLA extrusion to the Toxicity Requirements for the use on-board the ISS, it was necessary to perform a dedicated offgassing test, aimed at quantifying the contribution of PLA processing to the overall emission of toxic substances released by the payload.

The standard Offgassing Test according to the ECSS-Q-ST-70-29C procedure (NASA-STD-6001) would not be representative of the real offgassing phenomenon which develops when the P3DP is operated and which has to be measured. According to that standard test procedure the PLA would be just heated at 50 °C for

72 h, as bulk solid material rather than being heated to melting temperature and extruded in a thin filament of molten polymer rapidly solidified and cooled.

To determine the VOC release during an actual extrusion process, a dedicated test set-up and procedure have been conceived to accurately mimic the P3DP extrusion process, and to reproduce the physical parameters driving the offgassing phenomenon, i.e. the actual residence time of the polymer at higher temperatures as well as the actual ratio (exposed surface to air/mass).

The test set-up foresees to use a sealed Flask into which the polymer is extruded by means of a representative Breadboard Extruder. At the end of the defined extrusion process, the atmosphere inside the flask is sampled and analyzed via GC-MS for qualitative and quantitative determination of the contaminants released during the process.

The contaminants identified were below their respective SMAC (Spacecaaft Maximum Allowable Concentration) values. The toxicity hazard index, T, for the contaminants off-gassed from PLA-90 material during the extrusion process was found to be 2.3E−05. In practical terms the result of the test indicates that the contribution of the PLA processing to the overall Toxic Hazard Index of P3DP payload is essentially not significant.

2.10.2 Unintentional Generation of Solid Debris and of Fine/Ultrafine Particulates

It cannot be altogether excluded that during the FDM fabrication small fragments of solid PLA can be released, possibly due to the grip and local tear-off forces exerted on the surface of the raw PLA filament by the feeding mechanism.

In addition to the macroscopic debris potentially released, published studies suggest that FDM processing of PLA have a production of particulate matter at micro and nano size scale (fine and ultrafine) which is judged by NASA experts to represent a physical (not chemical) hazard to the crew.

Due to the need to control the above hazards, the design of P3DP is such that the FDM machine is contained inside a vented container which guarantees the retention of any sort of solid debris with a filtration of HEPA quality level.

3 Experiment Execution

The 2nd of February 2016 the Printer has been activated at around 13:00 GMT by the astronaut Scott Kelly.

The astronaut on-orbit operation consisted in the set-up of the printer on a rack front position inside US Lab, pointing the video camera configured for live downlink to the deposition plate to allow on ground operator to monitor the fabrication process Fig. 6.

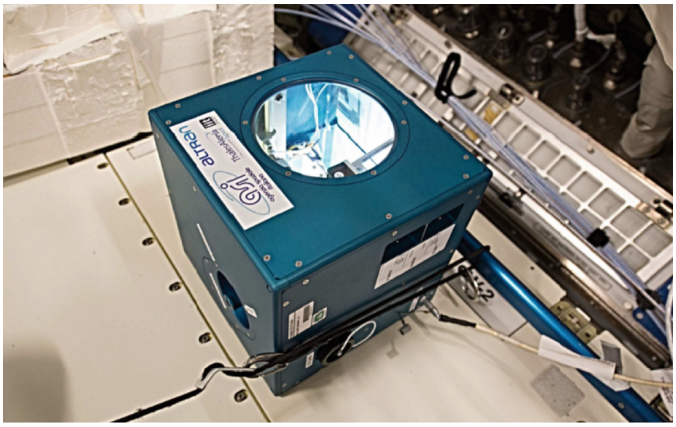

Fig. 6 The printer on rack front position inside US Lab

The technology demonstration started with the Built-In Test that was activated as first step. Once the printer finished Kelly was ready to start the fabrication of the test object by turning the switch to "PRINT".

The whole fabrication took about 50 min. and successfully ended without errors.

The only issue encountered was part of the setup (planned and performed under NASA responsibility), due to a missing power cable that was expected to be available as part of the Station equipment.

The delay was significant, however after a workaround solution the technology demonstration was successfully completed.

After the test execution the Portable on-Orbit Printer 3D was packed and stowed on board waiting for its return to Earth (with Space X8 return mission) where the fabricated object will be removed from the device and tested Fig. 7.

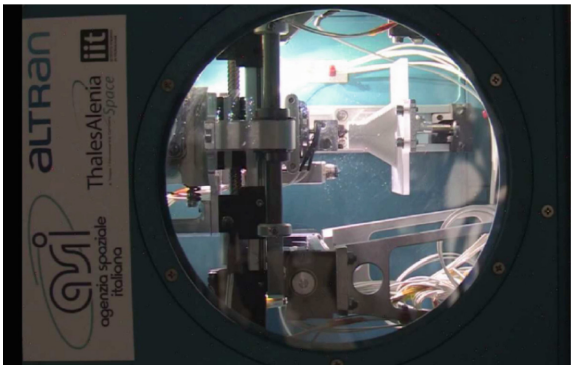

Fig. 7 Fabrication of the test object

4 Ground Test

To verify the possibility to realize in microgravity environments parts with the same properties of the ones produced on Earth, different analysis and tests will be performed on the orbit "printed" part, and on a similar part "printed" on ground.

The roughness on the surface of both samples will be measured with the use of Mahr Perthometer M1, using the average value of the ordinates from centerline, defined as Ra, theoretically derived as the arithmetic average value of departure of the profile from the mean line along a sampling length.

The surfaces of both samples will be also digitized by means of a 3D optical scanner, Gom's Atos Compact Scan 2 M, in order to compare them with the original CAD models. The ATOS Compact Scan provides accurate scans with detailed versatile resolution at high speeds. It is a type of coordinate measuring machine (CMM) that utilizes non-contact structured blue light technology to capture millions of precise points in a single scan.

The surface and the microstructure of both the parts will be also analyzed by means of a Leica LAS EZ4 stereomicroscope to identify defects on the surface and to evaluate possible differences in the deposition process. In a similar way the surface will be investigated trough Scanning Electron Microscopy (LEICA 1450MP) in low vacuum. In low vacuum condition is possible observe the parts without metallization, in this way the samples surfaces will be no subjected to any modifications.

The density of the samples will be measured based on Archimede's principles, according to standard ASTM B962-14. The measurements will be repeated three times per sample, using a ORMA BCA 200S balance (accuracy ± 0.1 mg).

The microstructure of the prototype will be also investigated in a not destructive manner by means of a micro-computed tomography, using a desktop μ-CT scanner (SkyScan 1174, Bruker). The scanner will be set at a voltage of 50 kV and a current of 800 μA and, depending on the morphology and size of the propotype, the sample will be scanned with the maximum resolution (down to a 6.5 μm pixel size). The exposure time per projection will be set according to the X-ray absorption of the sample in order to achieve the optimal quality of the shadow image. The sample shadow images will be reconstructed using the Nrecon software in order to obtain a 3D model of the sample. Eventual surface defects, porosity and excessive roughness will be observed. Using the CtAn software and setting an optimal grey threshold, the porosity of the sample will be identified and quantitatively evaluated on the reconstructed volume of interest.

Mechanical properties, in terms of nanohardness and elastic modulus, will be carried out using the NanoIndenter TI950 (Hysitron) equipped with in situ Scanning Probe Microscopy (SPM) imaging capability.

The most common method to analyze the hardness and modulus values from an indentation curve is the Oliver-Pharr method [2]. The tests are performed by applying and removing a controlled load to the specimens using a geometrically well-defined probe, producing traditional force versus displacement curves. The

analysis of these curves provide information regarding the mechanical properties of the sample.

The used indenter will be a cono-spherical probe, that is a conical shaped probe with a spherical end with an included angle of 90° and a radius of 1 μm.

5 Conclusions

The achievements of the "Portable on orbit Printer 3D experiment" will pave the way for a mature application of the selected additive manufacturing technology on board of the ISS, and further developments for direct manufacturing in Space.

The on-orbit investigation is aimed to provide information on how the material is deposed in microgravity (surface roughness, density and porosity of the deposed material, surface and internal defects, mechanical properties).

The main advantage derived from the use of additive manufacturing technology in space missions is a significant improvement of the maintenance logistics. Manufacturing items on-orbit as required can sizably reduce the amount of spares needed on board. Raw materials required by these manufacturing processes can be stowed more efficiently than final items and the benefit provided by this technology can be quantified in terms of volume and mass savings.

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Effects of Arctic Conditions on Human Performance

Anecito Reyes Balindres, Rupesh Kumar and Tore Markeset

Abstract Modern technologies are used to create competitive performance in industry, and highly specialized personnel are often needed to operate and maintain the technology. However, both the technology and the personnel are influenced by the environment in which the technologies are operated. In this paper we study how human performance is influenced by an Arctic environment in conjunction with a remote location. Based on a literature study, we map Arctic factors and study how they affect human performance in remote locations. The results show that operational and maintenance personnel may be significantly affected by the Arctic conditions. If not taken into consideration during the design phase, human and organizational performance may be significantly affected. Examples are discussed in relation to petroleum production in Arctic locations north of Norway.

Keywords Human performance · Human factors · Arctic conditions

1 Introduction

Modern production facilities depend on highly competent and skilled personnel to operate and maintain advanced and complex machines. To achieve high performance, the machines, the personnel and the organization need to perform well. If such a production facility is to be operated in a harsh, cold and remote environment like the Arctic, one should expect that the performance may be affected by environmental factors [1].

Humans are the most valuable asset, as the total operation relies mainly on them, and human performance is the determinant of any organization's overall perfor-

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mance. The performance of workers also relies on good management. Therefore there must be an appropriate system for performing tasks. The need for humans to stay fit and safe in the workplace must be predetermined. Managers must therefore consider the human workforce: what will keep them warm, tools and processes that will make it easy for them to work, and a good and suitable workplace.

The Arctic Circle is an imaginary line located at 66º30′N latitude and, as a guide, defines the southernmost part of the Arctic. North of this line, the Arctic area includes the Arctic Ocean, Greenland, Baffin Island, Russia, Alaska and Canada. The climate in the Barents Sea is described as harsh and unpredictable [2]; large parts of it are frozen in winter, and only the southernmost part, towards the coasts of North Norway and Russia, remains ice-free throughout the year. Temperatures may drop to −30 to 40 ºC and can easily reach lows of −50 ºC in the higher latitudes. In the mid-winter months the sun never rises above the horizon, whilst in the summer months the daily 24 h of sunlight melts the ice and topsoil frost. The Arctic environmental factors thus include low temperature, wind, icing and frost, snowdrift and darkness.

The extreme weather conditions and the remoteness present a large challenge to the manufacturing and service industries and are a major barrier to any kind of operation in the isolated areas of the Arctic. The remoteness of these regions influences the operation and may cause difficulties for communication and navigation. Modern production processes demand systems capable of constant and substantial exchange information. If the communication and information systems are not working properly, major operational delays could result. Furthermore, the unpredictable weather conditions and remote distances may cause delays in the transportation of materials and goods, and supplies in general, as well as of personnel for operation and maintenance activities.

The design of the equipment and production facilities has to be given special consideration with respect to maintenance, operations and support activities [2]. In addition, the human body must fit physically and mentally with the kind of work to be performed and the cold working environment in the Arctic. The equipment and circumstances that employees are working with (e.g. machines, tools, working area, supplies, etc.) will determine the performance of the organization and the production facility as a whole.

Working in a demanding type of environment like the Arctic is never easy, and operations will be difficult to perform. Remoteness and low temperatures, in combination with wind and darkness, are the major factors that will affect the personnel's ability to perform tasks and activities correctly within the allotted time. Workers who perform daily routine work outdoors during the harsh winter experience decreased performance and increased discomfort [3]. Moreover, these factors will cause physical and mental stress and ultimately negatively affect the health of a person, most likely reducing the work effectiveness and thus affecting the overall organizational performance.

In Norway, oil companies have started to produce oil and gas in the southwestern Barents Sea, north of Norway and Russia; they have also begun the exploration of oil and gas fields further north towards the ice edge. The Barents Sea

is predicted to become a major gas and oil supplier in the future [4]. Hence, it is of interest to study how Arctic conditions affect human operational and maintenance personnel, and how these effects can be mitigated through integration into the design of the production facilities and in the planning of Arctic operational and maintenance activities.

Against this background and based on a literature review, in this paper we will firstly discuss human factors in general and thereafter discuss how Arctic factors may affect the performance of humans working in Arctic conditions.

2 Human Factors

The International Ergonomics Association states that "Human factors is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and other methods to design in order to optimize human well-being and overall system performance" [5]. Human factors are concerned with both the anthropological and biological features of humans.

Often the performance of machines is dependent on the performance of the operating and maintenance personnel. If they lack training in how to operate or maintain the machines, the performance will be affected. Thus, in the conceptualization of the process of carrying out the desired output of the operation, one needs to consider how humans are going to operate the machine, and identify which factors influence human performance.

Blanchard et al. [6] detailed the following human factors to consider in human engineering:

- Anthropometric factor—deals with the measurements of the human body such as stature, sitting height, shoulder height, eye height, hand length, forward reach, wrist circumference, force, weight
- Human sensory factor—human sight, hearing, smell, touch sensors of human
- Physiological factor—produces stress due to environmental factors and conditions, such as the cold climate, which will reduce the sensory capacities
- Psychological factor—concerns the capacity of the mind to think and respond.

3 The Effect of Arctic Conditions on Human Performance

Holmer [7] defines a cold environment as an environment in which greater than normal heat losses are anticipated and compensatory thermoregulatory actions are required. Extremely cold temperatures can lead to light to severe health problems. Simple errors may lead to more severe consequences such as natural responses becoming slower due to increased energy consumption, and the constant distraction

of the condition and welfare of the team. Both physical and cognitive ergonomics must be reassessed and thought of differently.

The human body needs to have a normal body temperature to survive and work efficiently in cold temperatures. For example, it is not well known amongst engineers that cold has detrimental effects on cognitive and physical capabilities [8, 9]. The loss of body heat is uncomfortable and quickly affects work efficiency. Exposure to cold for short periods of time can produce serious effects, especially when the temperatures are below 10 °C [10]. The hands are the most probable locations for cold stress related to thermal discomfort and cold injuries, compared to the other parts of the body [11]. Moreover, exposure to cold will cause the metabolic rate of a person to insufficiently maintain the neutral heat balance. The body will cool down, which leads to a reduction in blood supply to the extremities, which, in the worst case, can result in physical amputation [12].

Physically, a person can be weak, unable to perform tasks, and may not produce the desired task outcome. In this case, the operation will be delayed, causing insufficient production. Mentally, negative effects to the body can cause disorientation. A person may not be able to think and concentrate in the usual way, which is likely to affect the tasks executed. Ultimately, this may cause accidents and breakdown of the system.

Furthermore, much work has focused on methods to reduce the consequences of unwanted incidences, and efforts to ensure the implementation of proper consequence reducing measures are important [13]. Projects in this area will have high demands on the design of systems [14]; thus there is a need for a good organizational basis. Machinery and equipment are amongst the factors involved in carrying out cost-effective organizational operations. Water, and the freezing of water to ice, can affect the construction of facilities, and the low temperatures will affect the properties of materials being used. Decision making regarding both cost- and time-effectiveness is a crucial challenge to managers. For example, working in fair weather conditions is different from working in cold and extreme weather conditions. Kumar et al. [15] stressed that “due to the complexity of machine systems, and the environment conditions, it is often difficult for maintenance and service personnel to physically access all the system components, which makes it hard to perform the tasks within a prescribed period of time”. The cold environment may cause lead to psychological and physical stresses, which in turn may lead to accidents, injuries and long-term sickness. Generally, working under extreme weather conditions is a serious matter that should be taken into consideration.

As the human body has limitations regarding adapting body temperature to a cold environment such as that of the Arctic, these factors are of direct concern. When the core body temperature begins to fall below the normal values, hypothermia starts [16], and extremely cold conditions adversely affect mental skills and cognition [17]. Thus, operations and cold temperatures coupled with physical distracters such as noise or moving environments will affect the quality of perception, memory and reasoning, further increasing the risk of error in decision-making. If the human body is exposed above the maximum sustainability, then it will cause injuries, sickness and maybe accidents.

The effects of being exposed to cold temperatures may be summarized as follows [15]:

- Reduced manual skills, dexterity, coordination and accuracy with impact on productivity and safety
- Increased risk of musculoskeletal injuries from stiffness of muscles and joints and reduced peripheral circulation
- Increased risk of accidents from reduced alertness, manual dexterity and coordination
- Discomfort from cold stiff hands and feet, runny nose and shivering
- Impaired ability to perceive cold, cuts, pain and heat
- Reduced decision-making ability

To work in Arctic conditions, one needs suitable clothing to keep the human body protected to low temperatures. This clothing consists of several protective material layers, and protection efficiency depends on insulation capacity as well as proper coverage [18]. The European Committee for Standardization (CEN) developed a European standard concerning personal protective clothing and gloves against cold, as stressed by [18].

Another important factor to consider is the illumination. This is the light available for operation and maintenance tasks such as visual inspection tasks [15]. Darkness reduces the efficiency of work; the period of winter darkness depends on the latitude north of the Arctic Circle and the relative position of the sun, the earth and the location [19].

The maintainability of a workplace located in the Arctic must be carefully studied and designed because workers need to wear clothing which is essentially heavy and thus their movement is affected [20]. In addition, the workplace must be designed with ample space for workers to take a break from exposure and must have proper heating.

4 Concluding Remarks

Arctic conditions present serious challenges to overcome. They will not only affect human performance but also the overall organizational performance. To reduce machinery breakdown and downtime, and to achieve the desired production performance goals, human factors need to be considered as an influence on the planning and decision-making processes.

Imrhan [21] proposed guidelines for (1) visual access; (2) anthropometric access; (3) design features for physical access; and (4) task simplification. Visual access is important to reduce the effect of winter darkness. Proper illumination needs to be designed in the operational workplace on the production facilities. Anthropometric access concerns the proper clothing to protect against the cold. Workers in cold environments require appropriate clothing, and the quality of the clothes and shoes

must be considered (e.g. lighter clothing and allowing the sense of touch). Physical access is an important design feature of a production facility. Machines and equipment should be properly placed in the correct locations, allowing the employees to move easily around the working area, and providing ample space for them to rest and regain body heat. Task simplification helps to achieve a high level of performance, and tasks should be designed to make it easy for people to conduct the work.

These guidelines are essential to aid those designing machines to consider human factors. Furthermore, it is crucial to consider human factors as early as possible in the design process to reduce stress, accidents, sickness and machine breakdown. Hence, proper integration of human factors in the design and planning will increase not only human performance but also the organizational performance.

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Multinomial Logistic Regression Model by Stepwise Method for Predicting Subjective Drowsiness Using Performance and Behavioral Measures

Atsuo Murata, Yukio Ohta and Makoto Moriwaka

Abstract The aim of this study was to explore the effectiveness of physiological and behavioral evaluation measures for predicting a drivers' subjective drowsiness based on a multinomial logistic regression model. The participants were required to steer a steering wheel and keep their vehicle to the centerline as much as they could, and to maintain the distance between their own car and a preceding car properly as much as possible using a brake or an accelerator. A number of measures were recorded during a simulated driving task, and the participants were required to report subjective drowsiness once every minute. EEG (electroencephalography), heart rate variability (*RRV3*), and blink frequency were the physiological measures recorded. Meanwhile, behavioral measures included neck bending angle (horizontal and vertical), back pressure, foot pressure, and tracking error in a driving simulator task. Drowsy states were predicted via a multinomial logistic regression model. Physiological and behavioral measures were independent variables in the regression model and equated to the dependent variable: subjective evaluation of drowsiness. The stepwise method was adopted for the estimation of parameters of multinomial logistic regression model. The interval used for attaining the highest prediction accuracy was a 100 s interval between 20 and 120 s before the prediction. This approach clarified that the parameters finally appeared in the multinomial logistic regression model were different among participants, which indicated that the optimal structure of the model for predicting subjective drowsiness should be different among participants.

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1 Introduction

Bowman et al. [1] stated that approximately 30 % of crashes were caused by drowsiness. The development of a drowsiness detection system would be effective for the prevention of drowsy driving that becomes a potential risk factor of crashes. Understanding the gross tendency of reduced arousal level alone is insufficient to develop such a system. A more accurate prediction of the point in time when severe drowsiness occurs and potentially leads to higher risk of crash must be conducted.

McDonald et al. [2] showed that the steering wheel angle was effective for predicting drowsiness-related lane-departures. Hanowski et al. [3] assessed drowsiness using an eye-closure measure and lane deviation performance, and showed that a multi-metric assessment system was more robust and effective than a single-metric assessment system using only an eye-closure measurement. Although succeeded in assessing or categorizing drowsy levels, these studies did not attempt to predict in advance the point in time with a higher risk of crash.

Murata et al. [4] applied Bayesian theory and proposed a method to evaluate the arousal level using EEG, HRV, and a tracking error during a simulated driving task. However, this study did not attempt to predict the arousal level. Murata et al. [5, 6] applied a logistic regression model to mainly physiological measures such as EEG, ECG, or EOG (Electroocurography) in order to predict the arousal level (the subjective drowsiness), and attained a prediction accuracy of about 85 %. Samiee et al. [7] evaluated the arousal level classified as alert or drowsy judged by Karolinska Sleepiness Scale (Åkerstedt and Gillberg [8]) using vehicle dynamic data such as the vehicle longitudinal position, the vehicle lateral position, and the duration of eye closure. They indicated that the proposed method could differentiate between alert and drowsy states with an accuracy of more than 87.78 %.

Murata et al. [9, 10, 11] used behavioral measures such as tracking error in a simulated driving task, and back and foot pressure, and demonstrated that behavioral measures are as effective as physiological measures. These studies also attained moderately high prediction accuracy.

An attempt was made to predict the subjective drowsiness using physiological and behavioral measures. EEG, heart rate variability (*RRV3*), and blink frequency were the physiological measures. Behavioral measures included neck bending angles (horizontal and vertical), back pressure, foot pressure, and a tracking error in a driving simulator task. Subjective drowsiness scores were predicted using a multinomial logistic regression model. Prediction accuracy will be discussed with regard to the two primary research questions. First, a multinomial logistic regression modeling of the psychological rating on drowsiness was conducted using the

three physiological and the five behavioral measures stated above. Prediction accuracy was discussed based on how it increases depending on the length of the data window used for the predicting the psychological rating on drowsiness. Second, using the identified data analysis interval (length of the data window), the prediction accuracy of the prediction model (multinomial logistic regression model) obtained by a stepwise method were discussed. On the basis of the results, some implications were given for the development of drowsiness prediction system.

2 Method

2.1 Participants

Eight healthy male undergraduate students from 21 to 23 years old took part in the experiment. The visual acuity of the participants in both young and older groups was matched and more than 20/20. They had no orthopedic or neurological diseases. All provide the experimenter with informed consent on the participation to the experiment. They were required to stay up all night and visit the laboratory. Under such a physical condition of the participant, the following experiment was carried out. As a control, the measurements were also carried out when the participant is under highly arousal state.

2.2 Apparatus

Electroencephalography (EEG) led from O1 and O2, Electrocardiography (ECG) led from V5 and Electrooculography (EOG) were acquired with A/D instrument PowerLab8/30 and bio-amplifier ML132. EEG, ECG, and EOG were sampled with a sampling frequency of 1 kHz. Goniometers (SG65, Biometrics Ltd) for measuring angles were attached to the back of a neck to measure its vertical and horizontal bend angles of a neck. Eight pressure sensors (OctSense, Nitta) were attached to the backrest of the driving seat for measuring the back pressure. Eight pressure sensors (OctSense, Nitta) were attached to the inner sole of a shoe for measuring the foot pressure.

2.3 Task

The participants sat on an automobile seat, and were required to carry out a simulated driving task. For both conditions (low arousal and high arousal conditions), the participants were required to carry out a simulated driving task. The participants were required to steer a steering wheel and keep their vehicle to the center line as

much as they could. Three types of the distances between two cars were used. If the participant kept the distance between two cars to a moderate level, the following car was encompassed by a green rectangle. If the distance between two cars was too short or too long, the color of the encompassed rectangle changed to different color (red for short distance or blue for long distance between two cars). The details are shown in Murata et al. [12].

3 Prediction of Subjective Drowsiness by Multinomial Logistic Regression Model

3.1 Data Processing

Before the EEG data were entered into a Fast Fourier Transform (FFT) program, the data were passed through a cosine taper window. A FFT program was carried out every 1024 data points (1.024 s) to calculate EEG-MPF. ECG and EOG were resampled with a sampling frequency of 100 Hz. The moving average per ten inter-beta intervals was calculated. Variance of the previous three inter-beat intervals was calculated as RRV3, which is regarded as representing the functions of the parasympathetic nervous systems. The relationship between these measurements and subjective drowsiness was examined. The psychological rating of drowsiness was checked every one minute in order to explore the change of drowsiness over time. EEG-MPF, RRV3, the number of blinks, and the mean tracking error were calculated every minute.

As for behavioral measures, the neck bending angles (horizontal and vertical), the back pressure, the foot pressure, and the tracking error in the driving simulator task were measured. The neck bending angle was sampled with a sampling frequency of 100 Hz. The foot pressure, the back pressure, and COP on the sitting surface were sampled with a sampling frequency of 50 Hz. The quantity of pedal operation and the tracking error were measured every second.

As it is generally observed that a driver's neck either moves back and forth or right and left, or stops moving with the accumulation of drowsiness, the neck bending angles (horizontal and vertical) were used as one of the behavioral measures. A traffic accident due to drowsy driving is induced by the excessive deviation of the vehicle from the inside lane. Therefore, the tracking error in the simulated driving task was used as a behavioral measure. Foot pressure was selected on the basis of the observation that the foot movement of drivers for the operation of the brake or accelerator pedal becomes less frequent with the progression of drowsiness. Back pressure was used on the basis of the observations that drowsy drivers move forward or backward according to the accumulated state of drowsiness. A forward movement produces less pressure to the backrest of the driver's seat, and a backward movement produces more pressure to the backrest. Eight pressure

sensors were attached to the backrest or the right shoe since the channel which was most sensitive to such changes due to drowsiness differed among participants. In the range of this experiment, at least one channel sensitively succeeded in detecting the behavioral change due to drowsiness.

3.2 Multinomial Logistic Regression Model

An attempt was made to predict subjective drowsiness by applying a multinomial logistic regression model to the measured data. The data included the following physiological measures: x_1: RRV3, x_2: EEG-MPF, and x_3: blink frequency per 10 s. The following behavioral measures were also included in the measured data: x_4: tracking error in the simulated driving task, x_5: neck bending angle (vertical), x_6: neck bending angle (horizontal), x_7: back pressure, and x_8: foot pressure.

The following multinomial logistic regression was used to predict the subjective drowsiness expressed as a value from 1 ("arousal") to 3 ("very drowsy"). The dependent variable was the subjective drowsiness, and the independent variables were aforementioned eight measures.

$$P(2\text{: a little drowsy}) = \frac{\exp(b_0 + b_1x_1(2) + \cdots + b_8x_8(2))}{1 + \exp(b_0 + b_1x_1(2) + \cdots + b_8x_8(2))} \tag{1}$$

$$P(3\text{: very drowsy}) = \frac{\exp(b_0 + b_1x_1(3) + \cdots + b_8x_8(3))}{1 + \exp(b_0 + b_1x_1(3) + \cdots + b_8x_8(3))} \tag{2}$$

$$P(1 : \text{arousal}) = 1 - P(2\text{: a little drowsy}) - P(3\text{: very drowsy}) \tag{3}$$

$x_1(2)$, …, $x_8(2)$ and $x_1(3)$, …, $x_8(3)$ show the value of each evaluation measure when the corresponding subjective evaluation was equal to 2 and 3, respectively. The prediction of the subjective drowsiness was conducted according to the calculated probability $P(1)$, $P(2)$, and $P(3)$. The category corresponding to the maximum value of $P(1)$, $P(2)$, and $P(3)$ was estimated as the prediction of subjective drowsiness. If the value of $P(3)$ was the maximum, the prediction of subjective drowsiness was regarded as 3 (very drowsy).

The prediction was carried out as follows. The data 20 s before the prediction was used. We assumed that a time interval of 20 s was sufficient to take a proper countermeasure such as forcing the vehicle to stop or warn drivers of the risk of a crucial accident. The prediction of the drowsiness rating was conducted using eleven evaluation measures before 20 –120 s of the prediction. The analysis interval ranged from 10 to 100 s. The following ten different analysis intervals (length of the data window) were used: −30 s to −20 s (10 s-interval), −40 s to −20 s (20 s-interval), −50 s to −20 s (30 s-interval), −60 s to −20 s

(40 s-interval), −70 s to −20 s (50 s-interval), −80 s to −20 s (60 s-interval), −90 s to −20 s (70 s-interval), −100 s to −20 s (80 s-interval), −110 s to −20 s (90 s-interval), and −120 s to −20 s (100 s-interval). The effect of the length of the interval used for the prediction on the prediction accuracy was examined.

The identified analysis interval (length of the data window) was used to obtain model parameters in Eqs. (1)–(3) using a stepwise method. The prediction accuracies Equations should be punctuated in the same way as ordinary text but with a small space before the end punctuation mark.

4 Results

First, the modeling results by a simultaneous entry method are summarized in Table 1. Three models, that is, (i) All of eight measures x_1–x_8 were simultaneously entered into the mode, (ii) Only behavioral measures x_4–x_8 were simultaneously entered into the model, and (iii) Only physiological measures x_1–x_3 were entered into the model. The comparison of prediction accuracy for model (i) among ten time windows used for prediction is shown in Fig. 1. The extreme time windows (20 and 30 s) and (20 and 120 s) were found to lead to a higher prediction accuracy. Therefore, the time window (20 and 120 s) was used for further analysis using forward selection, backward elimination, and stepwise methods.

The results of multinomial logistic model fitting by a forward selection method are summarized in Table 2. The results of model fitting by a backward elimination method are summarized in Table 3. The results of model fitting by a stepwise method are shown in Table 4.

Table 1 Comparison of prediction accuracy between three models (all measures entered, only physiological measures entered, and only behavioral measures entered). Simultaneous entry method

Participant	All of eight measures	Only physiological measures	Only behavioral measures
A	0.948	0.741	0.828
B	1	1	1
C	1	0.918	0.898
D	1	0.875	1
E	1	1	1
F	0.898	0.881	0.898
G	0.898	0.831	0.864
H	1	0.966	1
Mean	0.968	0.9015	0.936

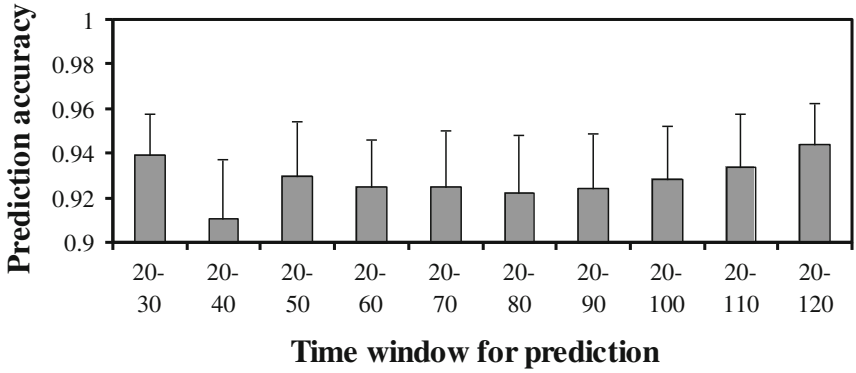

Fig. 1 Effect of length of time window on prediction accuracy (All of eight measures x_1-x_8 were simultaneously entered into the model)

Table 2 Results of multinomial logistic regression analysis when forward selection method was used. Forward selection method

Participant	Prediction accuracy	Measures entered into a model							
		MPF	TE	RRV3	nb-H	nb-V	Back-P	Foot-P	Num-blink
A	0.931		✓		✓				
B	0.981	✓	✓						
C	0.898				✓				
D	1		✓		✓		✓		✓
E	1	✓		✓					✓
F	0.847			✓					
G	0.915		✓		✓				✓
H	0.983		✓						
Mean	0.944								

Table 3 Results of multinomial logistic regression analysis when backward elimination method was used. Backward selection method

Participant	Prediction accuracy	Measures entered into a model							
		MPF	TE	RRV3	nb-H	nb-V	Back-P	Foot-P	Num-blink
A	0.914	✓	✓						
B	1	✓	✓	✓	✓	✓	✓	✓	✓
C	1	✓	✓	✓	✓	✓	✓	✓	✓
D	1	✓	✓	✓	✓	✓	✓	✓	✓
E	1	✓	✓	✓	✓	✓	✓	✓	✓
F	0.864		✓						
G	0.915		✓		✓	✓			✓
H	1	✓	✓	✓	✓	✓	✓	✓	✓
Mean	0.962								

Table 4 Results of multinomial logistic regression analysis when stepwise method was used. Stepwise method

Participant	Prediction accuracy	Measures entered into a model							
		MPF	TE	RRV3	nb-H	nb-V	Back-P	Foot-P	Num-blink
A	0.931		✓		✓				
B	1		✓				✓		
C	0.898				✓				
D	1		✓		✓		✓		✓
E	1			✓			✓		✓
F	0.847			✓					
G	0.915		✓		✓				✓
H	0.983		✓						
Mean	0.947								

5 Discussion

As shown in Fig. 1, the time window (20 and 30) and (20 and 120) led to higher prediction accuracy. It tended that entry of more measures into the model led to higher prediction accuracy as pointed out by Hanowski et al. [3]. Moreover, the mixture of behavioral and physiological measures contributed to high prediction accuracy as compared with only behavioral or physiological measures (see Table 1). It must be noted that using as many measures as possible for the prediction of subjective drowsiness from the practical viewpoint.

As shown in Tables 2, 3, and 4, higher prediction accuracy was obtained when the backward elimination method was used. However, it must be noted that this method finally needed more measures than the forward selection and the stepwise selection method. For Participants B, C, D, and H, the backward elimination method finally produced a model with all of eight measures. As for the forward selection and the stepwise method, at most four parameters were left in the final model.

The results of stepwise method indicate that the optimal prediction model is different among participants. In order to put such a drowsiness prediction system into practical use, each driver's data measurement must be carried out to identify the sensitive measures that are finally left in the model. Once this procedure was conducted, the optimal prediction system based on the proposed method can be used practically for each driver with an accuracy of more than 0.945. Designers of automotive preventive safety systems of drowsiness warning have no information on which evaluation measures should be used to predict drowsiness with a high accuracy based on past findings. The results also show that the sensitive measures are different across drivers, and shed some light on the basic knowledge that the evaluation measures of drowsiness should not be common to all drivers.

Although tedious pre-processing and preparation are necessary to put drowsiness prediction system into practical use, the subjective drowsiness system must be

individually customized. Before using such a prediction model, the designers of such a preventive safety system are required to acquire model parameters in Eqs. (1)–(2) for each user. This time consuming procedure might affect the practicability of such a system since each user needs to undergo a similar experiment to this study under the low arousal and high arousal states before such a system is actually used for predicting a subjective rating on drowsiness. At present, it is impossible to conduct on-line measurements and predict a rating score on drowsiness. It is also not certain when one should provide the participants with a warning.

Future research must explore how the predicted score on subjective drowsiness should be utilized for an effective warning system without false alarms (regarding an alert state as a drowsy state) and misses (regarding a drowsy state as an alert state). Another limitation of this study is that it is not known at present how ratings of 2 or 3 correspond with a crash risk. We must somehow explore how ratings of 2 or 3 are actually related to the risk of a crash. How the detection of a rating score of 3 (very drowsy) x times in a row, or y times out of z leads to a situation that corresponds to an actual crash in a driving simulator task should be empirically explored. In this manner, it would be possible to determine or speculate how situation with ratings of 2 or 3 during any interval are actually related to the high risk of a crash. For example, the detection of a rating of 3 five times in a row or nine times out of ten (10 min) might be closely related to the risk of a crash in a driving simulator task.

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Implications of Sedentary Lifestyle for Designing Dynamic Work in Times of Digital Selfness

Wilhelm Bauer and Christian Vocke

Abstract Physical as well as mental health represents substantial preconditions for people's well-being as well as productivity. In times of increasing share of skill-intensive work, societies worldwide in this connection are facing a further challenge: the so-called sedentary lifestyle characterizing those behaviors for which energy expenditure is low, including prolonged sitting time in transit, at work, at home and in leisure time. The study displays results and hypotheses for origination of diseases by sedentary lifestyle for the development of an integrated model in order to design dynamic work in times of digital selfness.

Keywords Big data · Biofeedback · Digital selfness · Dynamic work · Industrial internet · Mental disorders · Physical affections · Sedentary lifestyle

1 Introduction

In all western industrial nations, the share of physical work decreased over the last years. Employees do more and more knowledge work while sitting. The sedentary lifestyle moreover gained increasing influence on private life in large parts of the population. Already in 2003, an analysis of the distribution and determinants of sedentary lifestyles revealed a high prevalence of sedentary lifestyle in the EU (see Table 1) involving important public health burdens as well as an urgent need for preventive strategies [1]. The World Health Organization points a lack of physical activity among 25 % of women and 20 % of men in Europe [2]. As per the study DKV-Report 2015, adults in Germany nowadays spend around 7.5 h a day sitting at work and in their leisure time (24 % of the time working on the computer and

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Table 1 Distribution and determinants of sedentary lifestyles in the European Union (Percentage of sedentary people and 95 % CI in each of the 15 Member States of the European Union, Two Definitions: low energy expenditure [LEE], and no participation in activities and long sitting down [NP + LSD]) [1]

Country	nn	LEE			NP + LSD		
		Total	Men	Women	Total	Men	Women
Sweden	1001	43.3 (40.2–46.3)	48.1 (43.4–52.9)	39.7 (35.7–43.7)	6.4 (5.0–8.0)	9.4 (6 9–12.4)	4.2 (2.8–6.1)
Ireland	1001	44.1 (41.0–47.1)	47.6 (43.2–52.0)	40.6 (36.3–44.9)	7.4 (5.9–9.1)	7.4 (5.4–10.0)	7 4 (5.3–9.9)
Austria	931	46.8 (43 6–50.4)	48.5 (43.7–53.4)	45.5 (41.2–49.8)	7.9 (6.3–9.8)	8.0 (5.7–11.0)	7.9 (5.8–10.4)
Finland	979	46.8 (45.5–51.8)	53.6 (49.1–58.1)	44.0 (39.8–48.4)	6.2 (4.8–7.9)	6.6 (4.6–9.2)	5.9 (4.1–8.2)
Luxembourg	518	57.5 (53.2–61.7)	56.1 (49.6–62.5)	58.3 (52.5–64.0)	9.8 (7.5–12.6)	12.7 (8.9–17.5)	7.4 (4.8–10.9)
UK	1490	59.4 (56.9–61.9)	59.4 (55.7–63 1)	59.4 (56.0–62.7)	16.6 (14.8–18.5)	14.9 (12.4–17.7)	18.0 (15.5–20.7)
Denmark	1147	61.4 (58.5–64.2)	61.3 (57.20–65.3)	61.4 (57.5–65.3)	16.5 (14.4–18.7)	15.6 (12.7–18.8)	17.3 (14.5–20.51
Nether lands	1010	62.0 (59.0–64.9)	62.6 (58.2–66.9)	61.4 (57.2–65.5)	14.4 (12.3–16.6)	14.2 (11.3–17.6)	14.5 (11.7–17.6)
Fiance	1003	68.5 (65.6–71.3)	64.6 (60.2–68.8)	72.1 (68.1–75.8)	16.4 (14.2–18.7)	14.8 (11.8–18.2)	17.8 (14.7–21.2)
Italy	1000	69.3 (66.4–72.1)	68.0 (63.7–72.1)	70.5 (66.5–74.3)	18.4 (16.1–20.9)	17.9 (14.6–21.5)	18.9 (15.7–22.4)
Greece	1011	70.0 (67.1–72.8]	68.5 (64.1–72.7)	71.2 (67.4–74.8)	17.4 (152–19.8)	16.6 (13.4–20.3)	18.0 (15.0–21.4)
Germany	1159	71.0 (68.3–73.6)	70.2 (66.3–739)	71.8 (68.1–75 31	22.6 (20.3–25.1)	20.7 (17.5–24.3)	24.3 (21.0–27.8)
Spain	1000	71.0 (68.1–73.8)	68.5 (64.4–72.4)	73.7 (69.6–77.5)	18.0 (15.7–20.5)	17.2 (14.1–20.7)	18.8 (15.5–22.51
Belgium	9S2	71.7 (68.8–74.4)	67 5 (63.2–71.5)	75.9 (71.9–79.5)	18.3 (16.0–20.8)	15.3 (12.3–18.7)	21.3 (17.9–25.11

(continued)

Table 1 (continued)

Country	nn	LEE			NP + LSD		
		Total	Men	Women	Total	Men	Women
Portugal	1007	87.8 (85.7–89.7)	85.2 (81.8–88.2)	90.0 (87.3–92.3)	24.1 (21.6–26.8)	22.3 (18.7–26.2)	25.7 (22.2–29.6)

30 % watching TV). Besides it can be stated, that the younger the people the more time they spend sitting [3].

Scientific studies worldwide have been analyzing the consequences of too much sitting in recent years with the result to be a novel and important predictor of a variety of disease risks. At the same time research activities are proceeding individuals as well as companies are trying to prevent damages caused to health in private and in business manners. The combination of developments in the field of digital and social transformation builds a key success factor for retaining health through dynamic work.

2 Development of Diseases by Sitting

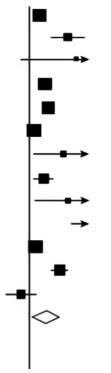
Numerous international studies prove long sitting times to have several negative effects on human health. Recent results display that damages to health do not only occur in the spine, but also in organic (e.g. arteriosclerosis, heart attack/stroke, type 2 diabetes, different forms of cancer, indigestion) and even psychological (e.g. limited mental performance, depressions) diseases.

2.1 Physical Affections

The American College of Physician conducted a systematic review and meta-analysis of 47 studies about the effects of sitting on human health. The results quantifying associations between sedentary time and hospitalizations, all-cause mortality, cardiovascular disease, diabetes, cancer and other diseases the majority of analyses found prolonged sitting to be linked to deleterious outcomes both independent of and in combination with physical activity (also see positive correlation between sitting time and mortality in Table 2) [4]. Analyses enrolled by the American Cancer Society in a large prospective cohort of US adults (53,440 men and 69,776 women) during a 14-year follow-up also verified time spent sitting (≥6 vs. <3 h/day) associated with mortality in both women and men after adjustment for smoking, body mass index, and other factors [5].

Cardiologists at UT Southwestern Medical Center in 2014 found sedentary behaviors to lower cardiorespiratory fitness levels based on data from 2223

Table 2 Associations between high sedentary time and health outcomes concerning all-cause mortality, adjusted for physical activity [4]

Study year (reference)	Country	HR (95 % CI)	Z Score	*p* value	HR (95 % CI)
All-cause mortality					
Seguin et al. 2014 (32)	United States	1.120 (1.060–1.183)	4.034	0.000	
Katzmarzyk et al. 2009 (27)	Canada	1.540 (1.246–1.904)	3.992	0.000	
George et al. 2013(25)	United States	1.700 (0.894–3.234)	1.618	0.106	
Matthews et al. 2012 (29)	United States	1.190 (1.118–1.267)	5.425	0.000	
Patel et al. 2010 (30)	United States	1.228 (1.177–1.281)	9.508	0.000	
Pavey et al. 2012 (31)	Australia	1.050 (1.080–1.070)	5.020	0.000	
Dunstan et al. 2010 (24)	Australia	1.460 (1.040–2.050)	2.186	0.029	
Inoue et al. 2008 (26)	Japan	1.166 (1.035–1.314)	2.522	0.012	
Stamatakis et al. 2011 (33)	Scotland	1.540 (1.059–2.239)	2.262	0.024	
Koster et al 2012 (28)	United States	3.260 (1.589–6.687)	3.224	0.001	
Kim et al. 2013 (36)	United States	1.072 (1.024–1.122)	2.982	0.003	
van der Ploeg et al. 2012 (34)	Australia	1.400 (1.267–1.547)	6.620	0.000	
Leó n–Munoz et al. 2013 (35)	Spain	0.910 (0.756–1.095)	–1.000	0.32	
Knapp-Hartung estimator		1.24 (1.09–1.41)			

Heterogeneity (I^2 = 94.96; P < 0.001; Q = 100.268)

participants in the National Health and Nutrition Examination Survey (NHANES). Thus sitting too much, not just lack of exercise is detrimental to cardiovascular health [6].

A cross-sectional study performed on 139,056 Koreans revealed prolonged sitting time and decreased physical activity level positively associated with increasing prevalence of non-alcoholic fatty liver disease (NAFLD) [7].

2.2 Mental Disorders

Beside the beforehand presented physical impact of the sedentary lifestyle, too much sitting also seems to have negative consequences regarding psychical effects. Corresponding to a study conducted in Spain too much sitting is increasing risks of mental disorders. The corresponding analyses predicate people with sitting time over 42 h per week are supposed to have a 31% risk of mental diseases [8]. Researchers at Dekan University in Australia suggest—although with limited evidence—a positive association between sitting time and risk of anxiety based on a systematic review of nine observational studies [9, 10].

2.3 Medical Measures and Recommendations

In order to reduce the quoted negative consequences to human health actually different measures and recommendations (e.g. doing moderate to vigorous intensity activities 30 min a day [11], short walks during lunch and throughout the day, taking the stairs instead of the elevators or hosting walking meetings at work [6]) are discussed. However, from the current state of research there is only little knowledge on methods of prevention. To define these it is necessary to investigate further essential questions from the medical point of view: What are the definite medical reasons for physical and mental damages to human health and starting from which duration is prolonged sitting getting dangerous? Afterwards guidelines minimizing the effects have to be defined also taking into consideration ergonomic insights as well as possibilities resulting from social and technological progress.

3 Digital and Social Transformation

The digital transformation changes business and private life likewise—in a radically and sustainable way [12]. At the same time, humans and the society are transforming, too. Individuality gains more importance, new communities develop and people live longer. This also effects human behavior and provides new impulses for business models. All citizens and workforces should be able to take advantage of the digital progress. An increasing, more intelligent and highly automated working and living environment, new digital mobile and seating solutions as well as a change of people's mind and resulting behavior can help to preserve healthy workforces and societies.

3.1 Internet of Everything and Total Connectivity

The industrial internet—as the system of systems—is becoming more and more a reality. Everything is going to be digitally connected: people, services and now all things of the physical world too, like buildings, machines, and automobiles, just everything (see Fig. 1). With the Internet Protocol version 6 as the new standard, an unbelievable large amount of internet addresses is at our disposal: so many, that we could easily connect every bacterium on earth to the internet.

The total connectivity here is a central driving force. Networking over the internet, systems linked via sensors and actuators, cloud computing as the base of data network, and the mobile and wireless system networks are the essential elements here. Therewith the living and working areas of people are getting smart and network themselves, new services develop and social networks are established. Thus, the digital transformation offers great opportunities to secure and enhance prosperity and quality of life by innovative systems (e.g. networked household appliances, interactive education tools, telemedicine) and new forms of mobile working as well as environments for dynamic work supporting employees' productivity and health.

3.2 Big Data and Data Analytics

In order to realize the prior to this predicted opportunities a huge data source will be the essential element—data is the asset of the future. The technology itself is just the enabler. After everything is connected and countless sensors are in service, the one, who can interpret the data, draws conclusions and can take actions towards

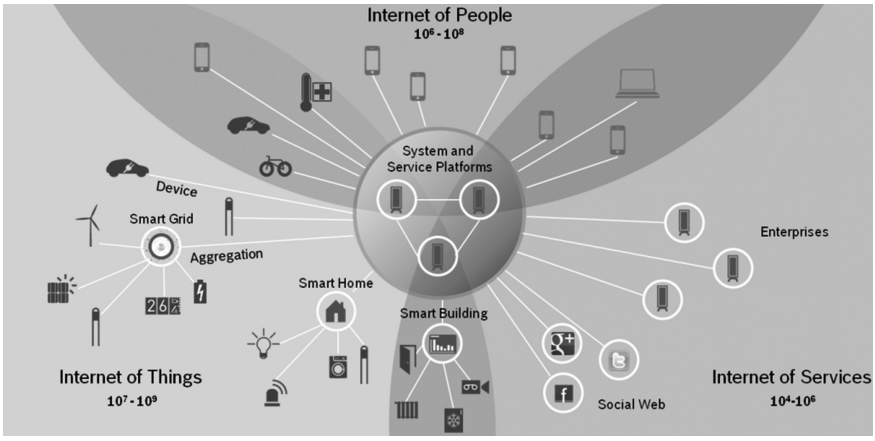


Fig. 1 The system of systems [13]

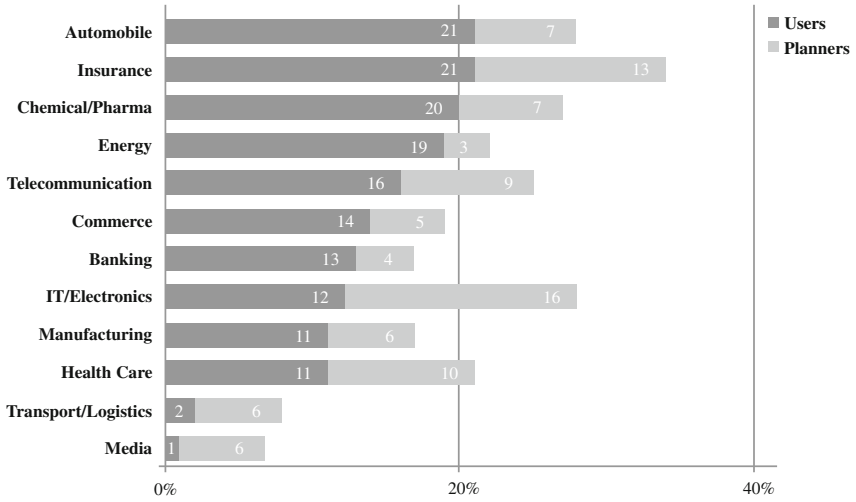


Fig. 2 Usage of big data analytics in companies; Basis: 706 companies ≥100 employees [14]

customers and systems will be successful controlling the business. Big Data is the big deal of the upcoming years. As Fig. 2 shows, many industries already make use of Big Data. As illustrated companies in the health sector are going to intensify their activities in the future, too.

Using Big Data new business models will emerge—digital business models. Many things are already possible, much more will come. For example, the mobility industry is already in advanced progress. On the one hand in this connection existing business models and companies are likely to come under pressure, while new will develop. On the other hand, this way new applications and systems arise—also in the field of smart health and work.

The benefit of Big Data depends on detailed analytics of reactive as well as proactive concerns (e.g. early detection of critical health conditions, better understanding the causes of diseases, optimization of configurations and controls, increased agility and flexibility in processes and work settings, new methods for monitoring vital data and development of adaptive and integrated health eco systems).

Of course, in Germany we discuss the potential threat of these developments in matters of data security, too. For this is a central concern and important topic for the society as well as for the companies, huge investments are intended and already executed [15].

3.3 *Technological Innovations and Digital Selfness in Health Context*

With the presented inflationary trends in the field of digital and social transformation, digital selfness is blazing its trail. Individuals as well as companies are more and more focusing on health and fitness supported by usage of digital tools both hardware and software (see Fig. 3).

The core of this subject consists of biofeedback solutions, e.g. fitness trackers, smartwatches, wearables or health and fitness apps taking the measurement of vital data (e.g. body weight, heart rate, blood pressure and glucose) and supporting people's and employees' behavior [16]. Getting recommendations with regard to the necessity of taking physical activity contributes to lower negative effects of sedentary time by constantly and controlled reduction.

Hence, new forms of human-technology-interaction establish optimizing health monitoring and leading to new, more flexible working processes and configurable work settings, too. Digital solutions take an important role in this context and an intelligent and secure way of health management with humans and digital tools and components as team players is possible.

Another essential element for creating an intelligent and connected health management within the industrial internet is building up a holistic health eco system combining mobile devices, integrated—sensor-based—and ergonomic seating solutions to business platforms as health portals offering new services and benefits to employees and companies. Of course, technologically not everything is available today to implement such a digital health management. A lot is available by now, and thus we can already start. For example, mobile devices and apps for health management as well as partly integrated seating solutions are already available and can be used modular—and in connection with innovative concepts for supporting

Fig. 3 Technological solutions for health and fitness—selected areas of application

behavioral change by organizational concepts (e.g. separate training concepts, work process redesign or added time concepts [17]).

4 Design Approach for Dynamic Work

Reflecting the challenge of sedentary lifestyle as well as taking into consideration given opportunities by digital innovations and changing social mindset concerning health as well as business needs for ensuring employees' productivity and well-being, dynamic work depends on the intelligent combination of organizational concepts, ergonomic solutions and digital tools (see integrated approach in Fig. 4).

The design of dynamic work in the process requires the conformance of the following basic requirements:

- Reduction of **sedentary lifestyle** as a central risk factor for health and productivity leading to physical affections and mental disorders
- Exhaustion of potentials in the context of **digital transformation** by usage of opportunities in the field of data analytics and interconnectedness
- Encouragement of **digital selfness** in business as combination of human awareness regarding health needs and affinity relating to usage of IT solutions

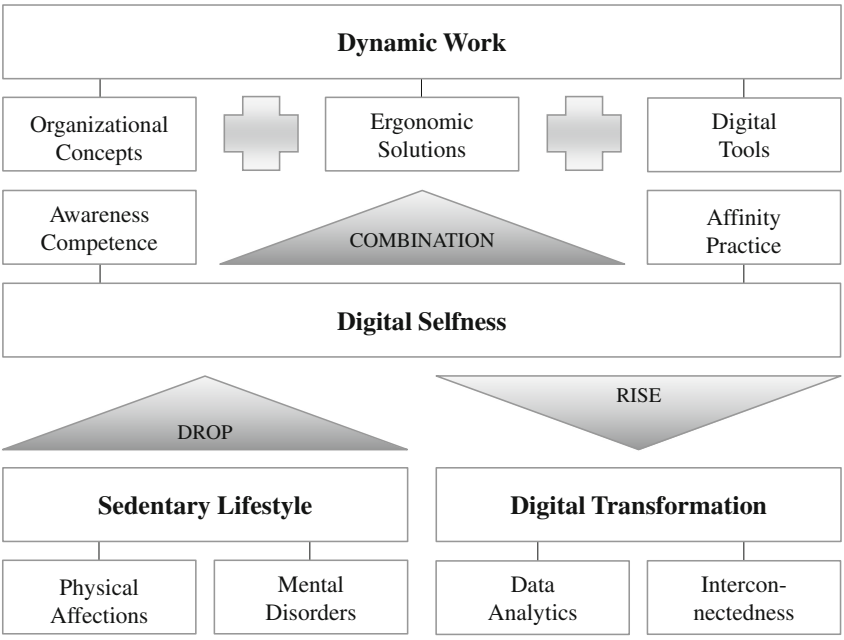


Fig. 4 Facing challenges of sedentary lifestyle—an integrated approach for dynamic work in times of digital selfness

- Combination of organizational concepts, ergonomic seating solutions and work environments and digital tools as key success factors for **dynamic work**

5 Conclusions and Demand for Further Research

The ongoing digital and social transformation will increasingly change our personnel life and work—also regarding to health manners. Concerning negative effects of sedentary lifestyle, it will be to us what we make out of it. Humans will decide for their own lives and their companies' success. Technology serves as an enabler. Many things are already possible, although not everything is necessary. The presented integrated approach for designing dynamic work based on digital selfness offers a broad variety of potentials combining digital, ergonomic and organizational factors. In order to reach continued optimization designing dynamic work and preventing physical affections and mental disorders by this especially further knowledge about medical causes (mechanisms, processes and durations) of health damages by sitting is essential. In the context of current research Fraunhofer IAO is conducting an international survey on the topic »Development of diseases by sitting« during March 2016 to present further scientific insights enriching the embodiment of the presented design model.

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Computational Prediction of Subjective Sense of Force Based on Muscle Activity Estimation

Yusuke Kishishita, Toshio Tsuji and Yuichi Kurita

Abstract We feel the effort during manipulation of a product. The effort takes a key role in the subjective product usability. It is known that muscle activity correlates with the subjective effort. Knowing the muscle activity is useful to predict one's subjective sense. In this paper, we propose a computational prediction method of subjective sense of force based on the estimation of muscle activity. In this study, we make a hypothesis the subjective sense of force changes according to the amount of the muscle activity. To validate the hypothesis, we developed a three dimensional musculoskeletal model, and estimated the muscle activity during a weight holding task. We also defined the perception change ratio based on the measurement of the relationship between the quantitative applied force and the subjective perceived force. In the experiment, the subjective sense of force was predicted by using the perception change ratio that depends on the muscle activity. The experimental results confirmed the feasibility of the proposed computational prediction method of subjective sense of force.

Keywords Muscle activity · Sense of force · Subjective sensation

1 Introduction

Knowing the muscle activity is useful to predict one's subjective sense of force. Takemura et al. have investigated the human force perceptual characteristics when grasping a steering wheel of a vehicle, and reported that the perceptual character-

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istics of force follow the Weber-Fechner law [1, 2]. They also reported that it depends on the posture of the human body and the direction of the load. The results suggest that the perceptual characteristics of force depend on the physical capacity governed by the body dynamics. We have proposed a computational prediction method of the subjective sense of force based on the muscle force estimation when a human holds a steering wheel [3]. Taking this into consideration, we made a hypothesis that the subjective sense of force changes according to the amount of the muscle activity. In this paper, we propose a computational prediction method of subjective sense of force based on the estimation of muscle activity. First, we measure the relationship between the applied force and the perceived force by human experiments during a weight holding task. Second, we estimate the muscle activity based on a three-dimensional musculoskeletal model, and develop the conversion equation between the muscle activity and the perception suppression ratio. Finally, we calculate the perceived force by using the perception suppression ratio, and evaluated the pre-diction performance of the subjective sense of force.

2 Experiment of Force Perception Characteristics

2.1 Experimental Protocol

Four healthy male adults aged 23–24 years old participated in the experiment. The participants were instructed to stand with an eye mask, and bend one's elbow 90° (Fig. 1). Then, the experimenter attached a bucket at one's forearm via a belt. The experimental procedure is as follows:

(1) The experiment puts a standard weight (1.5 kg) in the bucket, and asks the participants to memory the weight in 5 s.

Fig. 1 Overview of the weight holding task

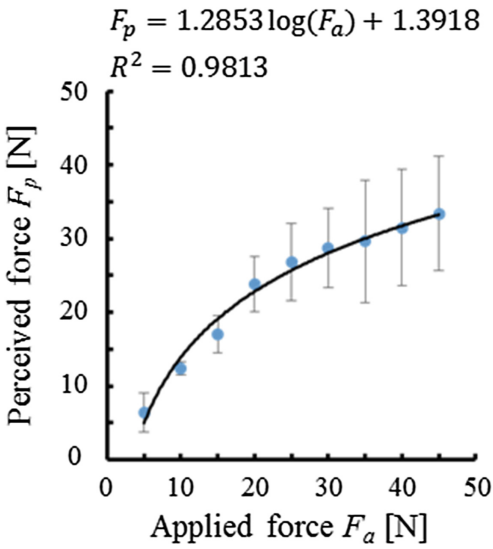

Fig. 2 Results of experiment

(2) The experimenter removes the standard weight, puts another weight in the bucket, and then, asks the participants to memory the weight in 5 s.
(3) The participants are asked to answer the subjective sense of weight by using the method of magnitude estimation.

The weight was randomly given from 0 to 4.5 kg with 0.5 kg interval.

2.2 Result of Experiment

Figure 2 shows the obtained relationship between the applied force that is determined by the weight and the perceived force that is obtained from the participants' answers. In this figure, the solid curve indicates the approximate curve. The results suggest that the perceived force is proportional to the logarithm of the applied force.

3 Prediction of Subjective Sense of Force Based on Muscle Activity Estimation

3.1 Method

Many studies have confirmed the role of muscle activity in weight discrimination [4]. Human's skeletal muscles have sensory system, such as the muscle spindle and Golgi tendon organ. It is known that the muscle spindles primarily detect changes in

the length of the muscle, and the Golgi tendon organs primarily detect changes in muscle tension. These receptors are believed to be responsible for the proprioceptive sense of a body posture and muscle effort. There is a sense of force associated with voluntary muscular exertion, which contributes to the perception of weight. Taking this into consideration, we propose the computational prediction model of subjective sense of force that considers human's posture- and direction-dependent perception characteristics by the estimation of the muscle activity.

Based on Fig. 2, the change ratio P of the perceived force, which is determined by the perceived force F_p and the applied force F_a can be calculated by the following equation:

$$P = \frac{F_p}{F_a} = \frac{1.2853 \log(F_a) + 1.3918}{F_a}. \tag{1}$$

where F_p is the perceived force, and F_a is the applied force. By determining the muscle activity that generates the particular force balancing with the external force, the change ratio of the perceived force against the external force can be converted to that against the muscle activity.

3.2 Muscle Activity Estimation

A three-dimensional musculoskeletal model was developed based on an upper extremity model. The maximum isometric force, the optimal muscle fiber length, and the pennation angle of the muscles were determined according to the parameters reported in [5]. The developed model is shown in Fig. 3. Muscle force was calculated by using OpenSim, which is an open source system for biomechanical modeling, simulation and analysis [6]. First, the position information measured by a motion capturing system was given. Second, the joint angle and the joint torque were estimated via an inverse kinematics and an inverse dynamics calculation based on the musculoskeletal model. Third, the muscle force that balances with the joint torque was determined by an optimization calculation of the muscle activity based on the muscle contraction model. Here, the muscle activity α_m $(0 \leq \alpha_m \leq 1)$ of the m-th muscle satisfies the following equation:

$$\sum_{m=1}^{n} \left(\alpha_m F_m^0\right) r_{m,j} = \tau_j. \tag{2}$$

where F_m^0 is the maximum isometric force, τ_j is the joint torque of the j-th joint, and $r_{m,j}$ is the moment arm parameter. The moment arm parameters were determined by the muscle length of the m-th muscle l_m and the joint angle of the j-th joint θ_j:

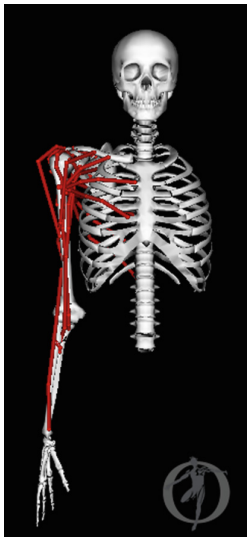

Fig. 3 Musculoskeletal model

$$r_{m,j} = \frac{dl_m}{d\theta_j}. \tag{3}$$

The relationship between the muscle force F_m and the muscle activity α_m are given by:

$$F_m = \alpha F_m^0 \bar{f}_l(\bar{l}_m) + F_m^0 \bar{F}^{PE}(\bar{l}_m). \tag{4}$$

where $\bar{l}_m = l_m / l_m^0$ is the normalized fiber length, $\bar{f}_l(\bar{l}_m)$ is the normalized active force-length relationship, and $\bar{F}^{PE}(\bar{l}_m)$ is the normalized passive force-length relationship. In this study, $\bar{f}_l(\bar{l}_m)$ and $\bar{F}^{PE}(\bar{l}_m)$ were obtained from [7].

By using the model, we estimated the muscle activity with the same condition as the experiment of force perception characteristics shown in Fig. 1 when various external force is applied. The estimation results are shown in Fig. 4. A linear relationship between the muscle activity and the applied force is observed.

3.3 Prediction of the Perceived Force

Figure 4 gives the relation between the applied force and the muscle activity as:

$$F_a = \frac{\alpha - 0.0041}{0.0049}. \tag{5}$$

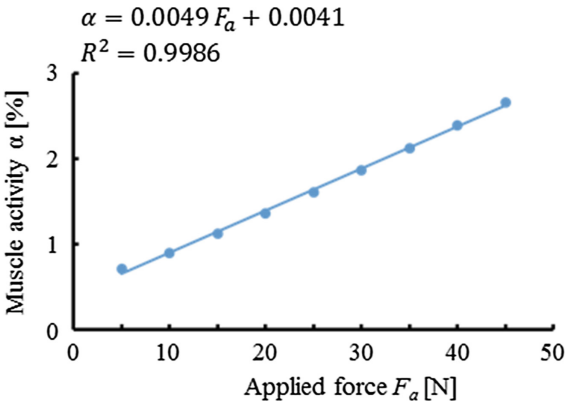

Fig. 4 Estimation results of the muscle activity. The *solid line* indicates the approximate line

Substituting this into Eq. (1) gives:

$$P = \frac{1.2853 \log\left(\frac{\alpha - 0.0041}{0.0049}\right) + 1.3918}{\frac{\alpha - 0.0041}{0.0049}}. \tag{6}$$

This equation expresses the perception suppression ratio as a function of the muscle activity. By using Eq. (6), the perceived force can be predicted from to the applied force by:

$$F_p = F_a \cdot P. \tag{7}$$

3.4 Evaluation of the Prediction Performance

To evaluate the proposed method, we predicted the perceived force by using the obtained perception suppression ratio in Sect. 3.3 with a different condition. The experimental protocol was almost same as the experiment in the Sect. 2; however, the direction of the applied force was changed to generate an extension as shown Fig. 5. The obtained perceived force from the participants' answers is shown in Fig. 6 as the squares. We also estimated the muscle activity by OpenSim with the musculoskeletal model, and calculated the perceived force by Eqs. (6) and (7). The predicted perceived force is shown as the curve line in Fig. 6. We can confirm a close tendency between the predicted and measured perceived force. This suggests that the proposed method has the possibility to computationally predict the subjective sense of force.

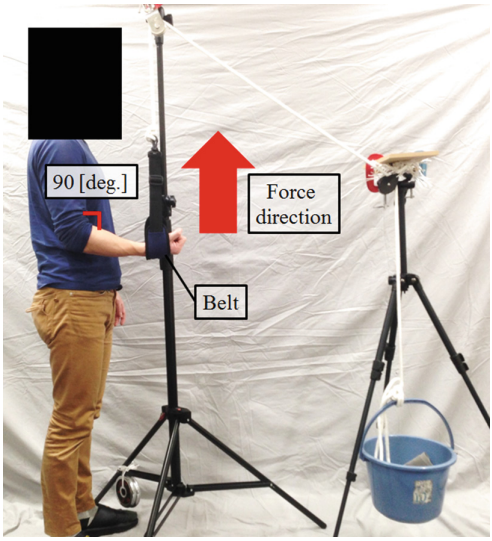

Fig. 5 Overview of the extension task

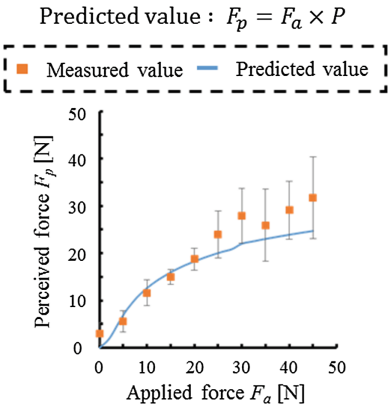

Fig. 6 Predicted and measured perceived force

4 Conclusion

In this study, we proposed the computational prediction method of the perceived force. The future work includes the quantitative evaluation of the prediction performance. Investigation of the effect of the physical capacity on the subjective sense of force based on tuning of the musculoskeletal model for individuals is also included in our interest.

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Ergonomic Factors in Virtual Intensive Interactions

Norma Antunano

Abstract The capabilities of building virtual organizations where people can interact and collaborate bring up variety of advantages, especially when face to face collaboration may not be always feasible. When the outcomes of virtual interactions and collaboration are measureable, and these are aligned to known objectives with accountability, client's performance to reach expectations and to achieve personal goals increases. At the same time the vision of driving a nurturing environment to emulate an on-site collaborative environment becomes more pronounced when favorable outcomes for the client and for the host of the virtual environment increase. This paper explores how the Smart Grid model and prediction analytics can work in tandem to facilitate client's efficiencies and performance at the same of driving system's performance feedback mechanisms related to the ergonomic design of the environment.

Keywords Virtual environment · Human factors · Context · Smart grid · Machine learning · Systems engineering · Client · User

1 Introduction

With more access to capabilities for virtual human interactions, for digital operations and for variety of more on-line interactions the virtual communities continue emerging. At the same time the existing virtual communities further refine themselves to maintain their presence, becoming stronger and evolve. At individual basis we have experienced in some way a virtual interaction for example performing an online transaction, attending an on line event, listening and viewing content or

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searching for information. The mediums to socially communicate in a digital world (like for networking, texting, e-mailing, sharing content), to support research, for on line transactioning or for gaming are now mainstream in countries where technology has been maturing and evolving. According to Internet World Stats [1], Internet penetration keeps growing and it is expected to support further growth of virtual based interactions as users become aware of the value additional on line resources and capabilities can offer. The development, deployment, release and implementation of workflows supporting a virtual system design supporting a particular mission (this may be an electronic transaction, play an on line game or enabling other online experience like the interaction in Facebook™ or Tweeter™) are being overcome in less time as learning curves, knowledge, demand and competition increase. These experiences reflect visions expressed through Epics and user stories successfully implemented in virtual platforms. From the client or user's perspective many of the experiences in the virtual systems are intuitively to learn. Transactions are usually executed through a series of repeatable steps according to established workflows by design. When the expectations from virtual experience consist on meeting a goal or a time bounded milestone with accountability (through digitally implemented workflows) the assumed or expected learning or engagement may not be easily predictable because there are variety of factors around that can be impactful. The virtual environment can be impacted by design characteristics of hosting platform, the variety of services by design driving different workflow options and applications coupled by the dynamics of the hosted environment. From the client's perspective, the contextual state and motivation for engaging in a virtual platform of this nature often bring other wave of influential factors. In a virtual interaction ergonomics in user experience plays a key factor; often ongoing physical movements (of the hands, fingers, wrist or even the arms) are needed to prompt an event or an operation. In addition, the client's physical posture(s) and his/her focus on the subject complement the readiness needed to virtually engage, collaborate or to learn in support of his/her mission or objective(s). With time bounded constraints and other rules built by design of the virtual system patience can be challenged. The client may try to learn how to navigate, adapt and accommodate to the design of the hosting environment while his/her time for response is counting, regardless if the environment is synchronous or asynchronous.

In the side of the system design hosting organization, as the value of hosting virtual interactions increases, the organization looks at adding more features, resources, even new options and services with the goal of increasing competitiveness of the system, expand its market, and to enhance client's experience. However the impact of adding perceived "value" may not always be favorable for the client or other stakeholders even when the intention may be good. Some of the additions may impact utilization and effectiveness of the hosting platform especially when the allocated infrastructure is not capable of supporting the ambitious mission. In the client's side, his/her effectiveness, productivity and experience may not be as expected even when the system appears to have more features.

2 Focus Scenario, Background and Related Work

2.1 Focus Scenario

From the client (user) perspective, the level of complexity experienced working and coordinating activities in a virtual platform may increase as more "features" and practically complexities are added as described in the introduction section. In regular basis, the client needs to be orchestrating what needs to be absolutely accomplished by certain time bounded deadline. The time needed to learn and feel comfortable with the ongoing changes impacting his/her work efficiency may overlap with the timeline allocated to address the work and execution needed against his/her goals and objectives. Considering experience and insights from regular virtual platform clients, learning and becoming familiar with new or significantly changed virtual host platform may take up to about 20 % of the duration of the event or engagement. In some cases relevant measurable execution (as illustrated through the Smart Grid Dashboard within Fig. 1) is a key enabler for achieving milestones such as completing a virtual educational course for credit, to complete an on line proposal, bid or an evaluation bounded by specified requirements.

Virtual environments supporting for example learning and education, or collaborative decision making following variety of processes and rules within a system, can require far more dedication than just learning to navigate a virtual system

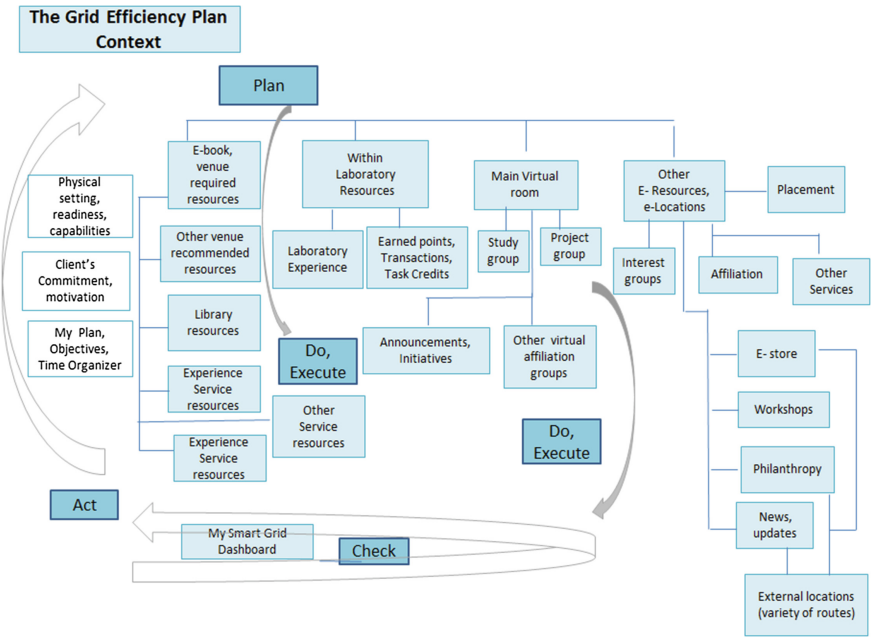

Fig. 1 Context for client's grid efficiency in a virtual platform

to complete transactions; there are also ongoing interactions that may last weeks or even months. To complete tasks in a virtual system, the clients may be also directed to additional virtual locations with applications that can be hosted by third parties, for example for accessing the Nasdaq dashboards, the information and analytical tools, to access electronic books, virtual learning laboratories, to access knowledge content like libraries, to access special services and other resources. A simplified diagram of the service categories of a virtual platform is shown by Fig. 1. From digital navigation perspective, under this scenario there is ongoing dynamism actively using and visiting variety of locations to accomplish milestones and objectives with accountability.

Clients may need to maintain regular engagements to complete personal and group collaboration in a virtual platform. Considering the perspective of a typical client without having the most advanced technology at hand, the level of navigation required to accomplish his/her objective(s) in a virtual platform with variety of governing requirements can contribute to fatigue or physical strain as physical position, the needed movements and repetitive actions in regular basis (may be from one to several hours per day) to navigate through the platform. The electronic pages hosted by the virtual designed system hold high density of information. The client has to regularly move the cursor throughout the page depending on what he/she intends or needs to execute or enable including moving to different locations (located in other virtual pages) as illustrated by diagram in Fig. 1. The need of regularly executing these physical and mental actions can cause strain if the execution last hours per day during weeks or even during months. Clients (users) need to be agile and properly skilled to effectively navigate through volume and richness of digital content [2].

From the perspective of facilitating virtual collaboration (also a client of the virtual platform) in a system with dynamic characteristics as described above, in order to encourage engagements including review of information generated by the virtual collaboration (like reading, analyzing, responding, researching, evaluating, generating reports and individual or group responses, and/of digitally listening contributions from each participant) are among some of the necessary activities to accomplish the mission. Per design of the collaborative environment, a facilitator role may be required to execute high volume of repetitive interactions enabled by regularly clicking the computer mouse for hours almost every day, by key stroking to type the communication, or by precisely touching the screen location to move to a targeted service/content as a command to complete reviews, responses and feedback. Part of the tasks involved can include finding specific information at specific locations, set-up and preparation of content, download and upload of information into specific virtual locations, regularly writing communication to interact with participants or as part of feedback or evaluation communications. Executing these combined tasks may lead to physical strain. Sensitivity and even sometimes physical strain (in the hands, fingers, writs, neck and/or the back) can impact human comfort or well-being. Certain posture (driven by what is physically comfortable for the body, the layout or design of the work station used to access the virtual environment) is needed to facilitate focus on a targeted objective at the time.

In addition maintaining visual and mind alertness when processing thoughtful information during prolonged periods of time add up to the strain. Accessing the virtual collaborative environment through smart phones can impact the span of human attention as information may be often confounded with overwhelming and irrelevant competing information for client's attention in the phone screen [3], in addition of the shrinkage of content size (or improperly formatted) presented in the screen. Regularly experiencing a virtual platform with the described characteristics, clients face the need of overcoming clutters of information while attempting to focus on their needs to achieve their objectives.

3 Background and Related Work

If we view the human brain as a core learning enabler in the context of ergonomics, the optical nerve routes information to the cerebral courtex via thalamus where the visual perception occurs. This nerve also routes the information for the mechanics of the vision for pupil control and for moving targets (Fig. 2) [4]. Prolonged activity can lead to fatigue and learning effectiveness can decrease [2].

With respect how users maintain focus in an environment where visual attention is a learning enabler, Koing et al. [5] identified the human visual span of attention is influenced by the location where attention is directed. Clients often provide feedback about options of making the engagement or learning more effective for them, and the learning virtual clients often prefer visual aids. Studies on the theory of attention from Treisman and Gelade [6] have found that humans can process multiple arrays of features in parallel, but such capability may not be adequate for when accuracy, attention to detail and critical thinking are needed. These are key characteristics in the learning process, during knowledge assessment, for enabling critical thinking and analysis for decisions making, or to set a strategy out of the experience. Yungi and Zhenxiang [7] identified a process to focus attention putting the human image processing as a pyramid; the algorithms proposed earlier by Marfil et al. [8] were referred in their study. Yungi and Zhenxiang's algorithm suggests a bottom up approach with the intensity as a feature at the bottom of the pyramid, followed by orientation and then by color at the top of a pyramid. The last

Fig. 2 Attention on the information displayed

feature at the top is referred as the "salient map model" representing how focus of attention is directed. Suh [9] through his work emphasizes about the influence of the contextual domain on defining characteristics and attributes the client expects.

4 Analysis and Study

Considering a baseline design of the hosting environment, and how humans typically drive their attention, the Grid Efficiency Plan Context (Fig. 1) becomes an integral component in a virtual distributed and collaborative system supporting cycles for moving at new levels of learning and critical thinking as it is shown by Fig. 3.

Considering the model shown by Fig. 3, feasibility of applying analytics to understand the relationships among interactive factors leading into ergonomics concerns was explored. Censored data and actual measures collected for two years from various virtual interactions in systems with similar profiles as described earlier in this paper are used in the analysis. The client's profiles (representing multiple participants) in contexts of facilitation of a learning virtual environment, and 780 data set records containing information on 24 variables were available for analysis. Regression analysis was initially selected as an attempt to understand important relationships among factors/variables leading to ergonomic concerns. Based on clients' inputs based on their experience there could be relationships between the

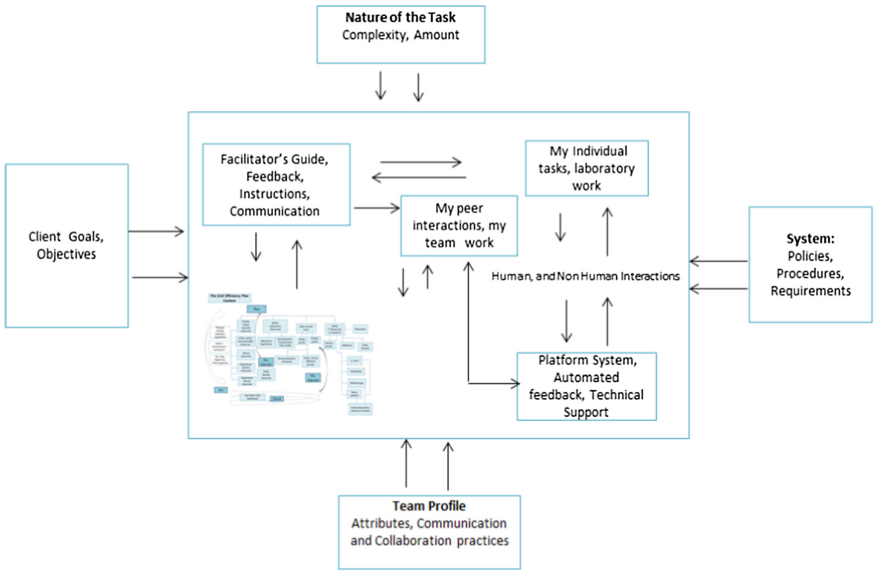

Fig. 3 Virtual collaborative environment, distributed awareness model

time spent in the virtual environment and the variety of factors impacting or driving execution. Applying stepwise regression a model of four predictor variables was determined to best represent the users' interaction. The users' or clients' time is primarily spent in laboratory applications viewing, executing simulations or other relevant to his/her objectives tasks, practicing and submitting tasks for automatic scoring or for human review, and collaborating with others in the virtual environment. The resulting regression model using JMP™ Statistical software from SAS™ is shown by Fig. 4. The four variables of the selected model are the time spent accessing image content files, the time spent in Laboratory applications, the time spent collaborating with others in the environment, and the time spent listening learning materials.

The model shows reasonable performance using the four predictors described earlier where the time spent by the client in the virtual platform is the dependent variable.

Now for the user/client with facilitator role in the virtual platform the study used information from 195 records hosting 26 variables. Applying stepwise regression the five predictors model identified a strong relationship between the time the virtual facilitator spends in the virtual platform and the number of keystrokes made. The five predictor variables are the keystrokes executed in the laboratories, the keystrokes executed in the collaboration environment with other client participants referred as "Keyst Class", the number of clicks in the Laboratories, the time spent in the Laboratory application, and the time spent in the class. The resulting model executed using JMP™ yielded the parametric results shown by Fig. 5.

The resulting models do not show departure anomalies of concern, for example there are not serious departures from normality in the residuals, or manifestation of collinearity. Through the results of these models we learned that the participants

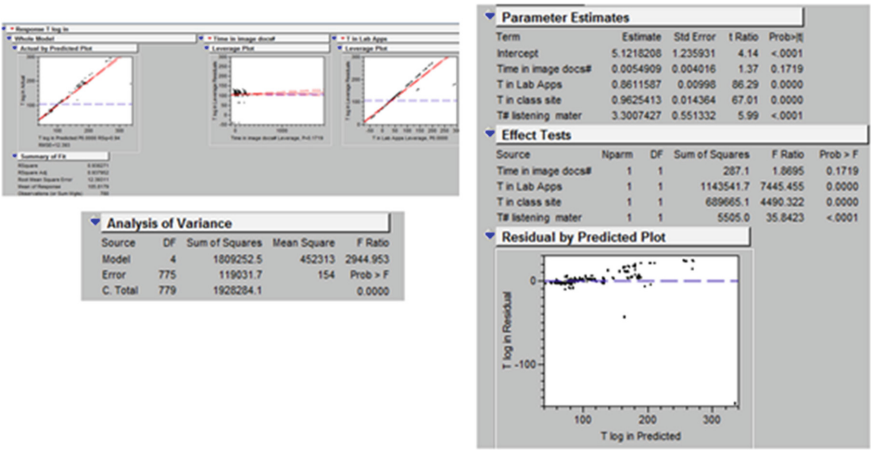

Fig. 4 Multiple regression model: relationship of Client's time in the virtual environment (using four predictors)

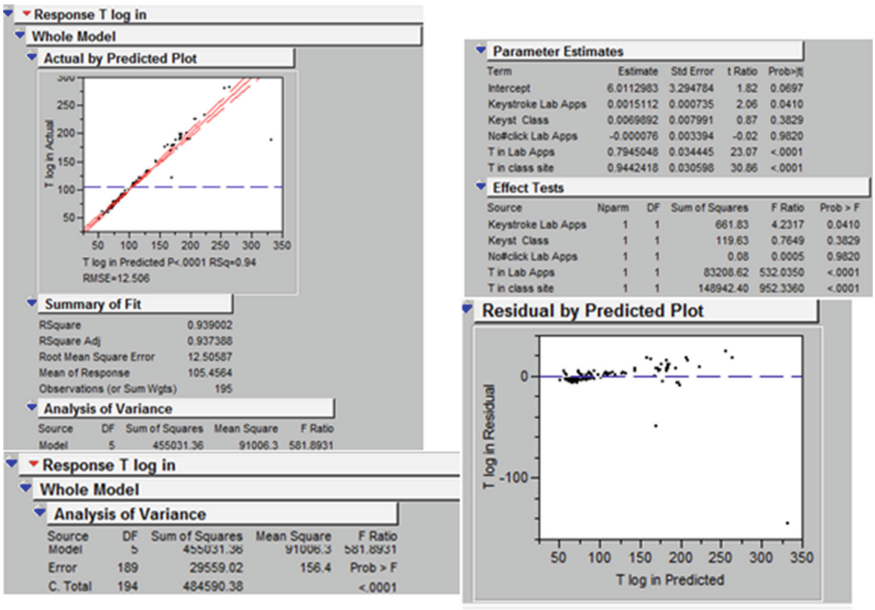

Fig. 5 Multiple regression model: relationship of facilitator's time in the virtual environment and its predictor factors

(referred as the clients) spend most of their time accessing information encouraging critical thinking, and working in their tasks. We also learned that key stroking related actions were not strong predictors of the time invested learning or exercising critical thinking. Significant time is invested completing these activities without a need of having to perform significant key stroking; however, to accomplish the mission clients likely exercise their visual and mental capabilities. In the facilitator's side, key stroking is a strong predictor of the time spent in the virtual platform. Without including the key stroking factors in the model, the R square (an indicator of goodness of fit of the model) adjusted of the model dropped down to the 0.50 range. In the model shown by Fig. 4, the key stroking related factors drive a poor R squared adjusted.

In addition, to find if pattern recognition through Probabilistic Neural Networks (PNN) enabled by the Dynamic Decay Adjustment algorithm from Berthold [10] can aid with predictability of the time the facilitator spends in the platform was applied to the same data set. The PNN capability from the analytics platform Knime™ aided in this study. The relationships of the five potential predictor variables, and the time the facilitator spends in the platform were explored considering the client's known profile This type of client has significantly more motion according to the number of keystrokes and the clicks of the mouse recorded. The 195 data sets used to build the model shown by Fig. 5 were also applied for the model outlined by Fig. 6. In Fig. 6 model 73 % of the data were used for training;

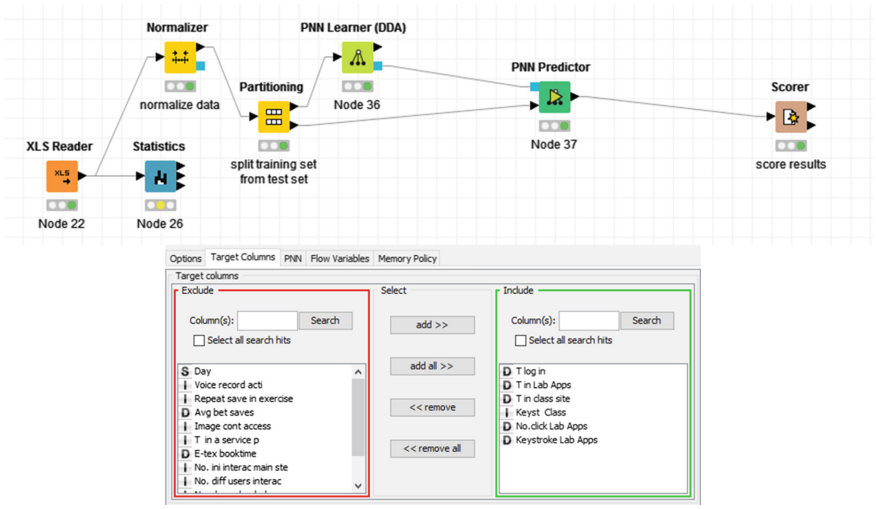

Fig. 6 PNN Model applied to predict the number of keystrokes in a virtual environment (based on the virtual facilitator client)

the balance of the data was used testing predictability of the model. The confusion matrix shows that the model could classify 67.4 % of the data correctly for the number of keystrokes when the leading predictor of the time spent in the virtual platform. The predictability of this model did not result as good as the predictability of the regression model, but with over 60 % predictability performance using a neural network model it cannot be just discarded. With simulation of 20,000 data sets using R Studio ® statistical programming language (once each of the predictor variables' distribution was identified) an improved predicting model could not be identified; the predictor mode could hold less than 40 % predictability. Further review to optimize the parameters used especially for the simulation model may help to enhance the predictability of the PNN algorithm applied to the virtual platform scenario(s) of interest.

5 Conclusions and Future Work

Through this research it is suggested to apply the Smart Grid principles to enable a continuous feedback mechanism to help drive higher levels of efficiency for clients working in a virtual environment with the described characteristics. Also, when utilizing the Smart Grid in combination with ongoing learning of the hosting environment from the virtual system perspective, its effectiveness may be improved earlier than later as there is more focus on prevention than reaction, better page and workflow ergonomic designs may be identified for implementation before clients' concerns escalate, plus there are opportunities to lead into better service and clients'

experience satisfaction. Future work includes exploring performance of other Neural Networks models using R Studio ® or Python® for both types of clients (participant client and facilitator client), understanding the characteristics of the information accessed by clients during their learning or critical thinking, and using other Analytics tools available in Knime™ to enable machine learning. We may also continue exploring the option of simulating the virtual environment to further sustain validation of the models under studied.

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Electromyographic Assessments of Muscle Activation Patterns During Driving a Power Wheelchair

Chi-Wen Lung, Tse-Yu Cheng, Yih-Kuen Jan, Hsin-Chieh Chen and Ben-Yi Liau

Abstract Power wheelchairs are essential for cerebral palsy children with mobility impairments. The purpose of this study was to establish a muscles sequence pattern of the upper limbs to help clinicians determine a child's readiness to control the joystick for maneuvering a power wheelchair. Five individuals performed four joystick control tasks, including forward, backward, left-turn, and right-turn. The X/Y positions of joystick and surface electromyographic (EMG) signals were record simultaneously. The surface EMG was used to record the contraction of four right upper limbs muscles, including extensor carpi ulnaris (ECU), extensor carpi radialis (ECR), pronator teres (PNT), and deltoid anterior (DA). A technique for analyzing and comparing the dynamic patterns of EMG collected during driving a power wheelchair was presented. Driving EMG patterns were computed to consist of both magnitude (amplitude) and phase (timing) components. For the magnitude component, the magnitude component of the EMG patterns is defined as the muscle during rest, slight contraction, or forceful contraction. The phase component of the EMG patterns is defined as the muscles of contraction duration with active or inactive regions in each joystick control task. The results showed that participants use more muscle efforts of the ECU and ECR compared to PNT and DA during four joystick control tasks. The active regions of the phase component were similar

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between the ECU and ECR. There were more phase component of forceful muscle contraction of the ECU compared to ECR during left-turn task. PNT muscles did not contract during the right-turn task. DA muscles were only slight contraction during the forward task. The findings imply that the joystick control strategy for power wheelchairs may be profiled by the muscle sequence patterns of the wheelchair users.

Keywords Power wheelchairs · Cerebral palsy children · Electromyography · Joystick

1 Introduction

The earlier work are interesting by clinical and research in power mobility for young children with significant mobility impairments [1–4]. Cerebral palsy is the most common mobility impairments in childhood, and an estimate of the population incidence is two to three per 1000 newborn infants [5]. The upper extremity impairments affecting activities in cerebral palsy require prolonged rehabilitation. Power wheelchairs are essential for many cerebral palsy children with mobility impairment.

The driving performance of power wheelchair corresponding the muscle activations of upper limbs may also be quite different [6]. The driving performance capabilities and limitations muscle activations for capabilities of power wheelchair remain unclear [7]. To improve accessibility to training, muscle activity profile requires a thorough understanding of the driving performance in power wheelchair. Although muscle activity is multifactorial, leading hypotheses are that muscles sequence pattern are associated with the driving performance of joystick in power wheelchair.

The purpose of this study was to investigate driving performance and muscle activity of the upper limbs while driving a power wheelchair in different task: forward, backward, right turn, and left turn. The muscles sequence pattern can help clinicians determine a young child's readiness to drive a powered wheelchair.

2 Methods

2.1 Participants

In this study, we use the joystick of power wheelchair and assess the muscle activity responses of the driving performance task. Five subjects were recruited in this study (N = 5; mean ± SD: age, 32.2 ± 14.1 years; height, 169.8 ± 10.5 cm; weight, 78.8 ± 18.6 kg; body mass index, 27.3 ± 6.2 kg/m^2). We further tested this system

in various conditions using an Institutional Review Board-approved protocol. A right-hand short-handle joystick equipped on a power wheelchair (TE-888 W, Shoprider, Inc. Centurion, South Africa) were used in this study for driving performance task.

2.2 Data Acquisition

We compared control interfaces based on EMG signals from the wrist muscles, because they related intrinsically to the hand movement. The selected physiological signals were EMG signals from the muscles that mainly contribute to wrist flexion-extension. The wrist muscles on the right side of the up limb: extensor carpi ulnaris (ECU), extensor carpi radialis (ECR), pronator teres (PNT), and deltoid anterior (DA). For muscle identification, electrical stimulator was used (KS-138 electronic therapeutic massager, E-neng Tech Enterprise Co., Ltd., Taiwan). Anatomical guidelines were used for approximate location of muscles. The skin was cleaned using alcohol, and then we used surface electrodes of the EMG (MA-300, Motion Lab Systems, Inc., Baton Rouge, LA, USA) applied to lightly abraded skin over the respective muscle belly. The signals were amplified with a bandwidth of 20–450 Hz and a gain of 1000. Meanwhile, we also recorded serial analog X/Y data of joystick in power wheelchair. The data acquisition of the joystick X/Y and EMG were synchronized recording at 1000 Hz by the analog-digital converter (USB-6218, National Instrument, Austin, TX, USA) (Fig. 1).

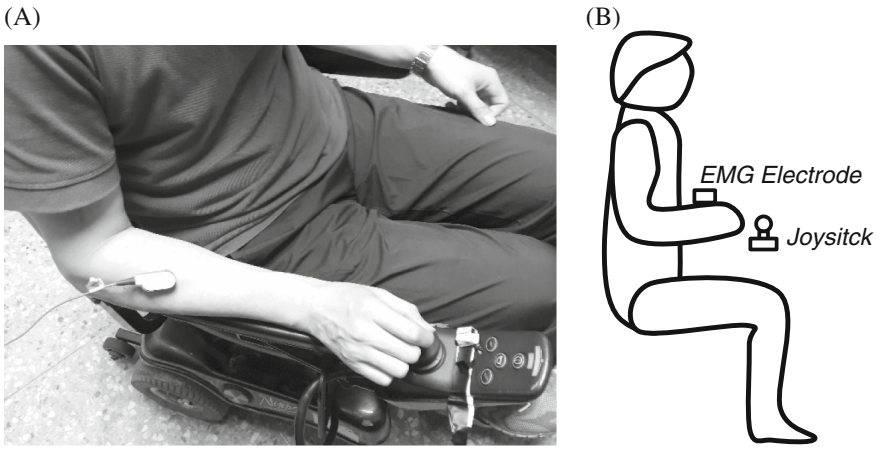

Fig. 1 Experimental setup. **a** Picture of the experimental setup; **b** Schematic diagram of the experimental setup. The forearm of the participants was securely lie one the armrests of the power wheelchair. The EMG electrodes placed at the specific muscles. The joystick was located in front of the subject

2.3 Driving Performance Tasks

The driving task in this study was performed in an indoor. Because this is a pioneer study, we turned off the power for immobile wheelchair during the performance tasks to prevent the subjects' distraction. The testing protocol included four tasks: forward, backward, left turn, and right turn. The order in which the participants tested each task was randomized.

Before the measurement, subjects were ask for the training trials. It allowed the subjects to become familiar with the control interface and to get as close to their maximum performance as possible before starting the evaluation trials. The experimenter informed the participants after each trial about the direction error of X/Y data of joystick and encouraged him/her to improve it.

Each trial was including 5 s moving the joystick with a 5 s rest period between trials. Subjects would continue move the joystick until they were asked to stop, it was approximately ten trials. Three stable trials were store for data analysis.

2.4 Data Analysis

Each EMG file was passed through standard signal-processing techniques. In order to obtain the envelopes, the EMG signals were full-wave rectified and smoothed using a second order low-pass Butterworth filter with a cutoff frequency of 5 Hz. Preliminary analysis revealed that a cutoff frequency of 5 Hz represents a good tradeoff between noise removal and control bandwidth. The filter values were normalized by maximum voluntary contraction (MVC) recordings and was used to scale each EMG. Prior to the experiment, the MVC for each muscle was obtained by a procedure in which each subject performed two 5 s MVCs at a 90° elbow angle with a 45 s rest period between contractions. Meanwhile, each task during was time-normalized to 100 data points per task.

Specifically, the EMG activity when the muscle is active (greater than a given threshold 3 and 15 % MVC) in the portion of the task cycle where it is normally "active," and also when EMG activity is inactive (below the threshold) when the muscle is in the portion of the gait cycle where it is normally "inactive.".

One-way analysis of variance (ANOVA) with Fisher's LSD correction was used for pairwise comparisons of the each muscle activity and strength time between four tasks. All statistical tests were performed using SPSS 22 (IBM, Somers, NY) at the significance level of 0.05.

3 Results and Discussion

Driving joystick used more muscle effort of the ECU and ECR compared with PNT and DA. The activation times were similar between the ECU and ECR with the exception of the left task (Fig. 2). PNT muscles was not activation during right. DA muscles was either silent or did not display phasic task-related activity with the exception of the forward (Fig. 2).

There was conspicuous lower muscles during slight contraction (>3 % MVC) while driving straight forward (Fig. 3a). In advance, there was muscles during forceful contraction (>15 % MVC) to execute a right task (Fig. 3b). However, each muscles activity time were no significant different between the four task groups.

Control Pattern showed the major muscles for driving joystick were ECU and ECR. ECR manipulates the wrist to move the hand towards the thumb (i.e., abduction) and away from the palmar side (i.e., extension). Meanwhile, ECU move the hand toward the ulnar side (i.e., adduction) [8]. The ECR and ECU muscles enhance wrist joint stability during the straight line (forward and backward). But abduction (i.e. left turn in this study) displayed reduced the contribution of ECU. That would be ECU insert at the base of the 5th metacarpal in anatomy. However, the major control joystick is thumb of the hand.

During execute turn tasks, right turn (i.e., abduction) apparently exerted more muscle activations, but left turns (i.e., adduction) gave more muscle effort. The results are consistent with our hypotheses that the joystick control strategy for power wheelchairs can be profile by the muscle sequence pattern.

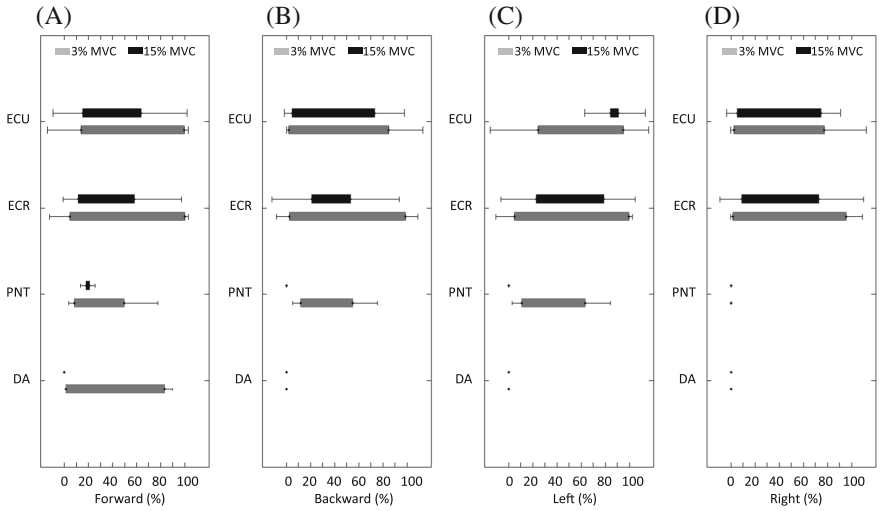

Fig. 2 The muscle sequence for four task. **a** *forward*; **b** *backward*; **c** *left*; and **d** *right*. *Gray line* EMG signal great 3 % MVC; *Black line* EMG signal great 15 % MVC; *ECU* extensor carpi ulnaris; *ECR* extensor carpi radialis; *PNT* pronator teres; *DA* deltoid anterior

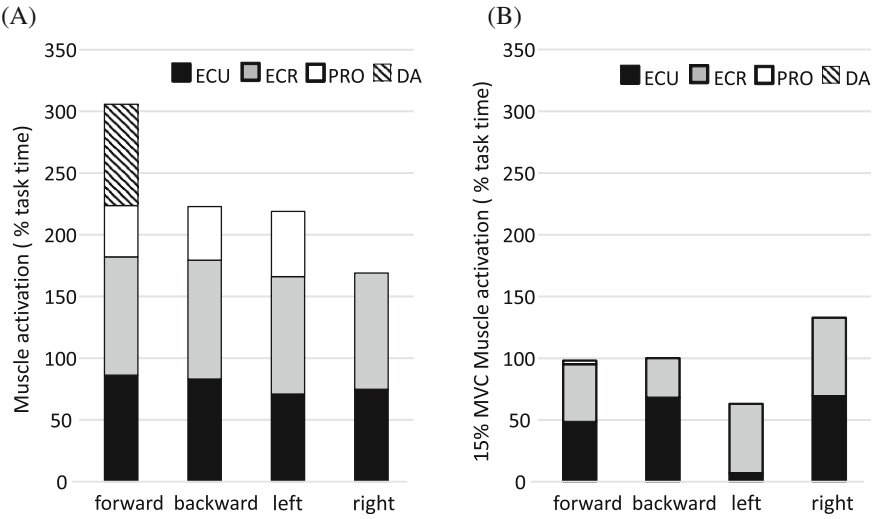

Fig. 3 Muscle activation of upper limb while moving joystick **a** the activation time great 3 % MVC; **b** the activation time great 15 % MVC. *ECU* extensor carpi ulnaris; *ECR* extensor carpi radialis; *PNT* Pronator teres; *DA* deltoid anterior

The limitations of our study are as follows: (1) this driving assessment was limited to a static environment, (2) the joystick was only test the right hand, and (3) the results were not acquired by power wheelchair users. It needs further investigation, particularly with regard to the features of the muscles.

4 Conclusions

The objective of this study was to investigate the effectiveness of joystick with application to muscle contraction of the upper limbs. The findings imply that the joystick control strategy for power wheelchairs may be profile by the muscle sequence pattern. The joystick control strategies required forceful contraction in the ECU and ECR (wrist extensors and flexors) to drive a power wheelchair than the PNT and DA. Abduction (i.e. left turn in this study) displayed in reduced the contribution of ECU.

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Part VIII
Wearables and Innovative Interfaces

Can Secondary Traffic Alerts Improve the Latent Hazard Anticipation Ability of Novice and Experienced Drivers? A Simulator Study

Tingru Zhang, Siby Samuel, Tracy Zafian, Cheryl Ann Nicholas, JingYi Zhang, Michael Knodler Jr and Donald L. Fisher

Abstract The current simulator study aims to investigate whether warnings of an impending latent hazard, delivered on Google Glass can improve both, young and middle-aged drivers' latent hazard anticipation ability. Twenty young and 30 middle-aged drivers were pseudo-randomly assigned to either the Google Glass condition or the control condition. All participants completed seven simulated driving scenarios with potential hazards. Participants in the Glass condition received text messages alerting them about the presence of a potential hazard, approximately 400 ft in advance of the hazard. Participants in the control condition received no such alerts. The results showed that warnings on Google Glass significantly improved the proportion of latent hazards anticipated by young drivers. The performance of middle-aged drivers was not affected by the warnings. It is concluded that head mounted displays like Google Glass offer a promising platform for the delivery of traffic warnings to help young driver better detect hazards on the road. However, its application on middle-aged drivers requires further research attention.

Keywords Hazard anticipation · Head mounted display · Age difference · Google glass · Eye behaviors

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1 Introduction

Head-mounted displays (HMDs) are wearable devices that can project images onto the visual field of the users. Applications of HMDs exist in military, aviation and commercial domains, particularly to deliver context-specific information such as maps, targets, or real-time traffic to the users [1–3]. In the driving domain, HMDs have been shown to be a safer and more efficient user interface than the traditional head-down displays (HDDs). Drivers are found to show better longitudinal control [4], more consistent lateral positioning [5], and shorter reaction time to emergencies, when interacting with HMDs compared to HDDs. This less distracting effect of HMDs on driving performance can be attributed to the fact that drivers are afforded the ability to read the information on the HMD while keeping their visual attention on the forward roadway, thereby helping them maintain a good situational awareness of the dynamic changes on the roadway environment.

The HMDs are functionally similar to head-up displays (HUDs). However, unlike HUDs where the display area is usually limited to the boundaries of the windshield, HMDs display visual content at a fixed position within the drivers' field of view. In a driving simulator study, Lauber and Butz [6] compared the effectiveness of HMDs and HUDs in delivering warnings to visually distracted drivers and showed that the driver reaction time and reaction accuracy were not significantly different between the two modalities. In a follow-up experiment [7], a marker indicating the location in which the warning would potentially be shown was introduced in both modalities. With the introduction of the marker, the reaction time in HMD condition was found to be significantly shorter (compared with the HUD condition).

The consumer market offers several low-cost, lightweight HMDs with functionalities such as texting, calling and photography to mention a few, Google Glass being one of the more representative products. A small number of studies have investigated the effect of the use of Google Glass behind the wheel on driver performance. Sawyer et al. [8] compared the behavioral impairments associated with texting while driving, using either a Google Glass or a smartphone. The results showed that texting using Google Glass was less distracting, as indicated by a lower subjective physical workload, higher average speed and shorter following distance for the participants in the Google Glass group compared with the smartphone group. However, the use of Google Glass is not necessarily distraction free, with evidence of prolonged driver reaction time to the sudden braking of the lead vehicle and an increased variability in lane position, being some examples of unsafe behaviors indicative of distraction [8]. Benefits from the use of HMDs was also confirmed in another study by He et al. [5], conducted on a simulator, which showed that drivers exhibited better lateral and longitudinal vehicle control (i.e. fewer lane excursions and more consistent headway distances with the leading vehicle) while texting using a Google Glass compared to texting using a smartphone.

While the above studies focus on vehicular control, the work by Young et al. [9] has examined how traffic sign detection, an indicator of drivers' hazard anticipation ability, can be influenced by reading text displayed, either on Google Glass or on a smartphone. In their study, participants were required to complete one simulated Lane Change Test (LCT; Mattes and Hallén [10]) while engaging in the secondary, text reading task. The results showed that although drivers in Google Glass condition reported a lower level of workload compared to drivers in the smartphone condition, they missed a greater number of lane change signs and were more likely to drift out of the lane. Together with existing evidence, these findings provide some support that while Google Glass may be used to render secondary tasks, the HMD may still induce unsafe driving behaviors in certain situations. And the nature and the content of the secondary task itself may play a role in worsening driving behavior, particularly anticipatory behaviors.

It is worthwhile to note that all available studies have exclusively used Google Glass to present driving-irrelevant information. An important application of HMDs in general is to assist users on their task performance. This raises the question of whether Google Glass may be effective in delivering road safety information or clues to drivers to improve their driving performance. The work by Samuel et al. [11] is probably the first study that has explored the potentially beneficial aspects of Google Glass on assisting driver latent hazard anticipation performance. Latent hazard anticipation refers to the drivers' ability to scan the areas of the roadway in order to detect and respond to a potentially threats that may or may not materialize on the forward roadway [12]. In their simulator experiment, one group of drivers received traffic warnings of an upcoming hazard using Google Glass when they were about 10 s in advance of the latent hazard while the other control group of drivers received no warnings. It was found that drivers in the Google Glass condition detected a higher proportion of hazards when they were 4–5 s away from the hazard. Given that the sample size in Samuel et al. [11] is relatively small (only 12 participants), the feasibility and effectiveness of using Google Glass to deliver traffic warnings requires further validation.

Almost all the above mentioned studies examining the impact of commercial-off-the-shelf HMDs (like Google Glass) on drivers' vehicle and eye behaviors have focused only on the younger driver population (<25 years old). The lone exception is the study by Young et al. [9] where the age of the participants ranged from 22 to 47 years old. Interestingly, this is the only study that does not support the idea that Google Glass may provide benefits to driving performance by reducing the distracting effect of secondary tasks (such as texting) presented on it when compared to smartphones. This raises the question of whether age can moderate the effects of Google Glass on driving performance. Studies have found that it is more difficult for middle-aged users to read the information displayed on small screens [13]. It is possible that a beneficial effect for young drivers may not translate to the middle-aged driving population, due to difficulties associated with reading and acquiring the warnings displayed on Google Glass. Hence, there is a

need to examine the possible age-related differences in the potential benefits of Google Glass on driving performance.

This study was designed to fill some of the existing research gaps in the literature on HMDs by exploring their associated benefits to safety when used to present safety-specific information. In particular, it aims to investigate whether warnings of an upcoming hazard projected on a Google Glass would in any way improve drivers' latent hazard anticipation abilities and also whether these improvements would persist for more experienced, middle-aged drivers.

The current study has two hypotheses:

Hypothesis 1: For young drivers, it is hypothesized that the drivers in the Google Glass condition would anticipate more hazards compared to the corresponding cohort in the control condition.
Hypothesis 2: Considering the age-related increments in the difficulty associated with reading and responding to text messages delivered on HMDs, it is likely that middle-aged drivers may not be able to react to the warnings in a timely manner. Hence, it is hypothesized that the middle-aged drivers in the Glass group will not exhibit improved hazard anticipation performance compared to their peers in the control group.

2 Method

2.1 Participants

Twenty young (18–22 years old) and 30 middle-aged (30–50 years old) drivers participated in this study with full approval from the Institutional Review Board at the University of Massachusetts Amherst. Twelve young drivers were assigned to the control group (M_{age} = 20.6 years; SD_{age} = 0.7; $M_{experience}$ = 4.2 years; $SD_{experience}$ = 1.6) and 8 to the Google Glass group (M_{age} = 20.5; SD_{age} = 1.3; $M_{experience}$ = 3.6; $SD_{experience}$ = 1.6). Four middle-aged drivers could not complete all drives due to simulator sickness and their data were removed from further analysis. The final middle-aged dataset contained 11 middle-aged drivers in the control group (average age = 40.5; SD = 6.5; $M_{experience}$ = 9.0; $SD_{experience}$ = 2.8) and 15 in the Google glass group (average age = 39.33; SD = 10.34; $M_{experience}$ = 8.8; $SD_{experience}$ = 2.1). All participants were active drivers with a valid driver's license at the time of participation and had normal or corrected-to-normal vision. Participants in Google Glass group could wear contact lenses, but they were not allowed to wear spectacles during the experiment since spectacles would interfere with the outfitting of the Google Glass and the data collection process. There was no such restriction for drivers in the control group. All participants were remunerated 30 dollars for their time.

2.2 Apparatus

The current study used a Google Glass, a head-mounted eye tracker (Applied Science Laboratories) and a fixed-base, full-cab, driving simulator (Realtime Technologies Inc.).

Google Glass. The Google Glass used in this experiment was the model XE-C. It was worn by participants like a regular pair of spectacles and was paired with an Alcatel android phone to display the message alerts sent to the cell phone by the experimenter. Incoming message alerts were in the form of a chime played through Google Glass's bone-conductor on the touchpad. The head-tilt gesture used to "unlock" the device was set to a threshold of 30°. The message was displayed on a transparent prism screen mounted in front of the right eye. Participants were required to read the message loudly to indicate the successful receipt of the alert.

Driving Simulator. The simulator used for this experiment was the Realtime Technologies Inc. (RTI) fixed-base, three screen driving simulator. The simulator consists of a full body Saturn sedan cab with automatic transmission. Three screens project 180° of visual viewing with 1280 × 1024-pixel resolution. The refresh rate is 30 Hz. A Logitech surround sound system was used to provide Doppler effects and environmental sounds.

Eye Tracker. The ASL (Applied Science Laboratory) Mobile Eye XG was used to record drivers' eye movement. This eye tracking system consists of a pair of optics-outfitted goggles a camera capturing the driver's eye, a camera capturing the scene ahead, an ultraviolet light source, and a small reflective spectacle. The sampling rate is 30 Hz. The system software integrates the recorded eye and scene image into a single video, with a superimposed crosshair representing the location of gaze. The eye tracker has an accuracy of up to 0.5° of visual angle.

2.3 Scenarios and Warnings

All participants navigated a total of seven mini scenarios with potential (latent) hazards. Incoming traffic alerts were sent via a text message to the Google Glass 400 feet (approximately 10 s) prior to the posted traffic sign that displays the same message. One example of a mini scenario (Fig. 1) is: The driver is navigating a two-lane (one in each direction) city road, with a minivan parked immediately upstream on the right-side extremity of the midblock crosswalk that the driver is approaching. The minivan obstructs the approaching driver's view of a potential pedestrian entering the crosswalk from the right side. The latent hazard in this scenario is the potential pedestrian, the traffic sign is the 'pedestrian crossing' sign and the warning sent to drivers is "Crosswalk ahead". A detailed description of all scenarios and the corresponding warnings can be found in the study by Samuel et al. [11].

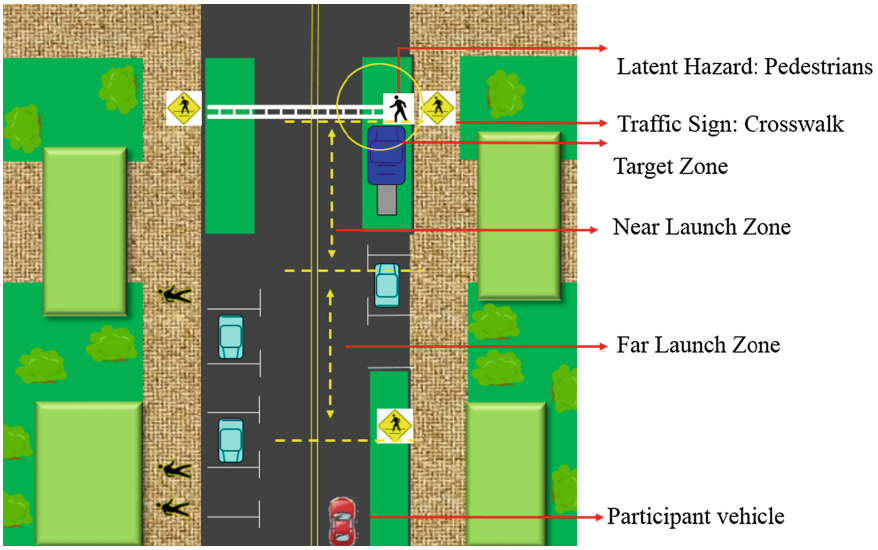

Fig. 1 Plan view of a mini scenario used in the experiment

2.4 *Experiment Design*

The current study uses a 2 × 2 Factorial between subject design with both, treatment condition (Google Glass/Control) and age (Young/Middle-aged) as between subject factors. Young and middle-aged drivers were randomly assigned to either the Google Glass condition or the control condition. All participants navigated the seven driving scenarios. Participants in the Glass condition received text messages warning them about the presence of a potential hazard. Sending of warnings was triggered at a fixed position in each scenario, which is 400 feet (approximately 10 s) in advance of the latent hazard. Participants were required to read the warning aloud to indicate successful receipt of the message. Drivers in the control condition received no such alerts.

2.5 *Procedure*

Upon arrival, participants were required to review and sign the consent form, after which they completed a short questionnaire collecting demographic and driving history-related information. Participants in the Google Glass condition then received fifteen minutes of training on Glass operation prior to the experiment. The training consisted of an overview of the Glass technology and practice trials of receiving and viewing the incoming message on the Google Glass prism by the head tilt method. The training would end when participants could successfully

receive the message three times in a row. Once the participant was seated in the sedan cab, the eye-tracker goggles was placed over the Google Glass (for the Glass group), eye-calibration was performed and the participant completed a practice drive to ensure he/she was comfortable with the simulated environment. Participants then navigated the 7 mini scenarios and completed a payment voucher following which they were debriefed and excused. The experiment lasted approximately 45 min in total.

2.6 Dependent Variables

We examined drivers' ability to anticipate latent hazards. A successful anticipation (coded as '1') was defined as glancing to the target zone at least once while participants are located in the launch zone. The target zone refers to the road area where a potential hazard could emerge and the launch zone refers to the area on the roadway where the participants should glance towards the target zone. Previous studies provide construct validity for the use of such target and launch zones [11, 12, 15]. Two launch zones, near and far, were predefined in this study. The near launch zone was defined as the 100 feet area immediately (0–100 feet) in advance of the hazard and the far launch zone was defined as the 100–200 feet area in advance of the hazard. The proportion of hazards successfully anticipated across the 7 testing scenarios were calculated for both the far and near launch zones. A two-way ANOVA (Analysis of Variance) was used to analyze the effect of age and Google Glass on drivers' latent hazard anticipation performance.

3 Results

The eye movement videos were coded by two experimenters independently. In case of inconsistency, a third experimenter would recheck the video and decide the best coding value. About 80 % of the coding results were found to be consistent between the two experimenters. An inter-rater reliability test was conducted and the Cohen's Kappa (inter rater reliability rating) for the sample was calculated to be 0.65.

3.1 Proportion of Alerts Successfully Sent and Received

There can be a small, communications delay that may be experienced between the warning message being sent by the experimenter and its subsequent display on the Google Glass prism. Drivers take about a second on average to view and read the warning message. A warning was deemed to be successfully sent only in those

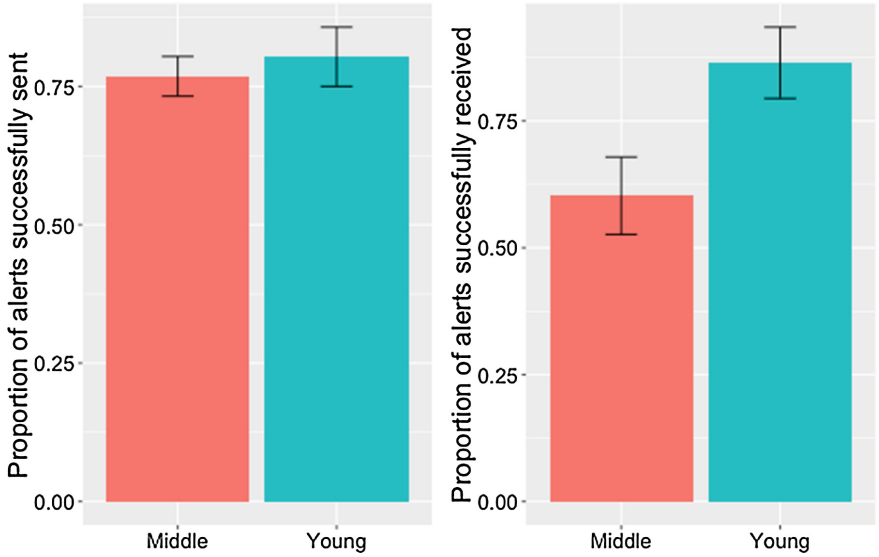

Fig. 2 Percentage of warnings successfully sent and received

situations where the warning was delivered on the Google Glass (as indicated by a chime) before drivers entered the far launch zone. Successful receipt of warnings by the participants is defined by whether drivers receive the message (as indicated by reading it aloud) before entering the far launch zone. About 76.83 % of all possible warnings were successfully sent to middle-aged drivers and 80.38 % to young drivers (Fig. 2). While young drivers successfully received 86.46 % of all the delivered warnings, middle-aged drivers only received 60.25 % of them. Data was submitted to an ANOVA and, the successful sending rates were not found to be significantly different between the two groups of drivers ($F = 0.317$; $p = 0.579$). However, there was a significant difference in receiving rates between the two groups ($F = 5.024$; $p = 0.035$). Only situations where warnings were successfully received by the drivers, were included for further analysis. All other events were excluded.

3.2 *Proportion of Latent Hazards Anticipated in Far Launch Zone*

On examining the proportion of latent hazards anticipated across both groups, the ANOVA results showed the main effect of age was significant ($M_{middle} = 54.0$ %; $M_{young} = 36.8$ %; $F = 4.296$; $p = 0.046$) while the main effect of Glass was not ($M_{glass} = 52.6$ %; $M_{control} = 41.2$ %; $F = 1.227$; $p = 0.276$). There was a significant second order interaction effect of age and Glass group ($F = 4.324$; $p = 0.045$),

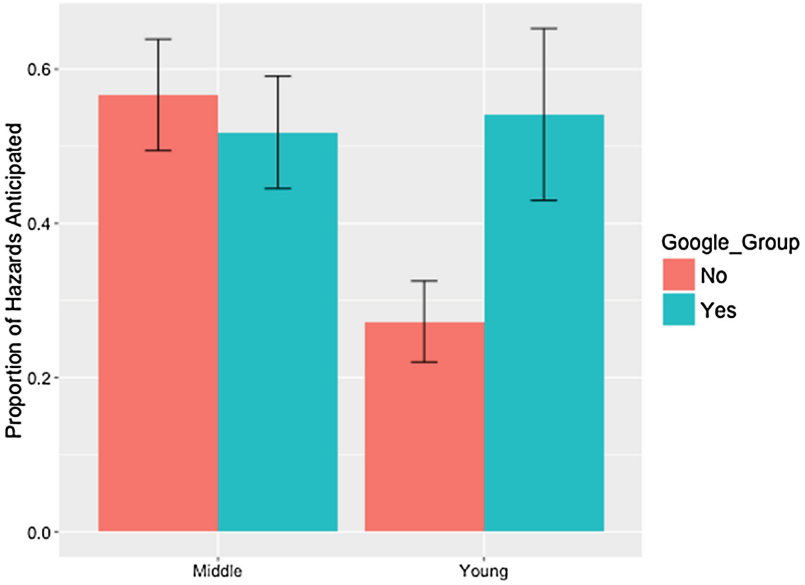

Fig. 3 Proportion of hazards anticipated in far launch zone

and as a result the effect of age at each Glass condition and the effect of Glass at each age level was separately analyzed (see Fig. 3). It was found that the latent hazard anticipation performance of young drivers was significantly affected by Google Glass, with drivers in the Glass condition anticipating nearly two times the proportion of hazards (M = 54.1 %) detected by those in the control condition (M = 27.2 %; F = 6.202; p = 0.025). For middle aged drivers, their performance was not significantly affected by the warnings from Google Glass (F = 0.221; p = 0.643). In the absence of warnings, young drivers anticipated a smaller proportion of hazards from the far launch zone than their middle-aged counterparts (F = 11.118; p = 0.003). However, in the presence of the traffic warnings, the hazard anticipation performance of young drivers approached a level, similar to that of middle-aged drivers (F = 0.032; p = 0.860).

3.3 Proportion of Latent Hazards Anticipated in near Launch Zone

The analysis of the proportion of latent hazards anticipated while in the near launch zone showed no significant main effect of age (F = 1.794; p = 0.197) and Google Glass (F = 0.423; p = 0.520) or their interaction effect (F = 1.798; p = 0.188). Young drivers anticipated 65.7 % of the hazards from the near launch zone while

middle-aged drivers anticipated 77.0 % of them. The proportion of hazards anticipated for participants in the Glass and control group was 68.8 and 75.8 % respectively.

4 Discussion

This study has explored the potential benefits of using Google Glass to present real-time, visual traffic warnings to drivers to alert them with respect to the presence of a potential latent hazard. It has been well documented in literature that young drivers lack the experience to develop good hazard anticipation ability, a cognitive skill that is shown to be critical for safe interaction with the traffic environment [14]. As a result, young drivers are less likely to fixate on areas where latent hazards could likely emerge [15, 16]. This finding has been replicated here, with young drivers found to anticipate a significantly smaller proportion of latent hazards in the far launch zone compared to the middle-aged drivers in the control condition. However, it was further found that when young drivers were alerted for the potentially hazardous events in advance, the proportion of hazards successfully anticipated doubled, approaching a level similar to that observed for the middle-aged drivers. The significant improvement supports the notion that young drivers are less aware of where to search for potential dangers, and simple hazard clues [1] or training [12] on hazards location can effectively direct young driver attention towards hazards.

Unfortunately, the alerts displayed on Google Glass showed no beneficial effect on the hazard anticipation performance of middle-aged drivers. The proportion of hazard anticipated in the far launch zone by middle-aged drivers actually decreased slightly (although not significantly) in the presence of the warnings. This is likely due to the fact that middle-aged drivers are slower at switching their attention (both visual and mental) from the HMD to the forward roadway (Patterson et al. 2006) [18]. As a result, there is a higher likelihood that middle-aged drivers may have still been focusing their attention on the warning message displayed on Google Glass when they were traveling in the far launch zone. It is also possible that the warnings in this study did not provide additional clues about the hazard compared with what middle-aged drivers were already aware of, given their greater driving experience. Since only approximately half of the hazards were successfully detected by middle-aged drivers in the far launch zone, there is still much room for improvement. Future studies are required in terms of assessing what assistive information should be provided to middle-aged drivers in order to help them better anticipate hazards on the roadway.

Some attentional distracting effects associated with HMDs have been reported in literature. For instance, use of HMD can limit the visual scanning range of the users or that HMD can result in the so-called cognitive capture effect (i.e. the inefficient attention switching from HMD to primary tasks) [17, 18]. These issues may increase the likelihood of users missing useful information in the outside roadway

environment. However, no evidence of such distracting effect for warnings on Google Glass was identified in this study. The fact that the warnings have either improved (young drivers in the far launch zone) or not impacted drivers' latent hazard anticipation performance suggests that Google Glass does not necessarily pose a visual distraction, at least when used to present task-related (driving related), traffic warnings.

While the use of Google Glass to deliver traffic warnings appears promising, more research attention is required for its practical application. First, only data for instances where warnings were successfully received was analyzed in the current study. In situations where warnings were not successfully received, it was observed that the drivers may have missed the entire scene developing on the roadway while struggling to obtain the warnings. Future studies should generate a more comprehensive evaluation of the effects of such traffic warnings on driver behavior. Second, no vehicular control data (such as velocity, lateral position, acceleration etc.) has been analyzed in this study and therefore, it is not known whether successful anticipation of the latent hazards translate to appropriate mitigating actions.

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Analysis of Stress and Strain in Head Based Control of Collaborative Robots—A Literature Review

Jochen Nelles, Susanne Kohns, Julia Spies, Christopher Brandl, Alexander Mertens and Christopher M. Schlick

Abstract The aim of this review was to provide an overview on possible fields where robots with head based control might be used. In that context another object was to investigate the effect of different neck movements on the user's stress and strain. All in all, 13 studies were included in this review. Their quality was evaluated by a checklist. A total of ten studies showed useful for the further approach. Five dealt with application possibilities for head based control. Four studies assessed the muscle activity of the neck via sEMG and five studies used other measurements for the assessment of stress and strain. In conclusion, there are many possible application areas for head based control which can be further developed to support working persons as well as disabled people. The application of a robot controlled via head movements will be investigated in an upcoming study following the recommendations gathered through this research.

Keywords Stress-strain-concept · Head movement · Head movement based control · Human machine interaction · Human robot interaction · sEMG · Motion tracking · Review

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1 Introduction

The recent development of industrial robotics leads away from (industrial) robots as part of (fully) automated manufacturing facilities, through to collaborative (lightweight) robots. Robots under development are located within a collaboration area together with the working person at the same workplace. This collaboration area is an area in which the robot and the working person can perform tasks at the same time during the manufacturing. Thus, the robots used in the industry are not limited to a movable component of automation, but working persons and robots working at the same time, in the immediate proximity and perform together a work task. This change raises inter alia the question of which input devices are suitable for a human-centered, usable, ergonomic and real-time capable (hands-free) robot control. The research project researches, develops and implements methods for supporting collaborative robots based on the measurement of head movements of the working person. Possible user scenarios for the robotic assistance system are jobs of skilled workers in the industrial assembly and office workplaces to support users with physical limitations or disabilities. Regarding the first scenario, robots could be integrated into manufacturing processes with hazardous materials. Like this, the human worker can control the robot from the distance in a safe area. Considering the second scenario, physically restricted working persons or elderly persons can—with the help of head-controlled robots—be enabled to remain in working life. This allows using the experience and skills of the users in an aging working population as long as possible. This review provides an overview of possible application fields for the head-based control of robots and gives implementations for future research on the ergonomic aspects of such a control. The planned research study deals with the head based control of a robot arm. Following Rohmert and Rutenfranz [1] stress-strain concept, to derive the corresponding design recommendations it is necessary to measure both the stress and the strain caused by the head based control of the robot arm. The physical stress in this case would be head movements (flexion/extension, lateral flexion, rotation of the head). The physical strain is represented by the muscular activity of the neck muscles. This review summarizes measurements that can be used to assess the user's stress and strain of the neck while moving the head in different angles and directions. The results gathered in the review shall serve as the basis for the planned research study on the effect of the head based control of collaborative robots on stress and strain.

2 Methods

2.1 Search Strategy

We conducted a systematic search in two online databases (Web of Science until 6 January 2016, PubMed until 22 December 2015) to select papers published in peer-reviewed journals. We searched for papers in Web of Science since 2000 and

in PubMed since 2010. To identify relevant papers we group the search terms into three groups: 'human-human-interaction', 'human-machine-interaction' and 'electromyography (EMG)'.

2.2 Inclusion Criteria

Studies were limited to those that are published in English. We search in the first step for relevant titles, in the second step we selected relevant abstracts and in the last step we read the paper to clarify whether the chosen paper are appropriate. We have chosen different criteria for the particular groups. At least we chose different terms for the particular searching group and databases: (1) 'human-human-interaction' (PubMed): "rotational head movements" OR "lateral head movements" OR "sagittal head movements" (2) 'human-machine-interaction' (Web of Science): "head movement" OR "neck movement" AND "head nodding" OR "head pitching" OR "head yawing" AND "control of robots" OR "control of machines" OR "control of computers"; (3) EMG (PubMed): "neck muscles" AND "electromyography". In addition we included two articles out of the systematic research.

2.3 Methodological Quality Assessment

We appraised each study using the following criteria: (1) 'topic/aim': Does the topic respectively the aim fit our searching context (e.g. head movement)?; (2) 'task': Should the subjects control something (e.g. computer mouse, robot-system)?; (3) 'study design': Do the authors describe the operationalization in explicitly, so that the study is replicable?; (4) 'measurements': Are sEMG or motion tracking used in the study?; (5) 'population': Differentiate the study various age groups or between healthy subjects and subjects with disability? (6) 'results': Does the study have relevant results? The criteria were summarized in a checklist, so that each criterion attached one point. For each study a quality score was expressed. The maximum score that a study can achieve are 6 points and the minimum score are 0 points. If a study had 0 till 3 points, we clarified this study as not relevant. So studies with 4 till 6 points are classified as appropriate.

3 Results

3.1 Characteristics of the Included Studies

The initial search identified 1123 references. After title and abstract screening, 20 references were retrieved for full text appraisal. After full text appraisal, 11 studies

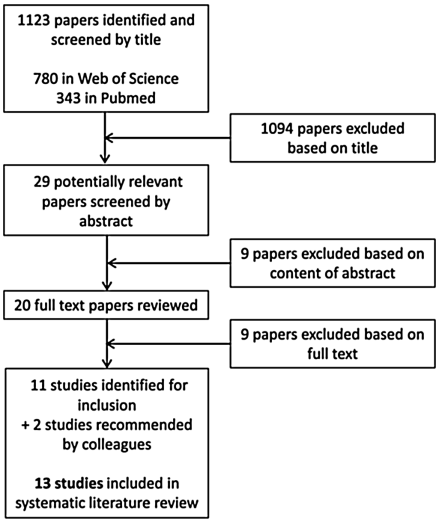

Fig. 1 Flow diagram of the study selection

were identified that met our inclusion criteria. In addition to the electronic search, two references recommended by colleagues were included (Rudigkeit et al. [2]). Altogether, 13 studies were included in this review. Figure 1 shows a flow diagram of the study selection. The extracted details of the included studies with their associated quality score can be found in Table 1. Ten laboratory studies, two field studies and one literature review conducted in 12 different countries were identified.

3.2 Application Context for Head Movement Based Control

In the research of the last years have been already many application fields in which head movement based control is explored. In the systematic research it could be found out three application fields: (1) human machine interaction; (2) human computer interaction; (3) human robot interaction. In the different research fields it could be found many laboratory studies.

(1) Human machine interaction: It could be selected many laboratory studies in which a wheel chair is controlled via head movement [3–5]. Craig and Nguyen [3] had designed a wheelchair which is controlled by head movements with a real-time head movement control system. The head movements of the subjects captured via a sensor, which is fixed on a baseball cap. The sensor had a wireless connection to a Personal Digital Assistant (PDA) which detected the head movements. Craig and Nguyen [3] found out that 97,14 % of the

Table 1 Extracted details of included studies (n = 13) with corresponding quality score

Topic/Aim	Task	Study design	Measurements	Population	Results	Author	Quality score
Evaluation of head movements through different methods	Assembly line task, 4 stations, preparation and installation of bumpers	Independent variables: 4 different tasks, 3 different measurements → 4 × 3-within-subjects-design dependent variables: angle of the head	Inclinometer on head and back, video observation	4 workers	Different angles at head and back movements, criteria: 0° < flexion < 20° and flexion > 45°	Zare et al. [12]	3/6
Identification of characteristics of non-verbal behavior (head movements) in communication	Application of measurement in different situations (dyadic conversation, clinical diagnostic, …) → interpretation of head movements	Independent variables: context of conversation, disorder dependent variables: movement of the head (sagittal, lateral, rotational)	Transducers attached to body parts send signals to ultrasonic receiver, subjective interpretation in different situations	Different (healthy, with clinical disorder)	Clinical study: e.g. patients with EPS show a normalization of head movements after change of medication	Altorfer et al. [14]	3/6
Comparison between 2 age groups regarding the effect of start position on the movement range of the neck	Rotation around the axle at different start positions: neutral, flexion and extension, protraction and retraction	Independent variables: 5 different start positions of the head, age group → 5 × 2-between-subjects-design dependent variables: movement range of the neck	Electromagnetic tracking, sensors on the forehead and sternum	2 age groups (each with 30 subjects): 18–30 years and 50–65 years	Start position influences anatomical structures that are involved in the limitation of the rotation of the neck	Walmsley [11]	5/6
Suitability of a head movement image (HMI) computer mouse	Users can swell their cheeks to activate and trigger the microswitch to command the cursor to single click, double click or drag, computer games should be played	Independent variables: head movement image (HMI) computer mouse; infrared computer mouse dependent variables: time needed to finish computer game; time needed to carry out commands	CCD monitoring camera	9 subjects with quadriplegia; all men; 33–43 years; experienced in controlling computers	Compared to the infrared computer mouse, the HMI computer mouse was more efficient ($p < 0.05$) in both tests		4/6
Pneumatic laparoscope holder controlled by head movement compared to manual operation by a scopist	Movement of the head (forth and back)	Independent variables: pneumatic laparoscope holder dependent variables: translation velocity of the head movement; tracking performance of the pneumatically driven robotic arm; tracking performance of the developed holder system	2 gyroscopes attached to head and body	"The operator"	Robotic camera holder quickly follows head movements of the operator		4/6

(continued)

Table 1 (continued)

Topic/Aim	Task	Study design	Measurements	Population	Results	Author	Quality score
Control of a wheelchair via head movements with a real-time head movement control system	Bending back and forth or to the left/right, when resting position changes, the system is recalibrated	Independent variables: head movements dependent variables: detection of the movements through a Personal Digital Assistant (PDA)	Sensor at a baseball cap, wireless connection to PDA → Bluetooth	10 voluntary subjects; 400 samples (200 training, 100 validation, 100 test set)	97.14 % of the movements correctly identified	Craig and Nguyen [3]	6/6
Investigation of sternocleidomastoid-activity while using a head control system (e.g. for wheelchair)	Comfortable sitting position, arms fixed, different head movements: flexion/extension, bending to the left/right, rotation to the left/right (30°, 45°, 60°) → targets on the wall; all movements 5 times, in between 3 min rest	Independent variables: head movements dependent variables: sEMG-value	sEMG (sternocleidomastoid SCM), ECG; EEG, blood volume plethysmography	7 volunteers (5 male, 2 female) average age 32 ± 8, 2 of the male subjects with disability at the spine	Bending of the head: stronger contribution of the ipsilateral SCM, EMG signal most consistent at rotation	Martinez-Coll et al. [4]	4/6
Control of a wheelchair via head movements or facial expression	Head movements: e.g. control mode 1: down → STOP or back; up: going forward; to the right/left → turning right/left, confirmation through preferred facial expression for the movements except for STOP; 10 experiments; route with obstacles	Independent variables: head movements and facial expression → mode 1 and 2 dependent variables: time needed for route	Emotiv EPOC headset → detection of EmoState, EEG signals	2 healthy subjects aged 31 years, 1 male, 1 female	HMI safe and reliable	Rechy-Ramirez and Hu [5]	5/6

(continued)

Table 1 (continued)

Topic/Aim	Task	Study design	Measurements	Population	Results	Author	Quality score
Investigation of changes in the muscle activity of the neck for different movement angles during flexion/extension	Movement angle: neutral, 30°, full range of motion, extension/flexion	Independent variables: movement, movement angle, muscle → 2 × 3 × 5-within-subjects-design dependent variables: muscle activity	EMG (sternocleidomastoid, splenius capitis, splenius cervicis, upper trapezius, middle trapezius)	24 students (average age 20,5 years)	Increased muscle activity at flexion and extension	Lee et al. [8]	5/6
Investigation of the effect of different tasks (e.g. stretching of the neck) during rest breaks at work	60 min writing task, each 20 min 3 min break, 3 groups: stretching, dynamic movement, control group	Independent variables: 3 group dependent variables: muscle activity, muscle pain, muscle productivity	EMG (right upper trapezius, right lower trapezius, right anterior deltoid and cervical erector spinae) Borg scale	35 secretaries aged between 18 and 40 years with computer-work determined neck pain, right handed	No difference between the different rest break interventions, muscle pain increases over time	Nakphet et al. [9]	4/6
Measurement of muscle activation and work load of female sewing machine operators	200 min of work at sewing machine	–	sEMG (bilateral cervical erector spinae and upper trapezius)	18 female sewing machine operators aged between 20 and 30 years, right handed	Amplitude higher before work begins → adoption of static position	Zhang et al. [13]	2/6
Investigation of the activation levels of different muscles of the neck and a gender effect	20 min; 36 tasks: e.g. flexion/extension, rotation, protrusion and retrusion, head leaning etc.; different angles	Independent variables: movements, angle dependent variables: muscle activity	EMG (right sternocleidomastoid muscle, right upper trapezius muscle motion capture	17 students (9 female, 8 male) aged between 20 and 26 years, right handed	No gender effect; sternocleidomastoid muscle more active at head movements, upper trapezius muscle more at trunk and arm movements	Ng et al. [10]	4/6
Identification of gestures via motion sensors	4 gestures: nodding (up, down), bending (left, right), 5 repetitions	Independent variables: gestures dependent variables: identified gestures through motion sensors	Motion sensors (IMU)	10 healthy students (3 female, 7 male) aged between 27 and 48 years	High average classification rate	Rudigkeit et al. [2]	5/6

movements were correctly identified. In addition Rechy-Ramirez and Hu [5] had designed a wheelchair which is controlled by head movements or with facial expressions. An Emotiv EPOC headset detected electroencephalography (EEG) signals of the subjects. The authors found out that the human machine interface worked safe and reliable.

(2) Human computer interaction: In the field of computer mouse control Chen et al. [6] tested the suitability of a head movement image (HMI) computer mouse in a laboratory study. The efficiency of a head movement image (HMI) computer mouse was compared to an infrared computer mouse in two tests. It could be found out that the head movement image (HMI) computer mouse was more efficient ($p < 0.05$) than the other one in both tests.

3) Human robot interaction: In the research of pneumatic laparoscope holder Tadano and Kawashima [7] tested the efficiency of a pneumatic laparoscope holder controlled by head movement and compared these results to manual operation of a scopist. Regarding to our searching context they found out that the robotic camera holder which is used quickly follows head movements of the operator.

3.3 Measurement of Stress and Strain

The measurement of stress and strain could also be found in various laboratory studies. It could be selected many studies where electromyography (EMG) is used to measure the stress of subjects during activate various muscles [4, 8–10]. Martinez-Coll et al. [4] measured the stress of subjects during wheelchair control. They found out that while bending the head the ipsilateralen SCM was contributed strong. Additionally they found out that the EMG signal most consistent at rotation. Lee et al. [8] investigated changes in the muscle activity of the neck for different movement angles during flexion and extension. The results of the investigation showed that the muscle activities of the subjects were increased both at flexion and extension. In addition Naphket et al. [9] investigated the effect of muscle activity at different tasks (e.g. stretching of the neck) during rest breaks at work. They measured the stress of various muscles (right upper trapezius, right lower trapezius, right anterior deltoid and cervical erector spinae. Furthermore the subjective stress of the subjects was measured with a Borg scale. They found out that there was no difference between the different rest break interventions and that the muscle pain increases over time. In a laboratory study Ng et al. [10] investigated the activation levels of different muscles of the neck. A gender effect was not found. Besides the strain of subjects via motion tracking was measured. They found out that the sternocleidomastoid muscle of the subjects was more active at head movements and that the upper trapezius muscle was more at trunk during arm movements.

3.4 Possible Head Movements for Head Based Control

In many laboratory studies different head movements and angles for head based control were used. Walmsley [11] investigated neck rotation around the axle at different start positions—neutral, flexion and extension, protraction and retraction—to carry out the effect of start position on the movement range of the neck. The authors found out that the start position influences anatomical structures that are involved in the limitation of the rotation of the neck. Zare et al. [12] used the following angles: 0° < flexion < 20° and flexion > 45°. In addition Martinez-Coll et al. [4] used 30°, 45°, 60° angles during left and right rotation. Also Lee et al. [8] used 30° angle during flexion and extension of the neck. Furthermore Ng et al. [10] conducted a study which aimed neck and shoulder muscle activity during standardized work-related postural tasks. At this, inter alia, neck extension and neck flexion with angles from 20–30° were examined.

4 Discussion

The aim of this review was to find possible application fields in which humans can control robots or machines via head movement. In connection with that, possible measurements should be collected which help assessing the user's stress and strain of the neck while controlling a robot. For this purpose, a systematic literature research was carried out. The findings shall serve as a guideline to develop a research study, investigating the stress and strain of the neck while controlling a robot arm via head movements.

4.1 Strengths and Limitations

Only one study (Walmsley et al. [11]) used two age groups (18–30 years and 50–65 years) when measuring stress and strain of the neck. Separating between rather younger and rather older people is considered practical because especially when it comes to strain important differences are assumed. Therefore, in the planned research study two age groups will be investigated.

Studies investigating head based control systems for the application at disability mostly did not divide their samples into healthy and disabled subjects. In two cases only healthy [3, 5], in one only disabled subjects [6] were investigated. Only one study [4] observed both healthy and disabled people [4]. This has the advantage that the two groups can be compared to each other, so that possible differences can be identified and used for a modification of the system.

It was very striking that nearly all of the studies found in our research did have small, mostly too small samples. Finding subjects especially can be difficult when disabled people are integrated in a study, because these are not easy to assess. Though, it is important to have an appropriate number of subjects in a study to gain reliable results. Samples always need to be representative for the population referred to.

The studies dealing with the head based control systems all showed good results regarding the identification of the head movements [2, 3, 5, 6]. In all cases the systems captured and identified nearly all of the movements and facial expressions and reacted correctly. This shows that well developed technology for head based control does already exist and is ready for further application in other fields.

4.2 Implications for Practice

Apart from the technological approach the consideration of the ergonomic aspects of controlling a robot via head movements is also essential. Through the research it could be found out that there are many possibilities for measuring the user's stress and strain of the neck. A very common method for assessing the physical strain, i.e. the muscular activity of the neck, is through surface electromyography (sEMG) [4, 8–10, 13]. When using sEMG, the position of the electrodes is important to get reliable results. Therefore, the use of muscles which are hard to access should be avoided. Most of the studies found in this research decided to measure the sternocleidomastoid, the trapezius and the cervical erector spinae muscle. A few studies also used electroencephalography (EEG) to assess the activity of the brain [4, 5].

4.3 Implications for Future Research

Referring the stress-strain concept by Rohmert and Rutenfranz [1] the planned research project will measure stress and strain. The physical stress, i.e. the head movements (flexion/extension, lateral flexion, rotation of the head), can be measured via an inertial measurement unit (IMU) or via an infrared motion tracking camera system. The resulting physical strain, i.e. the muscular activity, can be measured via (surface) electromyography, which is the common measurement [8, 9, 13]. The chosen measurements will help to evaluate the stress and strain to derive ergonomic recommendations so that the head based control system can be modified if possible.

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Design a Stretchable Elbow Brace by the Use of 3D Printed Mesostructure

Yun-Jing Li, Chien-Hsu Chen, Zheng-Yu Hoe and Zong-Xian Yin

Abstract In addition to the functionality, wearing ease is also an important element for joint protective garment design. Besides, clothing fit is one of the important factors controlling the wearing ease. However, previous research in this area has been neither sufficient nor systematic. As elbow joint is one of the most strained joint of the body, the skin surface around it also has significant length change. Therefore, in this research an attempt has been made to analyze and quantify the length variations of skin surface around the elbow joint, and arrange a stretchable mesostucture on the base of these variations. 3D printing with its advantages of rapid manufacturing and design complexity than traditional textile industry, it is the method used for making the prototype in this study. Finally, an application for elbow brace design of the research results is suggested.

Keywords Wearing ease · Clothing fit · Elbow brace · 3D printed textile · Stretchable mesostructure

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1 Introduction

Wearing ease is one of an important element for joint protective garment design, as a proper design of wearing ease can ensure wearers' comfort and mobility. Besides, clothing fit is one of the main factors controlling the wearing ease. Clothing fit is determined by the formability of the garment, meaning the ability to stretch or contract according to the deformation of the skin during static or dynamic postures. However, previous research in this area has been neither sufficient nor systematic. There has been merely some research about the protective garments in workplace, but rarely about the home and sports protection which are more commonly used in lives. Within protective garments used for joints, elbow braces are one of the most commonly used whether for athlete protection or for home care. There are two major types of elbow braces to wear: self-adhesive types and sleeve types. Self-adhesive types are provided with sticky tapes or buckles to fasten and to be size-adjustable for different users, so they are easier to put on and take off. Whereas, sleeve types are usually one-piece knitting structures, they have better fixity and flexibility which can prevent discomfort caused by large movement. However, sleeve types have the disadvantage of being more difficult to wear. Regarding these two types of elbow braces, they have different advantages of wearing ways, but there has been little consideration about the clothing fit of them, which also plays an important role in the functionality and wearing ease of the elbow braces. Besides, as joints are pivots of body movements, they determine how the body moves, but their mobility is also affected by the clothing fit of the protective garments. Therefore, some attempts have been made to quantify and develop reliable techniques to measure the decrease in joint mobility due to the wearing of protective garments. Huck [1, 2] and Adams et al. [3] tested the restrictions to body movement caused by the wearing of protective garments, and as expected, they suggested that it is important to consider the mechanism of body movement, including joint functioning when evaluating the restrictive nature of protective garments. However these studies only showed the fact and the amount of decrease in mobility caused by the wearing of improperly designed protective garments. For practical use, it is important to analyze how the restrictions happened, and how the designers can improve. On the other hand, as clothing fit is affected by the formability of the elbow braces, to achieve good formability, special consideration should be given to their elastic recovery property, viz., the ability to recover from repeated deformation during different dynamic movements. Further, as the deformation of the elbow braces is mainly affected by the expansion and contraction of skin surface during different movements, it is a good approach to realize how the deformation is caused by observing and quantifying the length variation of the expansion and contraction of the skin. Therefore, there were some studies suggesting the approaches to measure the anthropometric data variations of the skin surface between static and dynamic postures. Additionally, the approaches applied in these studies to quantify the length variations of the skin surface during different joint movements were similar, as the measurement methods used by these researchers were the concept of

defining the distance between two different locations by use of several dots or gridlines. Wang et al. [4] used 74 anatomical landmarks on the skin surface of the subjects. And they collected data about the girth, width and length of different joints as the information corresponding to the wearing ease of the clothing design. Apart from directly placed the landmarks on the skin, Makabe et al. [5] and Kirk et al. [6] used the experimental garments of elastic fabrics such as polyester or Lycra, and marked several orthogonal gridlines with consistent distance on the experimental garments. By means of the experimental garments, it could be more accurate and easier to mark and measure the change of the landmarks or gridlines during dynamic movements. Therefore, in this study, an elastic-fabric garment marked with several horizontal and vertical gridlines is used as the experimental garment for quantifying the skin expansion and contraction value of the elbow joint dynamic postures: bending the arm by different degrees from 0 to 150.

In order to design a stretchable elbow brace based on the values of skin expansion and contraction during the elbow movements, a well-stretchable meso-structure is used for the construction. In addition, 3D printing is the method used for making the prototype in this study, with its advantages of rapid manufacturing and design complexity than traditional textile industry. As there has been a stretchable meso-structure named Mesostructured Cellular Materials which has been adapted in several studies of 3D printed flexible textile design [7, 8]. It was originally developed by Andreas Bastian with the attempt to explore a flexible 3D printed structure. Such a structure can create a bending surface without buckling or folding [10]. As a result, a mesostructure adapted from the Mesostructured Cellular Materials is used for the design in this study. However, the material used for the 3D printed Mesostructured Cellular Materials in the past studies were inflexible ABS or PLA filaments, even the structure was flexible, it might be fragile and even broken while bent. As a result, an elastic filament named TPE (thermoplastic elastomer) is used for making the stretchable 3D printed mesostructure of the stretchable elbow brace in this study.

2 Methods

A more objective method to define the clothing fit values have been quantifying and analyzing the expansion and contraction of body's skin surface during body movements. Manual tape measurement is one of the common methods used for collection of anthropometric data, and it is more suitable than another 3D scanning method when obtaining data in dynamic postures. Whereas, there has been another method similar to the tape measurement method by an experimental garment marked with vertical and horizontal gridlines, this method also has an advantage of no body contact. Therefore, the experimental garment method is used in this study to collect the data about the length of skin surface during elbow joint movements. And the elongation rate of the skin length between the expansion and contraction was also analyzed. Then the sizes of the stretchable mesostructure were adjusted according to the length variations of each vertical and horizontal gridline. In

addition, due to the advantages of the 3D printing technology, such a high-performance structure was easier and faster to be manufactured. Therefore, there is an application of the research results to design an innovative stretchable elbow brace made by 3D printing stretchable mesostructure.

There were two major steps as below:

1. Acquisition of anthropometric data: Made an experimental garment of elastic Lycra fabric according to the arm circumferences of the subject, and marked several vertical and horizontal gridlines on it. Next, the length variations of each gridline between the postures of bending the arm by 0–150° were collected.
2. Configuration and 3D printing of the stretchable mesostructure: Based on the data collected from step one, adjusted the sizes of stretchable mesostructure and arranged them on the corresponding positions of the elbow brace, and made a prototype by 3D printer with the use of elastic TPE filament.

2.1 Acquisition of Anthropometric Data

To accurately collect the anthropometric data of skin surface by the use of experimental garment, it should be as fitting as possible. That means, the fabric can stretch and recover according to the expansion and contraction of skin surface during dynamic postures. As there have been some studies exploring the performance of different elastic fabric, it has been generally suggested that Lycra fabric has the best stretching performance and it also has a more consistent amount of stretching when stretched in different directions. As a result, it has been commonly used in protective garments to provide the wearer a better mobility. Besides, Kirk et al. [6] used the spun yarn containing Lycra to make the experimental garment attempting to study the relationship between the stretching of skin and clothing fit. Therefore, Lycra fabric was used to make the experimental garment in this step.

As an elbow brace should be fitting to the subject, the circumferences of the elbow and related segments on the upper and lower arms of the subject were measured. Then a customized experimental garment of Lycra fabric was complete. In order to measure the vertical and horizontal differences of skin stretching, several orthogonal gridlines with the consistent distance of 1 cm were drawn on the back side of this experimental garment. The process is displayed in Fig. 1.

As the elbow joint is a kind of hinge joint, its movements of flexion and extension are all located on one plane. And the general range of the elbow motion is between 0 and 150°. Therefore, it has been an effective way to define the desired motion of the joint by marking the pivot and axis of different degrees on the related plane, as the motion board Makabe et al. [5] used in their study to define different motions of the upper limb. Therefore, in this study, the motion of the elbow joint is defined from 0 to 150° with the consistent distance of 30°, and the pivot and each

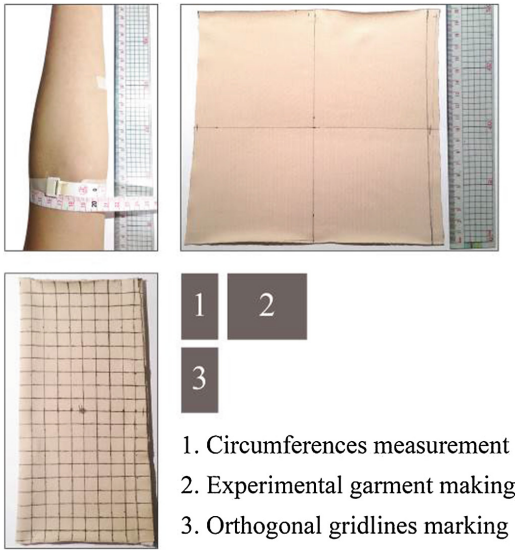

Fig. 1 Making of the experimental garment

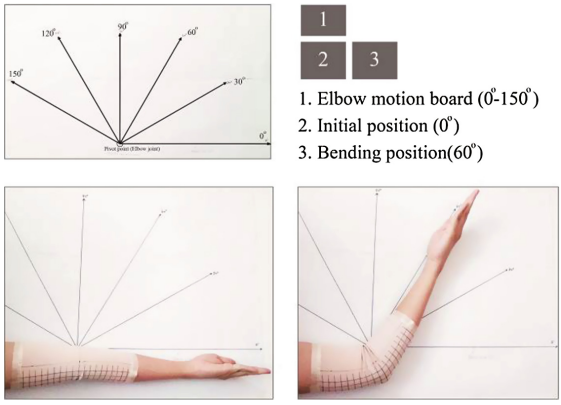

Fig. 2 Elbow motion board with the elbow motions

axis are drawn on the motion board as shown in Fig. 2. The subject wearing the experimental garment then stood side against the motion board, and raised the arm aligning the 0° baseline which had been adjusted according to the subject's height, and the elbow joint should be aligned to the pivot. As to collect the length for calculating, images at three front views of the upper arm, the elbow joint and the lower arm of each elbow posture were taken by a camera from a consistent distance. By doing so, it could be ensured that all gridlines in these images were more similar to their real size without deformation. As to measure the length of each gridline in the images, the measuring tool of the image editing software was used in this study to measure the distance of two neighboring dots as shown in Fig. 3.

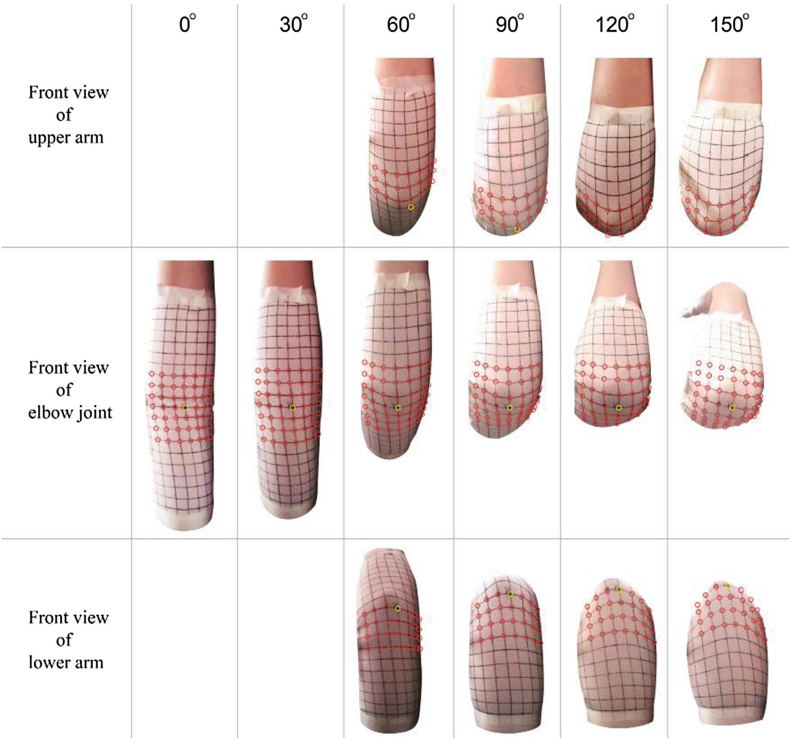

Fig. 3 Three different front views during different elbow postures for measuring the length of each gridline

2.2 *Configuration and 3D Printing of the Stretchable Mesostructure*

As 3D printing has many advantages in rapid manufacturing, there has been an increase in the 3D printed textile in recent years. Besides, it has overcome many limitations of the traditional manufacturing such as the design complexity, and it is more cost-efficient and environmentally sustainable as being an additive manufacturing. The diversity of filaments is another feature of 3D printing. Therefore, there have been some studies about the flexible performance of the 3D printed textile, with the purpose to make the softer and more comfortable 3D printed textile like the traditional knitted textile [7–9]. In these studies, the flexibility is obtained by the characteristics of flexible filaments such as TPE. TPE (thermoplastic elastomer) is a flexible material and acts much like elastic rubber. As it also has excellent abrasion resistance, as well as consistent diameter and smooth feeding properties, it is allowed to print high-quality things. Therefore, TPE filament is the material used for 3D printing in this study. As there has been a stretchable

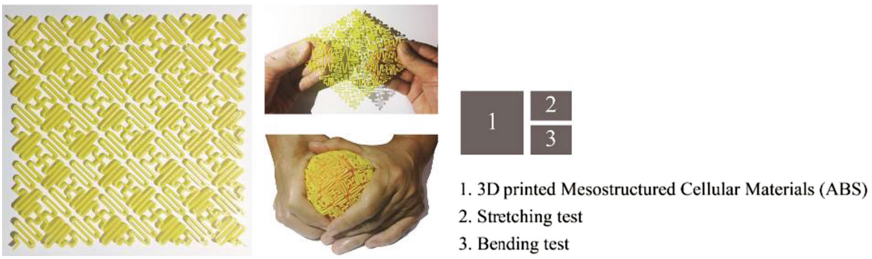

Fig. 4 Stretching and bending test of the 3D printed mesostructured cellular materials

mesostructure named Mesostructured Cellular Materials which has been adapted in several studies of 3D printed flexible textile design [7, 8]. It was originally developed by Andreas Bastian with the attempt to explore a 3D printed flexible structure. Besides, this structure has a property named synclastic. That means, it can assume compound curvature by bending in two orthogonal directions on the same side, hence it can create a bending surface without buckling or folding [10] as the stretching and bending test shown in Fig. 4. Therefore, as the advantages described above, the 3D printed stretchable mesostructure adapted from the Mesostructured Cellular Materials with the use of TPE filament is used for the prototype of the stretchable elbow brace designed in this study.

The configuration of the Mesostructured Cellular Materials can be varied by the use of different arrangements, or the gradient adjustment in size and density. Such a good example was the 3D printed corset designed by Lussenburg et al. [8], as it was entirely constructed of 3D printed Mesostructured Cellular Materials by changing the constructions and gradient size for different parts. 3D printed flexible structure has also been used as a good connector with the soft fabric to make a stretchable clothing such as the corselet and bracelet projects in the study of Mikkonen et al. [7]. With the inspiration of these projects, an application of the result of this study is made by the use of adapted 3D printed mesostructure connected with the elastic fabric of Lycra. In Fig. 4, by stretching and bending the 3D printed Mesostructured Cellular Materials, it can see that the flexibility of this structure is obtained by the expansion and contraction of the curved lines within it. To explain it further, in Fig. 5, the initial length without stretching is determined by the length of each horizontal segment, and as the structure is gradually stretched to the sides, the opening of each curved lines becomes bigger and hence the angle of each vertical segment becomes gradually smaller until it turns a horizontal line when it is laid as 0°. As a result, as the structure is totally stretched as a horizontal line, its initial length can expand 3–4 times as shown in Fig. 5. Based on this expansion process, the stretchable mesostructure used in this study was designed according to the results of the skin stretching values, especially the minimum value (as the initial length), maximum value, and the elongation rate.

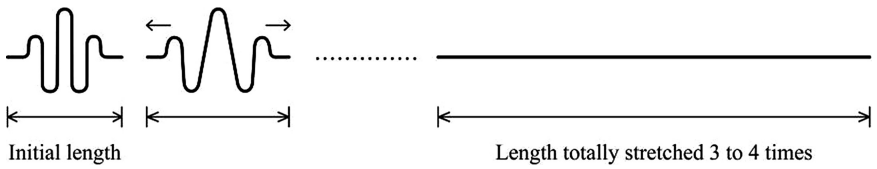

Fig. 5 Expansion process of the mesostructured cellular materials

3 Results and Discussion

3.1 Length Variations of Each Gridline During Different Elbow Movements

Tables 1 and 2 show the length of each vertical and horizontal gridline during each elbow joint motion from 0 to 150°, in each field are three data about the minimum length, the maximum elongation rate and the angle at which when it stretches to the maximum value. In Table 1, the maximum length of each vertical gridline appears at different degrees of motions. However, the vertical gridlines located in the same horizontal section (the vertical gridlines in the same section of two nearby horizontal gridlines) stretch to the maximum during the same degree of motion. On the other hand, Table 2 shows the length of each horizontal gridline during different degrees of motions. It can see that the maximum value of each horizontal gridline almost simultaneously appears at the motion of 150°, and the horizontal gridlines located between the same two nearby vertical gridlines stretch to the maximum value at the same time, too. From these two results, it can see that though the length variation of each gridline isn't evenly distributed, the gridlines in the same sections (such as the vertical gridlines located in the same section between the horizontal gridlines number 1 and 2 as shown in Fig. 6) commonly stretch to the maximum value at the same time. On the other hand, as most of the maximum elongation rate of the gridlines are less than 50 %, these are all within the expansion range of the Mesostructured Cellular Materials. Therefore, in order to ensure that all of these gridlines can also contract to their minimum length well, the initial length of each mesostructure arranged on them should be the minimum length of the corresponding gridline. Therefore, the average minimum length of the vertical gridlines between each horizontal section and the average minimum length of the horizontal gridlines between each vertical section are calculated as shown at the rightmost row and the lowest row of Tables 1 and 2 separately.

3.2 3D Model of the Stretchable Mesostructure

As the results of Tables 1 and 2 show that the gridlines in the same sections commonly stretch to the maximum values at the same time. And as the reason that

Table 1 Length of each vertical gridline (minimum length (cm)/maximum elongation rate (%)/ angle of the maximum length)

	A	B	C	D	E	F	G	Average minimum length
1-2	0.9410.6 % (150°)	0.96 10.4 % (150°)	0.95 43.2 % (150°)	0.93 42 % (150°)	0.93 26.9 % (150°)	0.90 16.7 % (150°)	0.79 20.3 % (30°)	0.91
2-3	0.8223.2 % (30°)	0.83 24.1 % (30°)	0.86 32.6 % (60°)	0.80 35 % (30°)	0.76 39.5 % (30°)	0.67 50.8 % (30°)	0.59 66.1 % (30°)	0.76
3-4	0.867 % (30°)	0.84 20.2 % (150°)	0.79 44.3 % (150°)	0.81 42 % (150°)	0.83 32.5 % (150°)	0.84 20.2 % (150°)	0.77 18.4 % (30°)	0.82
4-5	0.6066.7 % (30°)	0.70 47.1 % (60°)	0.91 23.1 % (90°)	0.86 32.6 % (90°)	0.81 33.3 % (90°)	0.76 32.9 % (90°)	0.78 16.7 % (90°)	0.77
5-6	0.8517.7 % (90°)	0.95 13.7 % (120°)	0.99 18.2 % (120°)	0.97 22.7 % (90°)	0.96 20.8 % (120°)	0.90 17.8 % (120°)	0.73 32.9 % (90°)	0.91
6-7	0.978.3 % (90°)	1.03 14.6 % (120°)	1.05 21 % (120°)	1.03 22.3 % (120°)	0.97 24.7 % (150°)	0.96 17.7 % (120°)	0.85 20 % (120°)	0.98

Table 2 Length of each horizontal gridline (minimum length (cm)/maximum elongation rate (%)/ angle of the maximum length)

	A-B	B-C	C-D	D-E	E-F	F-G
1	0.72 51.4 % (120°)	0.98 13.3 % (120°)	0.90 14.4 % (90°)	0.93 19.4 % (90°)	0.86 27.9 % (150°)	0.58 75.9 % (150°)
2	0.74 52.7 % (150°)	1.01 12.9 % (120°)	0.88 32.8 % (150°)	0.92 29.4 % (150°)	0.81 46.9 % (150°)	0.54 96.3 % (150°)
3	0.77 49.4 % (150°)	1.00 21 % (150°)	0.91 36.3 % (150°)	0.88 44.3 % (150°)	0.69 79.7 % (150°)	0.54 118.5 % (150°)
4	0.82 32.9 % (150°)	0.98 13.3 % (150°)	0.89 16.9 % (30°)	0.87 35.6 % (150°)	0.69 66.7 % (150°)	0.43 134.9 % (150°)
5	0.83 32.5 % (150°)	0.97 11.3 % (150°)	0.86 12.8 % (90°)	0.84 28.6 % (150°)	0.57 87.7 % (150°)	0.48 137.5 % (150°)
6	0.86 25.6 % (150°)	0.95 9.5 % (150°)	0.87 9.2 % (90°)	0.80 26.3 % (150°)	0.53 96.2 % (150°)	0.41 146.3 % (150°)
7	0.87 26.4 % (150°)	0.99 6.1 % (90°)	0.89 9 % (90°)	0.78 28.2 % (150°)	0.54 88.9 % (150°)	0.32 175 % (150°)
Average minimum length	0.80	0.98	0.89	0.86	0.67	0.47

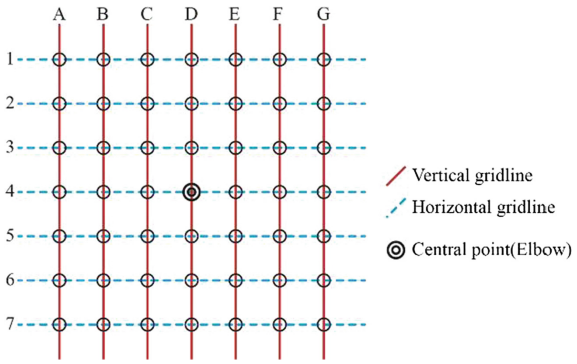

Fig. 6 Illustration of each vertical and horizontal gridline

all of the maximum elongation rate of the gridlines are within the expansion range of the Mesostructured Cellular Materials, the initial length of each mesostructure arranged on them should be the minimum length of the corresponding gridline. Therefore, the proportion of the stretchable mesostructure is adapted from that of the Mesostructured Cellular Materials, and a gradient adjustment in sizes is made based on the average minimum length of the gridlines between each section. And the 3D model is made in the Solidworks software, as it is one of the commonly–used CAD software for the digital manufacturing. Besides, in order to make a seamless connection between the 3D printed mesostructure and the soft Lycra fabric for the entire design of the stretchable elbow brace, several button holes are evenly distributed along four sides of the mesostructure in the 3D model. Finally, the 3D model for 3D printing is shown as Fig. 7.

3.3 Prototype of the Stretchable Elbow Brace

As shown in Fig. 8, a prototype of the stretchable elbow brace as an application of the research results is made with the use of the 3D printed stretchable mesostructure

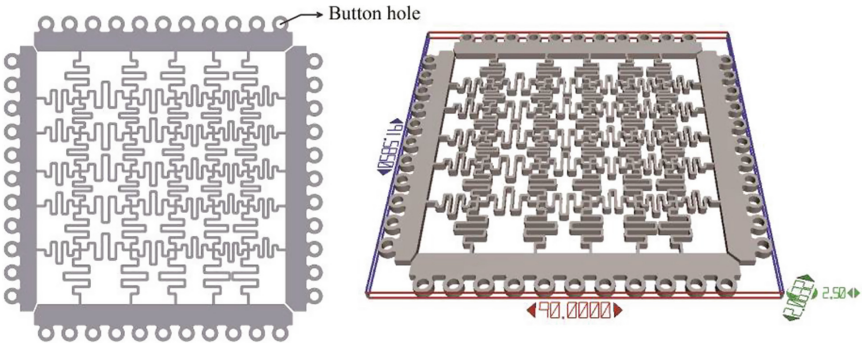

Fig. 7 3D model of the stretchable mesostructure

Fig. 8 Prototype of the stretchable elbow brace

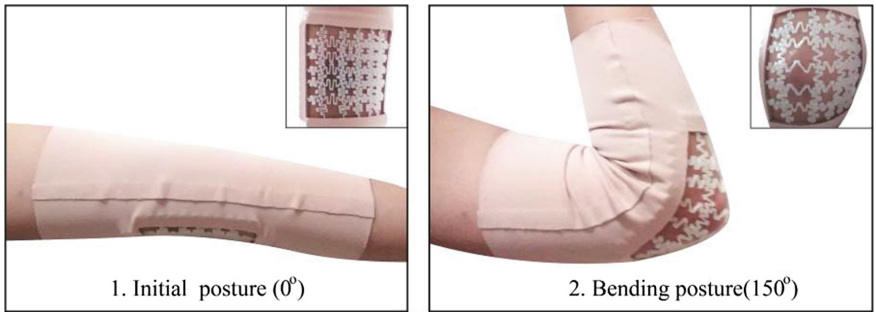

Fig. 9 Clothing fit test of the stretchable elbow brace

and the elastic Lycra fabric. To test the clothing fit performance of this stretchable elbow brace, the subject wearing the stretchable elbow brace bends the arm by 0–150°. Figure 9 shows the result of the clothing fit test, it can see that as the flexibility characteristics of the elastic TPE filament and the stretchable mesostructure, the section of the elbow brace around the elbow joint is more fitting to the skin no matter bending the arm by the minimum or the maximum degree.

4 Conclusion

An attempt has been made to analyze and quantify the length variations of skin surface around the elbow joint during different degrees of elbow motions. By using the experimental garment marked with the orthogonal gridlines, and the motion

board defined with the standard elbow motions by 0–150°, the anthropometric data about the expansion and contraction values of the skin surface are collected. To design a more stretchable elbow brace with a high performance of clothing fit, a stretchable mesostructure adapted from the Mesostructured Cellular Materials with a gradient size is made based on the data from the experiment. Finally, the stretchable mesostructure is made by the FDM 3D printer with the use of elastic TPE filament. Further, to construct the entire stretchable elbow brace, the 3D printed stretchable mesostructure is connected seamlessly with the elastic Lycra fabric with the use of several 3D printed button holes. Generally speaking, in this study, a method is suggested to systematically quantify the anthropometric data about the skin's expansion and contraction, the data is further used for the design of the stretchable mesostructure. Finally, by using this method, an innovative 3D printed mesostructure connected with the elastic Lycra fabric is used for the more stretchable elbow brace design that has a better clothing fit performance. It is suggested that, this method can be used for the designer to design the protective garments or other high-performance clothing, as clothing fit is one of the important properties to them.

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Development of a New Information Interface for Elderly Using Vibrations

Stefan Lutherdt, Fred Roß and Hartmut Witte

Abstract For older people it is often necessary to have additional orientation aids esp. when they have to leave their familiar environment. To find a location for implementing such a supporting and helping information interface into daily used and well-known things shoe soles were identified as a possible usable place. To derive the requirements and application parameters several tests were processed and afterwards with their results test equipment consists of sandals with vibrational soles, power supply and electronic components for controlling it was assembled. First tests had shown the general applicability of these soles and shoes to give the needed information to older people, but some optimizations have to be done before the system can be applied for daily use.

Keywords Vibrational interface in shoe soles · Vibrotactile stimulation · Orientation aid for elderly · Information interface

1 Motivation and Project Aims

The change in the demographical pyramid is one reason for the increasing number of age caused diseases. Therefore, it is reasonable to develop new devices to help the elderly to obtain quality of life and independence.

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Fig. 1 LECHAL (Hindi for "bring me home"), (*left*): version as a whole shoe with integrated vibration sole; (*right*): sole-only version to integrate vibration stimuli into any kind of shoe [4]

In the last years, researches more and more focused on vibrotactile stimulation, especially in the field of interface design. Throughout the years, more improvements were achieved due to different studies on the devices used, the target group and the application area on the human body. Initially, the actuators were embedded in a belt [1, 2]. This stimulation zone provides a large contact area with the actuator, and consecutively the capability to realize a high information load. Due to the density of receptors, this solution delivers a usable device for many target groups, but not for elderly people.

Another area for the application of vibrotactile stimuli has been considered to be helpful, the foot sole. In the study of [3] a vibrotactile prototype shoe was designed for examination of navigational skills, only with the aid of those stimuli. The addressed group described in [3] mainly were blind people. The LECHAL shoe (shown in Fig. 1 [4]), a commercial solution for navigation by vibrational stimulation, was also first dedicated to blind people, now it can be used for sports and wellness, for tracking activities and vital parameters.

The present study concentrates on the interface in the foot sole. The main reason is the familiarity with the device. For the target group of elderly people, who may have a starting memory disorder or other possible problems with their orientation, it is important to use a device that they are already familiar to, and which is used on a daily basis. To realize the given requirements the implementation of the interface in a shoe sole was the best option to ensure the usage for elderly people. To realize a user fit-ted device it is necessary to research the basics.

2 Concept and Basic Studies

The aim of the study was the fundamental research concerning the vibrotactile sensibility of the foot sole in loaded condition and the possible transmit-table information for an user fitted device.

For this aim it was at first necessary to derive basic information about the sensitivity of foot soles against vibrational stimuli. To get this information a special test bench was developed and assembled shown in Fig. 2.

To know the type, amount and code of vibrational information given to a foot sole is necessary for a successful design and high level of user acceptance. Because

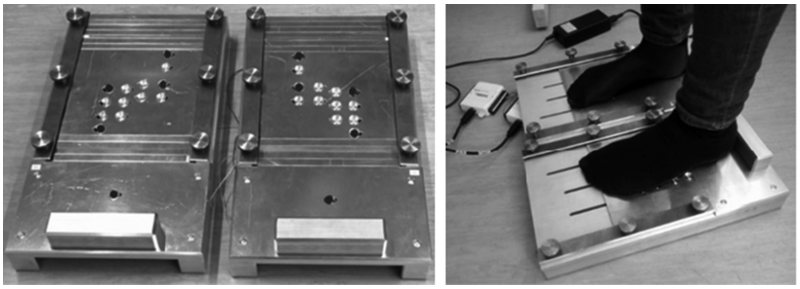

Fig. 2 Test bench for determination the sensitivity to vibrational stimuli at the foot sole (*left*); test bench during executing a test (*right*)

there are only a little of knowledge about presentation of information by vibrational foot soles, it was a need to investigate these basic findings. Of course, it is well-known how many receptors for vibrational stimuli people have and where they placed in the dermis [5]. But real working parameters like the best stimulation frequency, amount and type of transferable information and at least the resulting vibration patterns etc. are not known and published. Furthermore it has to be investigated the influence of special conditions under walking (movement of feet, stretch and declamp of foot soles and foot arch, thermal influences and so on).

The first test results were that it is generally possible to stimulate foot soles with vibration, and the best stimulation frequency is between 170 and 200 Hz which is adequate to other studies [6]. This frequencies well matches the most sensitive area of human mechano-receptors. Their position within the foot sole is shown in Fig. 3. From these receptor positions the shape and number of used vibration actuators was derived.

Like shown in Fig. 4 the first tests (pretest and tests at the test bench) had not quite good recognition rates except the actuator under the ball. But the integration of actuators into the shoe sole (leather) had given the expected results (see Fig. 4

Fig. 3 Position of the receptive fields of the four different mechano-receptors on human foot sole ([7] *left*); schematic array of the 14 actuator positions at the test bench with the four used actuators marked in *black*

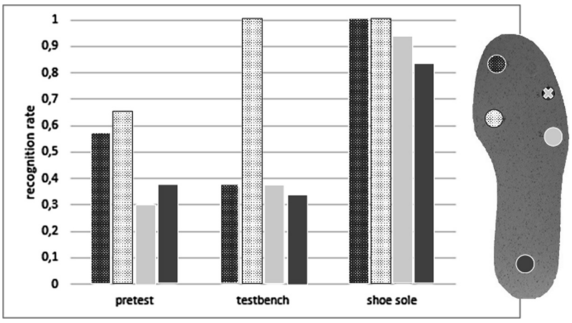

Fig. 4 Comparison of recognition rates from pretest and test bench to rates of shoe sole; belonging actuator positions (*right* outside)

diagram right outside). With a failure rate during recognition tests less than 20 % an interface for information transmitting could be promising to develop.

These basic tests had shown the general suitability of vibrational stimuli under the foot sole. Restricting is that best recognition results were got when the foot sole had no weight preload [6]. The more soften fixation from leather of shoe soles against alloy metal of test bench gave a higher amplitude respectively a lower damping of vibration which lead to higher recognition rates.

Generally the fore part of foots (ball, toes) gave better results (amount of recognized stimuli and higher spatial resolution) then the retral part (heel). This is confirm to the allocation of mechano-receptors like shown in Fig. 3.

3 Systems Structure and Components

The new developed interface consists of five major parts as shown in Fig. 5: The control unit (1) could be a PC-server or mobile device, which gives coded signals via Bluetooth to BT-module of the shoe sole interface (2). These signals contain

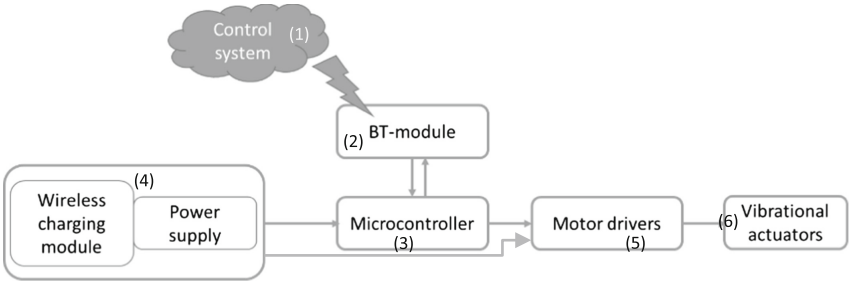

Fig. 5 Schemata of basic interface components

information about the actually necessary vibrational actuators (6). The microcontroller (3) interprets these information and gives out an adequate signal to the belonging motor drivers (5). They deliver enough currency coupled with pulse wave modulation to drive the vibrational actuators. The amount of used actuators, their position under the foot sole and alternating or changing the actually vibrating motors gives the ability to code information for the user. The power supply is realized by a LiPo-accumulator, which will be charged by a self-developed wireless charging module.

3.1 Vibration Motors

To create the vibrational stimuli common vibration motors are used like well-known from smartphones. They are shaped like small coins and were clamped into wholes of the leather shoe sole. It exists two types of these coin-shaped vibration motors, the excentric rotating mass motor (ERM-type) and the linear resonance actuator (LRA-type). The performance parameters and schematic setup of the ERM-type motor which is used for the interface is shown in Fig. 6.

Because of observed damping of the resulting frequencies under the preload given by the user's weight an additional noise measurement was executed. We measured the noise with microphone and analyzed it with a MATLAB algorithm for frequency analyzes (FFT analyze), the main spectral part is determined by the frequency of the rotating excentric mass. It could be derived that the frequencies decreased in a maximum range of 10–15 Hz. At the same time currency increases of about 2–3 mA.

3.2 Control and Communication

To control the vibrational stimuli a microcontroller is used. It is communicating with all components via different bus systems (I^2C, RS232/FTDI and to external

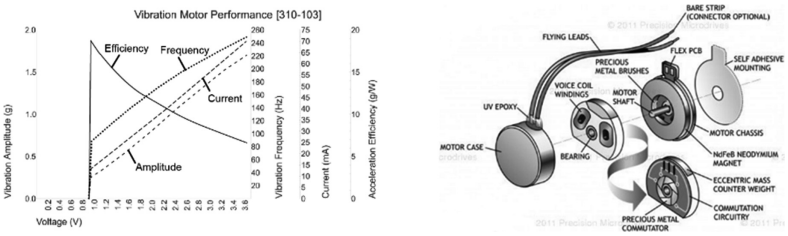

Fig. 6 Performance characteristics of the used ERM coin motors (*left*, own image after [8]), schematic of parts of the ERM motor (*right*, [9])

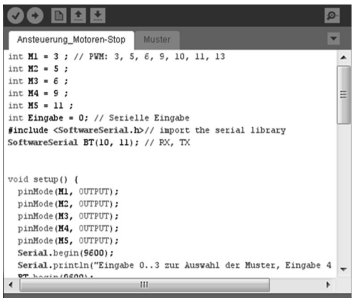

Fig. 7 Part of screenshot from control program of microcontroller ARDUINO mini

unit via Bluetooth). All of the used components are compatible to ARDUINO™ form factor and its parameters. As microcontroller an ARDUINO mini derivate called Wattuino with BT-module was used in the test object. Figure 7 shows a part of the program (sketch) to control the five motors. It is possible to change the vibration shapes by using a smartphone with a terminal app.

3.3 Wireless Charging Module

It was a basic requirement from users that the shoes respectively the contained accumulators for power supply have to be able to charge wireless. For this reason a charging module (transmitter and receiver, see Fig. 8) was developed and assembled with do-it-yourself components. To make the receiver part of the shoe more robust against humidity and mechanical stress it was molded into an epoxy resin

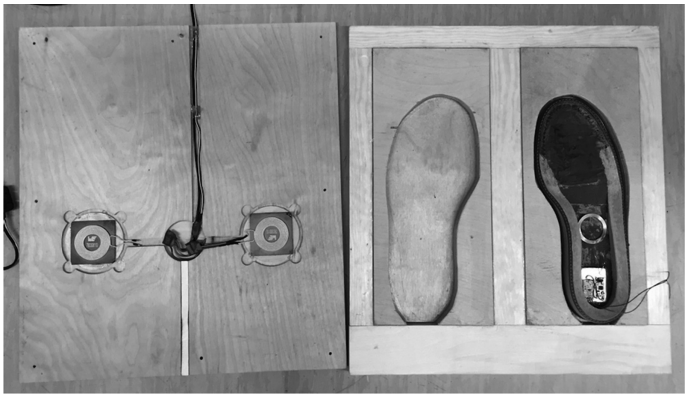

Fig. 8 First prototype of the wireless charging module with inserted test sole (*right*), at both sides are visible the charging coils (at the *left* transmitter side with magnetic shields)

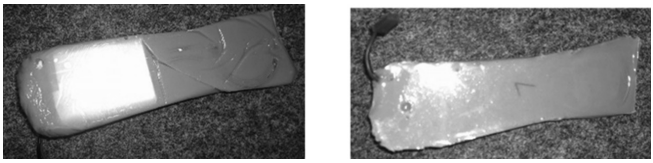

Fig. 9 Molded sole wedges with the inside visible LiPo-accumulators

(see Fig. 9). The second effect of this was that it could be used as stabilization element in the retral part of the shoe to bear the heel. Inside the shoe there is commonly a wedge which was removed. This was necessary to get the needed space for the electronic components, but the lost stability could be compensated with the molded wedges. Because each shoe has an active vibrating module, both soles need to be supplied with electrical power and then re-charged.

The power supply allows the use of the shoe soles with vibration for about 6 h, and it needs the same time to re-charge the accumulators. This should be done during nighttime (user's sleeping phase) when the user does not need the orientation aids.

4 Integration into Shoe Soles

To be able to execute user tests with the newly developed shoe soles a project partner (an orthopedic shoe company) made a pair of test sandals with locker straps (shown in Fig. 10, left side). With these sandals (in two common sizes) it was possible to process tests with elderly users independent from different foot sizes or necessary medical socks or bandages.

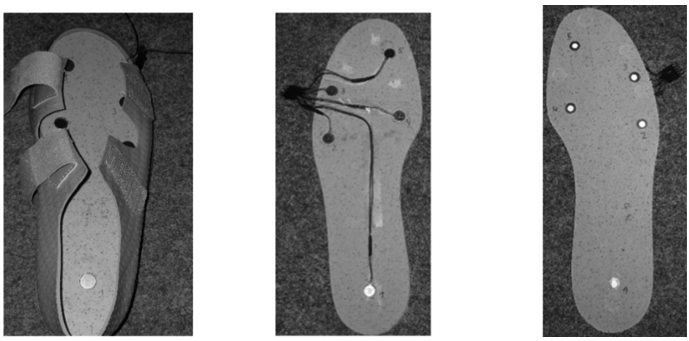

Fig. 10 Test sandal (*left*) and removed shoe soles with integrated vibration motors (*back* and *top* side)

5 Conclusion and Outlook

The tests had shown that it is generally possible to give information by vibrational stimuli to foot soles, and it is possible to create and implement such a vibrational interface with all necessary components into a shoe or sandal. For real use of this system some optimizations and adaptations have to be processed. So it is necessary to integrate a pressure sensor for detecting the moment of lifting the foot to start the vibrational stimuli. That is necessary because the vibration motors do not rotate resp. could not produce enough vibration amplitude when the user is standing directly on it. But from the moment of lifting the vibration can be good recognized till the next ground hit.

Also for use in real environments as well for further production processes it is necessary to optimize the wiring of all components, preferably with special ribbon cables which can be integrated into the stitching process of the whole shoe.

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Standardization of Human-Computer-Interface for Geo-Fencing in Small Unmanned Aircraft Systems

David Thirtyacre, Robert Brents, Michael Goldfein, David Hunter, David Ison and Brent Terwilliger

Abstract The use of small unmanned aircraft systems (sUAS) has increased significantly in the past year. Geographic fencing (geo-fencing) is software built into most medium-cost consumer sUAS. This software is typically used to limit the altitude above launch point, the flight distance from the transmitting controller, and/or restrict flight inside a no-fly zone. While the concept of a geo-fence is simplistic, the human-computer-interface (HCI) varies drastically among platforms, and even between software iterations on the same platform. This research examines the HCI of three popular consumer-level sUAS with regard to geo-fencing. The software procedures and human interface for the DJI Inspire-1, 3D Robotics IRIS+, and Yuneec Typhoon Q500+ were evaluated through review of relevant literature, software, and flight-testing. This assessment yielded several recommendations for geo-fencing software for sUAS.

Keywords Small unmanned aircraft systems (sUAS) · Geo-fencing · Human-computer · Interface flight-testing

1 Introduction

The Federal Aviation Administration (FAA) and other governmental organizations are looking toward geo-fencing as a major component of unmanned systems integration into the National Airspace System [1]. The safety cushion providing separation of aircraft, manned and unmanned, may become dependent on geo-fencing; software which is not standardized and varies greatly between aircraft. This research identifies and addresses the need for standards in liveware-software-hardware functionality applied to small unmanned aircraft systems (sUAS).

This project featured testing and evaluation of three popular consumer-level sUAS to compare and contrast the methods used in geo-fence implementation.

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Human factors are a major consideration for proper HCI in any automated system and standardization between manufacturers on critical functions is essential. With in-depth knowledge of each aircraft's geo-fence software, common definitions, monitoring displays, and data input methods are recommended.

The manufacturing and operation of sUAS has increased significantly in the past few years. As of August 2015, www.UAVGLOBAL.com reported 432 UAS manufacturers in the commercial and military industry worldwide. However, very few industry standards are available for the human interface software to follow. This has created a situation where critical functions and information passing between the human operator and the unmanned system are specific to the platform and software load [2]. One of many critical data interfaces involves defining a geo-fence–a "fence" that limits flight beyond a defined distance or altitude [1].

There are a variety of limitations that currently exist or have been proposed by the FAA in the 2015 release of proposed regulations, including creation of Part 107 of the regulations designated to cover sUAS. By creating geo-fencing to identify the airspace, altitudes, or distances required can substantially assist operators and enhance safety. Geo-fencing for airspace allows for the demarcation of places where sUAS operations may be limited or prohibited. For example, the FAA is proposing operators to require air traffic control permission to operate in controlled airspace (Class B, C, D, and E airports), thus a warning geo-fence could be placed to notify users they are approaching or within an area that warrants additional action by the operator [3]. For locations at which sUAS operations are prohibited, such as around Washington, D.C., restricted airspace, or in National Parks, geo-fencing can be used to disable a sUAS from taking off or prevent it from entering the area [3–5]. Geo-fencing can also limit altitude of operation, e.g. 400 feet above ground level (AGL) or launch. Altitude geo-fencing may also be incorporated for controlled airspace, as each type varies in shape and altitude [6]. Distance geo-fencing can be used to maintain the necessary proximity to the operator to sustain adequate signal range. Dynamic geo-fencing can also be utilized to prevent a sUAS from entering temporary flight-restricted areas, such as during disaster relief [7]. Future geo-fencing capabilities may include the ability to prohibit flight beyond visual line-of-sight or at night.

Although open manipulation of geo-fencing can defeat the intent of the safety enhancement, these limitations can sometimes prevent legitimate use of sUAS to take place. Ideally, non-recreational, authorized operators would be able to remove restrictions that interfere with approved operations. For example, if a user had FAA authorization to operate at an airport, the geo-fencing for that particular unit could be disabled or removed. Customizable geo-fencing could be potentially helpful for individual operators to avoid certain areas, fly specific paths or altitudes, and to be a good neighbor to surrounding populace. As is clear, geo-fencing can be a very useful, if not necessary tool, to not only assist users fly safely but also to comply with existing and future regulations or limitations [3, 6, 7].

2 Purpose

The objective of this practice-oriented research is to examine the human-computer-interface (HCI) used to manipulate geo-fence settings for three consumer-level sUAS. The HCI to enter and monitor geo-fencing parameters on sUAS varies by manufacturer and platform which may cause input and interpretation errors. Additionally, each of the three platforms incorporates varying levels of access and control of the geo-fence. This lack of standardization may lead to errors of omission (e.g., failure to enable the geo-fence) and commission (e.g., incorrectly entering geo-fence parameters). These errors can contribute to serious safety-of-flight issues including separation of manned and unmanned aircraft. The intent of this research is to identify best practices and recommend a standard interface scheme for sUAS.

3 Background

The concept of a geo-fence and the ability to incorporate it into sUAS software has been around for several years. However, until the sUAS manufacturer DJI made a mandatory software upgrade for its Phantom fleet in 2014 which included No-Fly zones, it was not activated in consumer level aircraft [8]. Since then, several manufacturers have installed similar programs in an effort to curb the rising number of sUAS incursions into high-density controlled airspace, and their liability should an accident occur.

While the FAA works to establish new regulations to govern unmanned aircraft, lawmakers in Washington DC have become impatient. In particular, Senator Chuck Schumer (D-N.Y.) introduced legislation in September 2015, which would mandate the use of geo-fencing. In a press conference, Laing (2015) quoted the Senator, "My amendment, which I am attaching to the FAA Reauthorization bill, would require geo-fencing or other similar technology software on every drone that would prohibit flying near airports and other sensitive areas" [9]. The Senator is recommending legislation to legally establish no-fly zones around airfields by leveraging the geo-fence software.

The no-fly zone is one application of geo-fencing, but the same autopilot algorithms may be used for other services. Some aircraft allow a maximum altitude above launch (often confused with general discussions of height AGL) entered into the system to restrict how high the sUAS can fly. Other manufacturers allow operators to input a maximum range from the launch point that the aircraft may travel, while still others elect to hard-code their maximum range and altitude. None of this matters unless the aircraft is receiving and processing an accurate position and altitude, most likely from global positioning system (GPS) localization. Understanding how the aircraft's geo-fence is defined, how it functions, and how the HCI operates are key factors for flight safety.

The three sUAS examined in this project each use geo-fence software to limit flight range and altitude. However, each platform utilizes a different user interface. The specifics of each UAS geo-fence are described in the following sections.

3.1 DJI Inspire-1

The Inspire-1 employs a mobile device to display information and provide the operational interface with the unmanned aircraft. The mobile device, an iPad in this case, is also used to display the camera view and allow camera control. Many settings are available on the main camera page including one-touch controls for the shutter, return to home, auto takeoff and land, gimbal control, as well as displaying the telemetry data [10].

After entering general settings, the main control menu is selected to bring up the geo-fence dialog. Unfortunately, the same page controls several other control inputs and is not labeled as "Geo-fence," only "MC." Data is entered through the "Set maximum flight altitude" entry dialog allowing settings from 10–500 m. Interestingly, the geo-fence parameters can only be entered in meters, regardless of the units (e.g., metric or imperial) selected on the general settings page. However, if the height value converts to greater than 400 feet (120 m), a warning appears that flight above that altitude may not be appropriate. A similar process, first toggling on "Maximum Distance" then typing in the range from 15–500 m, is used to enter the maximum distance [10].

The Inspire-1 operates in three main flight modes: F (Function) mode, A (Attitude) mode, and P (Positioning) mode. P-mode is the normal mode used with a strong GPS signal and is the only mode that both the selected altitude and distance geo-fence are active. When A-mode is selected, only the altitude geo-fence is active and a default limit of 120 m activates, regardless of the entered value [10].

No-fly zones are included in the Inspire-1's database. These 'manufacturer imposed' geo-fences are always enabled as long as a sufficient GPS signal is received. The no-fly zones are comprised of both takeoff restricted zones and restricted altitude zones, depending on the distance from the protected airfield or restricted area. The aircraft response to different no-fly situations is beyond the scope of this paper and consumes four pages of the user manual [10].

3.2 3D Robotics IRIS+

The 3D Robotics IRIS+ functions as more of a traditional remote control (i.e., recreational hobby) aircraft without a mobile device requirement. As with the Inspire-1, both altitude and distance geo-fence parameters are selectable. However, changing from the default values requires a separate software package from the manufacturer. The free software download of Mission Planner is available on the

manufacturer's website but is not required to fly the aircraft [12]. Without Mission Planner, the geo-fence defaults to "on" with the factory preset values of 100 m for altitude and 300 m for distance. When the aircraft is connected to Mission Planner through either a USB connection or the aircraft's telemetry, the geo-fence parameters can be changed [11].

The Mission Planner software, depicted in Fig. 1, is extremely capable and allows manipulation of almost all of the IRIS + settings, including preprogrammed route of flight. Once connected to the aircraft, the geo-fence parameters are accessed through the configuration button and then selecting geo-fence from the drop down menu. Settings on the geo-fence page include maximum altitude and radius values, selection of altitude and/or range, the action taken when the geo-fence limit is reached, and enabling the geo-fence [12]. The Mission Planner depicts no-fly zones around controlled airfields on the moving map display but does not currently inhibit flight inside the zone. Although the Mission Planner software is not required for flight, 3DR highly recommends its use [11].

3.3 Yuneec Typhoon Q500+

The Yuneec Typhoon Q500+ aircraft and Yuneec ST-10+ controller are delivered as a set. The ST-10+ acts as both a controller and video display for the integrated camera. This display also functions as a limited interface with the system through a touch screen menu. Similar to the other aircraft discussed, the Q500+ has a

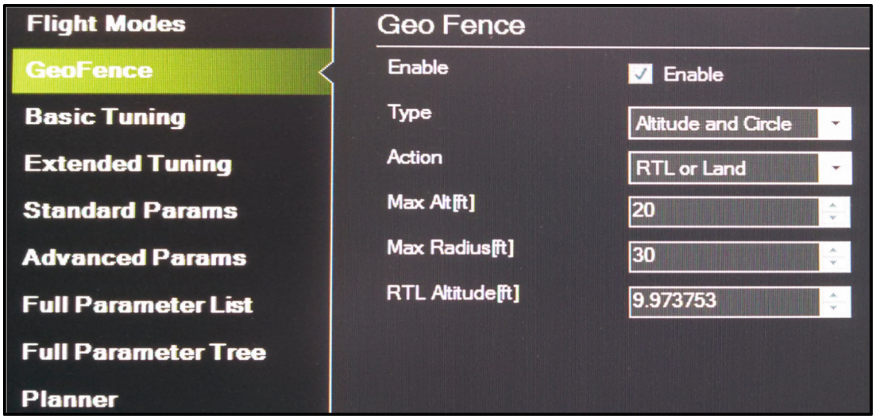

Fig. 1 IRIS+ mission planner geo-fence page. Screen capture from "Mission Planner 1.3.32." Developed by M. Osborne, 2015

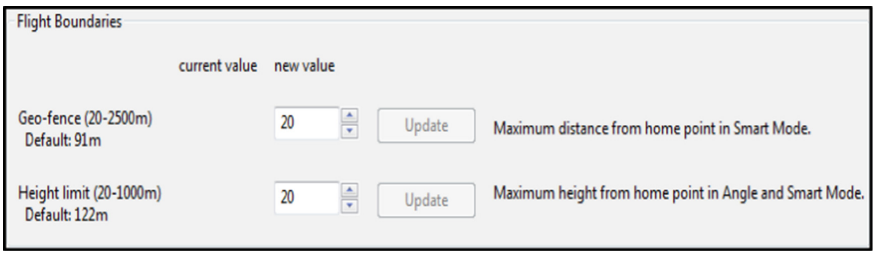

Fig. 2 Q500 GUI flight boundaries page. Screen capture from "Q500 GUI 1.01." Copyright by J. Russell, 2013

geo-fence for both altitude (default value 122 m) and distance (default value 91 m). However, the geo-fence is not fully active in all modes, only during operation in "Smart Mode" (described in detail below). The geo-fence parameters are only adjustable through the graphical user interface (GUI) program available for download on the manufacture's website [13].

The Q500+ GUI requires access to an interface connection inside the battery bay of the aircraft. Once connected to a computer through USB, the aircraft is powered up and the GUI started. As seen in Fig. 2, the geo-fence entry page is labeled "Flight Boundaries," and allows entry of both altitude and range.

The flight boundaries page mentions both Smart and Angle Modes. Smart Mode is primarily used for operators unfamiliar with UAS operations. This mode changes the control mapping from aircraft centric to transmitter centric (e.g., moving the control lever away will move the aircraft away from the transmitter regardless of aircraft heading). Angle Mode is the typical, aircraft centric control method used for most UAS. Interestingly, only the altitude limitation is active when in Angle Mode. To limit the aircraft in both altitude and range, Smart Mode is required. The Q500+ software is factory set with airport no-fly zones similar to the Inspire-1. The aircraft cannot be flown inside these areas [13].

3.4 Aircraft Geo-Fence Summary

While the three aircraft described above all contain geo-fence software, the implementation is very different. The characteristics of each aircraft's software is presented in Table 1. Even the no-fly zones created to deconflict manned aircraft from unmanned aircraft are implemented differently in each aircraft. The need for standardized definitions, status monitoring, and method of data entry is readily apparent.

Table 1 Geo-fence capabilities of three sUAS

Software options	IRIS+	Inspire-1	Q500+
Installed geo-fence software	Y	Y	Y
Auto no-fly zone restrictions	N	Y	Y
User disabled	N/A	N	N
Altitude geo-fence	Y	Y	Y
User input parameters	Y	Y	Y
Distance geo-fence	Y	Y	N*
User selected value	Y	Y	N*
Data entry interface	MP	App	GUI
Live changes	Y	Y	N

*Geo-fence distance limit in Smart Mode only. Adapted from 3DR [11], DJI [10], and Yuneec [13]

4 Discussion

Several issues were identified during the aircraft review. Each manufacturer approached the geo-fence concept with different definitions, displays and entry methods. This may lead to confusion, delay, and misunderstanding. These three areas are discussed below.

4.1 Definition

The first apparent issue from the software review is the definition of a geo-fence. The Inspire-1 does not refer to the settings as a geo-fence and the Q500+ only refers to the distance, not the altitude as a geo-fence. Only the IRIS+ defines the menu items under the title geo-fence. Since geo-fence is now common vernacular among sUAS regulators and operators, it should be adopted as the standard label for any range and altitude limiting software. For the purest who believes a "geography fence" does not apply to altitude, the term 3D Geo-Fence could be used to include the third dimension of altitude. There could also be a time component (i.e., when flight is limited to a time "window") resulting in a 4D geo-fence. These terms are unambiguous and could be used when describing a platform's capabilities. For example, the IRIS+ software supports 3D geo-fencing. However, the understood definition of a geo-fence is irrelevant unless the operator understands what aspect of the fence is enabled.

4.2 Monitoring

None of the aircraft tested display the status of the geo-fence on the main control page (other than a ring on the map view). Understanding the status of the geo-fence

is critical to flight safety since automation surprise (i.e., the unanticipated actions taken by an automated process) can cause confusion, misinterpretation, and possibly loss of aircraft control [14]. Whether or not the geo-fence is enabled, the modes that are active, and the set values need to be obvious on the main control page. A simple method would be to only display values that are enabled and code them in green (not close to the limits), yellow (approaching limits), and red (limit reached). The operator would only need to crosscheck the information to understand the status of the geo-fence and anticipate the autopilot's reactions to reaching a limit. In addition, when a limit is reached and the aircraft executes the programmed response to the limit, the broken limit could flash to inform the pilot which limit was reached. This could include no-fly zones as well by displaying "NFZ," indicating that the no-fly zone geo-fence is active.

Each of the aircraft tested use GPS as the primary input to determine the location of the 2D geo-fence and GPS and/or barometric pressure for altitude. If these sensors fail to provide data (or accurate data), the operator should be notified; preferably by two methods. The Q500+ employs a vibration coupled with an on-screen message to ensure the operator understands that GPS is lost. This method is an excellent example of attracting attention through the use of salient cues [15]. Variations of this method should be employed to augment visual cues on the main control page with respect to geo-fence status. Understanding what limits are active is critical, but an intuitive, single entry location is also important.

4.3 Data Entry

Entering geo-fence data into the sUAS should be quickly accessible, intuitive, and standardized. Each manufacturer will undoubtedly develop their own interface however, a few general rules should be followed.

1. *Available*. Changes to the geo-fence parameters must be available during flight operations with the basic equipment. Requiring a separate computer connection to adjust the values reduces the likelihood that an operator will use the geo-fence effectively.
2. *Ease of Access*. Entering the data should be no more than one menu deep. A major issue for an operator of multiple sUAS is recalling where the geo-fence entry page resides. An icon on the home control page, possibly with the letters GF, linked directly to the data entry page, would be ideal.
3. *Intuitive*. All of the parameters associated with the geo-fence should be displayed in the same manner and on one page. A good example of this is on the IRIS+ Geo-fence page shown in Fig. 1. Each parameter is displayed in an easy to understand format including the aircraft reaction to encountering a limit.
4. *Standardized*. All manufacturers should label this software as a geo-fence and have a compulsory set of parameters that are displayed and user-selectable. This

set should include parameters for the user-defined geo-fence and the no-fly zones; even if the no-fly zones are not selectable:

- No Fly Zones: Factory Enabled
- User Geo-fence: Enable/Dis-enable
- Maximum Altitude: Select
- Maximum Range: Select
- Aircraft Response: Hold/Land/Home

4.4 Display Recommendation

Many options exist to accommodate the three requirements of availability, accessibility, and intuitiveness. Building on these requirements from Sect. 4.3, Figs. 3 and 4 are offered as examples. This interface is applicable to tablet and built-in-display-based GCS applications. A similar interface with text-only input and display is also possible.

Figure 3 illustrates a simplistic main display with embedded geo-fence status information. The operator can quickly interpret which geo-fence is active, the limiting parameter, and how near the aircraft is to each limitation. A color scheme adds intuitive interpretation of aircraft status: green indicating the aircraft is operating inside 80 % of the maximum value, yellow inside 95 %, and red when within 96–100 % of the set parameter. When the limit is reached, the red distance flashes, the controller vibrates, and a voice warning sounds, producing several salient cues.

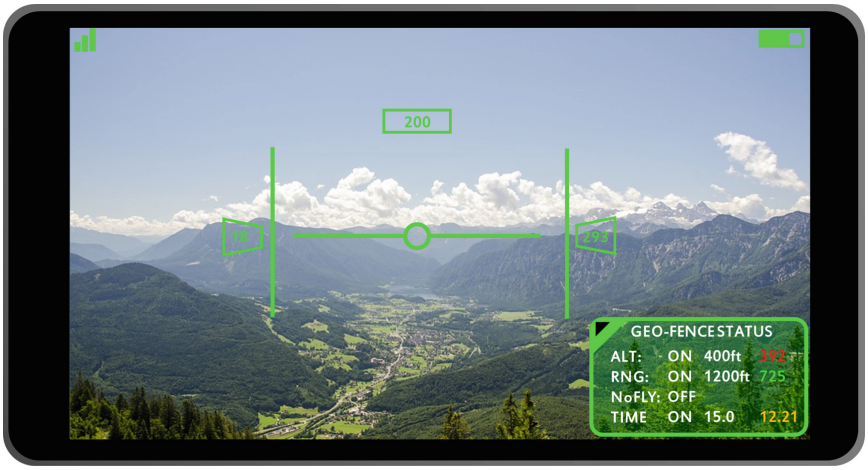

Fig. 3 Geo-fence status and parameter display on main control screen. Base image from: https://pixabay.com/static/uploads/photo/2015/12/08/01/03/aerial-view-1082304_960_720.jpg

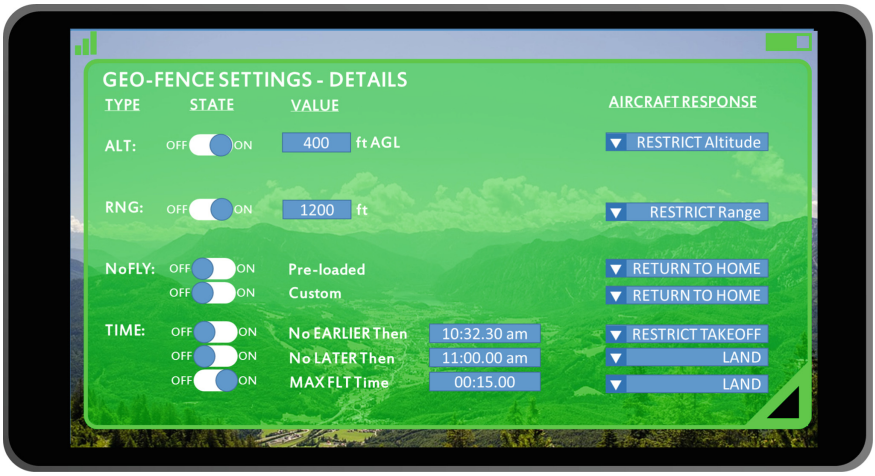

Fig. 4 Geo-fence settings details data entry page. Base image from: https://pixabay.com/static/uploads/photo/2015/12/08/01/03/aerial-view-1082304_960_720.jpg

The geo-fence setting details are selected by touching the geo-fence status display. An example of the setting details page is illustrated in Figure Y. This display allows input, through an interactive menu, of the state (on/off), value (input parameter), and the desired aircraft response when a geo-fence limit is reached. Aircraft response options include warning only, restrict aircraft from exceeding parameter, hold, return to home, and land immediately.

5 Conclusion

Few standards are used in the development of sUAS. As the complexity, capability, and availability of these systems increase, so does the need for standardization. The cockpits of today's manned aircraft all have a similar control panel and flight display layout, forged from decades of refinement and standardization. The rapidly growing domain of sUAS must begin to standardize not only displays but definitions as well. One area that requires immediate attention is in geo-fencing. The geo-fence technology available for sUAS is robust and well tested. However, the myriad of manufacturer designs for geo-fence implementation is specific to each aircraft which creates confusion and human errors.

The diversity seen in this research on geo-fencing exposes only a small fraction of the issues. The sUAS community must begin to define standards in other areas such as flight displays, low fuel indications and actions, camera manipulation, autonomous flight, and even the definitions themselves. It appears that much of the

human factors research conducted on manned aviation were overlooked by many manufacturers of sUAS [16]. Basic human factors concepts must be applied to unmanned systems, especially the area of HCI.

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Development Gestural Interface for Motorized Wheelchair Control

Beatriz Silva, Emylle Santana and Ivana Maia

Abstract The project contributes to the development of technologies to aid mobility vehicle technical and control of the desktop or housing with disabilities from semi-automatic methodology. The proposal consolidates enabling to the holders of locomotor disability a intuitive gestural interface for control of the wheelchair and control of environmental elements of interior for easy interaction, starting with studies based on the principles of biomechanics, usability and ergonomics analyzing the dynamic behavior of wheelchair user. This initiative also contribute to the consolidation of the research group in assistive technology in Maranhão (Brazil), which include a multidisciplinary team in the areas of mechanical engineering, ergonomics, design and computer science, involving institutions such as IFMA and UFMA.

Keywords Accessibility · Gestural interface · Assistive technology

1 Introduction

In Brazil, approximately 14.5 % of the population have some form of disability [1]. In this context, the Assistive Technology is important tool to provide to this part of the population to fully use your duty. As for people without disabilities the goal of technology is to make things easier for people with disabilities the primary role of technology is to make things possible (Radabaugh 1993).

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Through assistive technology have been created lot of tools to help people with disabilities, as assistance for daily living, augmentative communication (additional) and alternative (CSA) accessibility features to the computer, environment control systems, projects Architectural accessibility, orthotics and prosthetics, adaptations prostheses vehicles, help for the blind persons or with low vision, aids for people with hearing impairment and mobility assistance. For to help the patient with locomotor disabilities to overcome challenging situations in daily mobility in the city or in the family environment, current assistive technologies contribute in the development of easy handling mechanisms that enable the user independence wheelchair, reducing their mobility limitations. The main technologies employed include the chair designs of motorized wheels and adapted environments such as developed in the Design Department in conjunction with the Department of IFMA Mechanics (Federal Institute of Education, Science and Technology of Maranhão) and Applied Computing Center (NCA) UFMA (Federal University of Maranhão), at where this project it is associated.

The problem of this project is the identification of intuitive gestures in development of gestural interfaces to control motorized wheelchair and control of indoor and its elements without the use of buttons, switches or mechanical controls. The gesture is a movement of the body that contains information to facilitate communication. It intends to use gestures effectively communicating from technology, so it is desirable that these are naturally intuitive. The gestures studied in this research are the Free form, the user doesn't need to touch or handle any data input device, which will be perceived by sensors that capture movement.

Intuitive gestures make up the gestural vocabulary to be used in this interface, providing the user comfort in the execution of gestures, as gestural interaction makes the natural man/machine interface. The process of associating a gesture to the determined action of the system takes into account factors such as ergonomics, intuitiveness and objectivity, which highlights the importance of this research. Thus, this study investigated how to establish appropriate actions for the design of this interaction, which involves people with physical disabilities and assistive technology.

2 Objective

The objective of this project is related to the promotion mobility independence of people with spinal cord injuries at different levels. The overall objective is to develop a repertoire of gestural interfaces to control motorized wheelchair eliminating the use of buttons, levers and buttons (Free form) making it possible to adapt the control by gesture recognition, allowing the adaptation use of the chair powered to several classes of special needs of medullary injured and individually customize, allowing you to adjust the movement of the chair to a range of disabilities made by the physically disabled. The specific purpose of addressing ergonomic research motor difficulties of people with spinal cord injuries, studies on the gestural inter-faces, identification of intuitive gestures.

The gestural repertoire defined in this project makes the Gesturefy interface, software developed at Applied Computing Center NCA/UFMA. This initiative also contributes to the research group consolidation in assistive technology in the Brazil, specifically in Maranhão, which join multidisciplinary staff in the areas of mechanical engineering, ergonomics, design and computer science.

3 Methodology

Was study on ergonomics, engaged in the organization of work according to the proposed order and man adaptation conditions to work. The study was important because contributes to safety promotion and people's wellbeing and consequently the effectiveness of the systems in which they are involved.

After this phase, the study focused on the Physical Ergonomics applied to Sitting Posture position and the upper limbs, the position that people who make use of wheelchair takes most of the time. At this stage it was concluded that the upper limbs, elbows and forearms should be supported in the arms of the chair so as to minimize stress on the hands and forearms and avoid causing injury. The gestures that are to be used should be easy to accomplish, intuitive, and more likely to be remembered and ergonomically organized aiming at the total comfort of the user.

In the course of the study, which lasted twelve months, they were carried out training visits with software developed by Núcleo de Computação Aplicada (NCA/Federal University of Maranhão/Brazil) for monitoring gestures that make up the repertory. The program created Gesturefy is based on Leap Motion Platform—a dispositive with a sensor for capturing movements with an effective level of accuracy in detecting gestural profundity and user behavior.

To define the repertoire from intuitive gestures and evaluate the software, were experiments performed with disabled groups and groups of non disabled persons, made in dependence of the Federal Institute of Maranhão (IFMA) and in circulation places such as integration terminals (bus), squares, beaches etc. In four months.

4 Results

Test performed with intuitive gestures.

To facilitate the analysis of the test, they were used numerical patterns to identify gestures.

Suggested Standard:

Hand + active fingers

Like this:
Hand: R (right hand) or L (left hand).
Fingers assets: 1 (thumb), 2 (index finger) 3 (middle finger) 4 (ring finger), 5 (pinky).
For the experiment were chosen five commands: Forward, backward (reverse), left, right and stop.

4.1 Command 1: Forward

Group of actions suggested by respondents, considering the starting position with the fist:

- R2 (static): 77 times achieved (36.7 %).
- R12345 (static): 131vezes performed (62.38 %) (Fig. 1).
- R1 (static): 2 performed (0.95 %) (Fig. 2).

Fig. 1 Gesture R12345 (static), finished in open hand

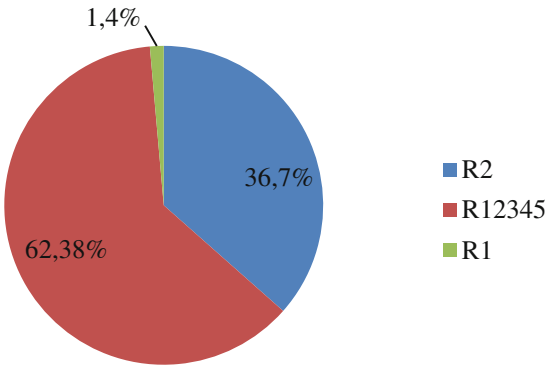

Fig. 2 Results of experiments performed about command 1

4.2 Command 2: Back up

Group of actions suggested by respondents:

- R12345 (hand raised or being raised): 173 times performed (82.38 %).
- R2 (index finger closed): 23 times held (10.95 %).
- RD (hand and arm sliding back): 6 times performed (2.85 %).
- R1 (thumb in evidence): 8 times performed (3.80 %) (Figs. 3 and 4).

4.3 Command 3: To Right

Gestures:

- R2 (turned/tilted to the right) 63 times performed (30 %).
- R12345 R (inclined to right) 141 times performed (67.14 %).
- R1: 6 times performed (2.85 %) (Figs. 5 and 6).

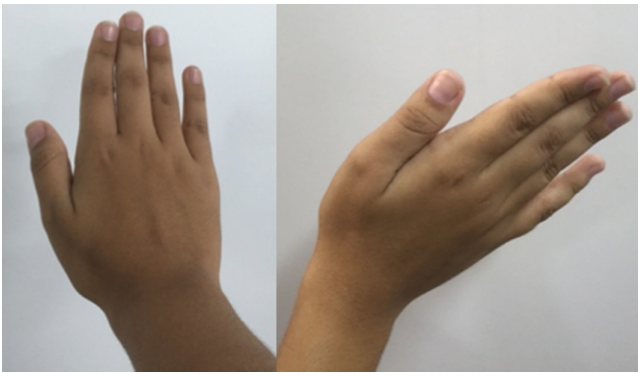

Fig. 3 Gesture R12345 (hand raised or being raised)

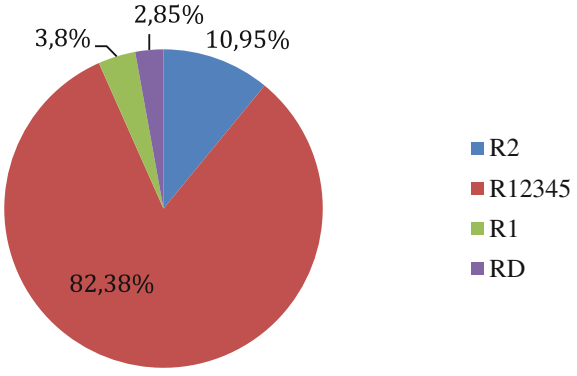

Fig. 4 Results of experiments performed about command 2

Fig. 5 R12345 R (turned/tilted to the *right*)

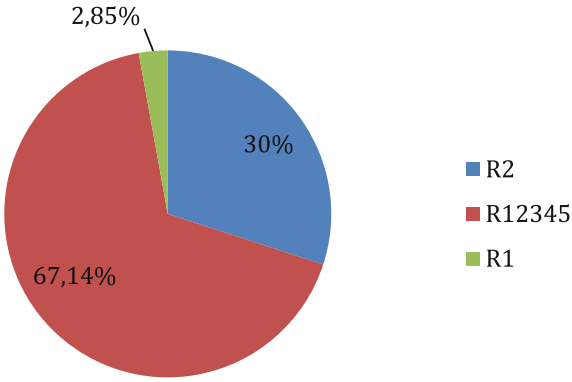

Fig. 6 Results of experiments performed about command 3

4.4 Command 4: To Left

Gestures:

- R2 (turned/tilted to the left) 63 times performed (30 %).
- R12345 (face/inclined to the left) 141 times performed (67.14 %).
- R1: 6 times performed (2.85 %) (Figs. 7 and 8).

Fig. 7 R12345 L (turned/tilted to the *left*)

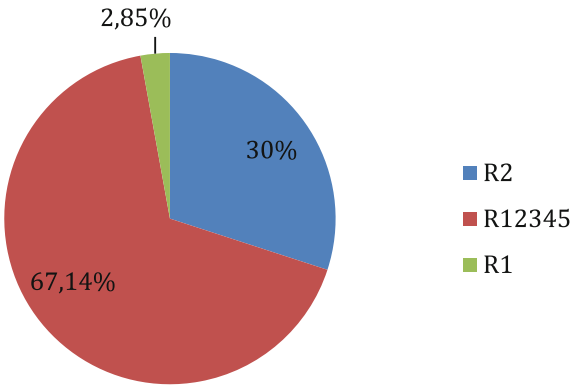

Fig. 8 Results of experiments performed about command 4

4.5 Command 5: Break

Gestures:

- R (still closed hand) 179 times performed (85.23 %).
- R12345 (hand is lowered): 31 times performed (14.86 %) (Figs. 9 and 10).

Fig. 9 Gesture R (ending in static closed hand)

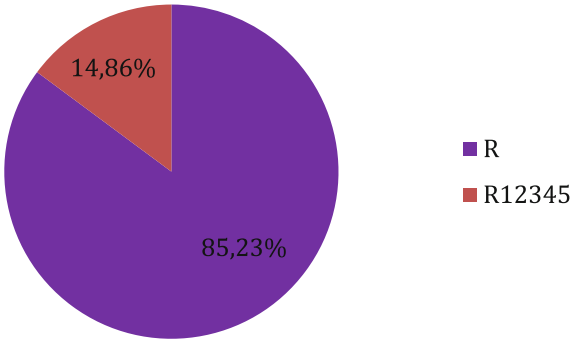

Fig. 10 Results of experiments performed about command 5

4.6 Explanations

Justification to R2 group gesture (held in Commands 1, 2, 3 and 4): Group R2, gestures made with only the finger active indicator. People did the gesture mainly by the relationship that the gesture has every time. The gesture R2 in every gesture commands refers people use to emphasize some function, such as when they are pointing directions.

Justification to group gesture R12345 (held in Commands 1, 2, 3, 4 and 5): R12345 Group, gestures open hand. The gesture was first performed by the people to be more practical and not necessary to lock/folding fingers. Used for commands to stop or reverse by remembering commands naturally used as a vehicle brake, a pedal or indicate stop (justification expressed by some interviewed).

To the right commands/left was kept for convenience and to continue the position of the fingers. This group of gestures as well as being the most used and repeated by those interviewed would be the most comfortable and ergonomic for the wheelchair, preventing pain in the joints of fingers or muscular pain.

Justification to gesture R1 (held in Command 1, 2, 3 and 4): Group R1, gestures made with only the active thumb. Gesture with a little repetition. First made in charge accelerating and braking on the idea of an imaginary joystick—as said respondents. And following the idea of "positive", he was made the gesture of the direct command/left.

Justification group gesture RD (held in Command 2): gestures made a closed hand. Gesture with little repetition rate. The gesture is the fist being slid back as if pulling a lever imagination—justification used by the interviewees (a lever, such as the reverse). In addition to having a low percentage in income gesture would not be best applied as the project aims to create a repertoire that helps a great diversity of people dispensing mechanical controls and not making the same path that the mechanical control would (not be ergonomic and comfortable for the wheelchair, causing shoulder pain).

Justification group gesture R (held in Command 5): gestures with closed hand. Gesture most used by respondents to the command symbolizing the end of an action —speed up/go forward.

The gestures more used as command throughout the research were the gestures of group R12345. With the justification: In group R12345, the gestures are made with an open hand. The gesture was first performed by the people to be more practical and not necessary to lock/folding fingers. Also used for commands such as stop or reverse by remembering everyday commands such as stop a vehicle, a pedal or indicate that something stop (justification expressed by some of the people interviewed). And for the right commands/left was kept for convenience and to continue the position of the fingers. This group of gestures as well as being the most used and repeated by people interviewed would be the most comfortable and ergonomic for the wheelchair, avoiding musculoskeletal disturbs.

5 Discussion

In the definition of gestural repertoire was chosen by intuitive gestures instead of suggesting new and simpler movements, based on the intention of minimizing the difficulties in the user adapt to the new technology.

According to Carl Gustav Jung [2], we call intuition inner ability to see possibilities, based on a history of perceptions and individual relationships with the world [2]. Kant [3], think intuition as knowledge which relates immediately to objects, showing unique realities and does not depend on abstraction, that is, what is known without deduce to complete [3]. Thus, the application of intuitive gestures on the interface refers to the immediate use of the truth without the aid of reasoning. West [4] suggests that the interactions teach now be the new standard for the next generation and can be much better than the previous ones, even if they are a little less intuitive [4]. However the physical and mental capabilities of the user of a particular interface should be considered, add learning a gestural repertoire to the project scope would change the intention of working from the Natural Interaction.

Develop applications that deal with Interaction Natural means creating systems capable of understanding the actions of the users while they are interacting naturally with the environment around you. In this sense, when the interaction use intuitive gestures, people do not need to learn specific instructions, the interaction happens naturally and easily. According Valle [5], the natural interface follows a paradigm in order to respect human perception. Interact with such systems is extremely intuitive and enjoyable [5].

6 Conclusion

The development of a gestural interface based on a repertoire of intuitive gestures to control wheelchairs for people with mobility limitations, favors the mobility and independence of citizens from gaming technology use associated with the mechanics of the chair movements.

The application of the repertoire of gestures by performing practical experiments recognition, and prove the efficiency of Gesturefy software with different people showing diversity in motor impairment levels clearly demonstrate the usability of the interface, as the gestures present ergonomic and intuitive characteristics.

The scientific merit of this project is to enable the control of the adjustment of the motorized wheel chair to a variety persons, using only gesture recognition, eliminating mechanical controls, thus improving the quality of life of these people regarding their independence. The contribution is also given in the study group consolidation in Assistive Technology in Maranhão (Brazil), which brings together scientific and social values the motivation object for studies to improving the quality of life of people with disabilities, so that they can make use of their skills

and abilities with physical and emotional comfort. As a study in scientific research primary level, awakes the scientific vocation encouraging the participation of students of technical level course in scientific and technological research activities.

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Review on Evaluation Methods to Pre-detect the Stroke Using Wearable Devices

SeungNam Min, Kyung-Sun Lee, DongJoon Kim, Se Jin Park, Youngseob Seo, Murali Subramaniyam and Seoung Eun Kim

Abstract The overall aim of this study is to collect stroke assessment methodology for pre-detect the stroke using the wearable devices. The particular objectives of the study were (1) to find various stroke-monitoring methodologies, (2) to compare stroke-monitoring methodologies, (3) to develop a methodology that can pre-detect the stroke. For this purpose, a systematic search was conducted using Google Scholar for studies published from 2010 to 2015. The search was restricted to papers published in English and containing the terms "stroke motion", "stroke detection", "stroke application". The literature survey revealed various stroke detection methods including motion pattern, gait analysis, head impulse test, electrocardiogram, eye movements, muscle activity recognition, and so on.

Keywords Stroke · Assessment methodology · Motion pattern · Monitoring

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1 Introduction

Vertigo and dizziness account for 2.6 million US emergency department (ED) visits per year, about 4 % attributable to stroke [1]. Roughly, 250 to 500,000 involve a high-risk-for-stroke clinical presentation known as acute vestibular syndrome (AVS) [2]. There have been many studies performed to monitor continuously and interpret stroke patient's recovery process. In particular, in clinical settings research has shown that data from inertial motion sensors can be used to estimate the outcome of selected scales of standard clinical motor function assessments, such as the Wolf Motor Function Test (WMFT) [3].

The rehabilitation training programmes aim at improving motor function, skills, and patient performance, changes in patient activity patterns are likely. For example, when a hemiparetic stroke patient relearns how to use the affected arm in daily activities, motion balance between affected and non-affected arms may change. Similarly, regaining motor capabilities may have an effect on behavior and trends in activity patterns. For example, a patient could become more active and involved, thus walk more frequently.

Many studies aimed at investigating methods for stroke patient rehabilitation. For example, using motion balance, eye tracking and so on. However, our study aimed at studying method to find stroke symptoms (i.e., pre-detect stroke symptoms). To achieve, (1) Find various stroke-monitoring methodologies, (2) Compare stroke-monitoring methodologies, (3) Developing a method that can pre-detect the stroke. The purpose of this study is to collect stroke assessment methodologies for pre-detect the stroke using the wearable devices (i.e. smart watch and so on).

2 Method

2.1 Literature Review

A systematic literature review of stroke was conducted in the Google Scholar (https://scholar.google.co.kr/, 1 March 2016) using the following keywords and their combinations: "stroke motion", "stroke detection", "stroke application" and so

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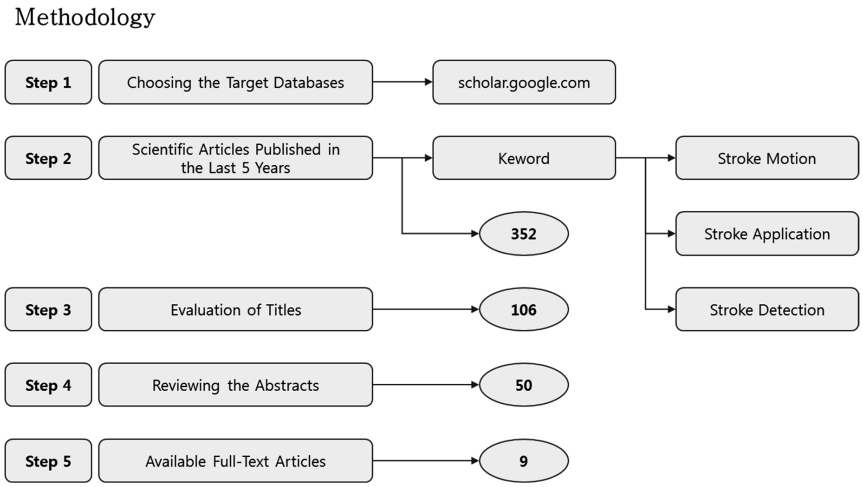

Fig. 1 Methodology of literature review

on. The literature search was restricted to the period from 2010 to 2015. The search was restricted to articles written in English. Three hundred and fifty-two articles were accessed for the last five years by searching keywords. Then articles were shortlisted, with 106 based on the title, 50 based on the abstract, and finally, nine articles were selected by reading the full text. After screening the titles and abstracts of the studies found, the full texts were evaluated for definite inclusion (Fig. 1).

3 Result and Discussion

Nine papers were found as shown in the Table 1. The focus of the paper include physical motion, muscle activity, acute vertigo and so on.

On summarizing each paper. Savitz et al. [4] demonstrated the sources of preventable medical errors. In order to achieve that, collected pilot data on cerebellar ischemic strokes, which were initially misdiagnosed in the emergency department. All the collected data were reviewed and finally categorized types of errors leading to misdiagnosis. Edlow et al. [5] and Nelson et al. [6] studied that Head impulse using a test of vestibular function, tests the vestibulo-ocular reflex (VOR) and distinguish a peripheral process (vestibular neuritis) from a central one (cerebellar stroke) (Fig. 2).

Newman-Toker et al. [7] studied to standardize the bedside oculomotor tests (head impulse test, nystagmus, test-of-skew) for emergency department use. They adopted a novel application of a portable video-oculography device measuring vestibular physiology in real time. Their results that the bedside oculomotor tests using video-oculography was 100 % accurate. Moreover, concluded that it is

Table 1 List of paper

No.	Title	Analyze	Author
1	Pitfalls in the diagnosis of cerebellar infarction	Gait coordination	Sean I. Savitz et al.
2	Diagnosis and initial management of cerebellar infarction	Head impulse test	Jonathan A Edlow et al.
3	The clinical differentiation of cerebellar infarction from common vertigo syndromes	Head impulse test	James A. Nelson et al.
4	Quantitative video-oculography to help diagnose stroke in acute vertigo and dizziness Toward an ECG for the eyes	ECG and eye movements	E. Newman-Toker et al.
5	Detection of motion disorders in cerebral apoplexy patients using non-linear analysis and EMG signal	EMG signal data	Ali dolat abadi et al.
6	Study of electromyographic signal in stroke patients	The performance characteristics of EMG	Yan Zhao et al.
7	Comparative study of electromyographic signal in stroke patients	EMG signal data	Yan Zhao et al.
8	A hybrid intelligent recognition system for the early detection of strokes	Human activity recognition (HAR)	José R. Villara et al.
9	Development of stroke detection method by heart rate variability analysis and support vector machine	Monitoring heart rate variability	Keisuke Kamata et al.

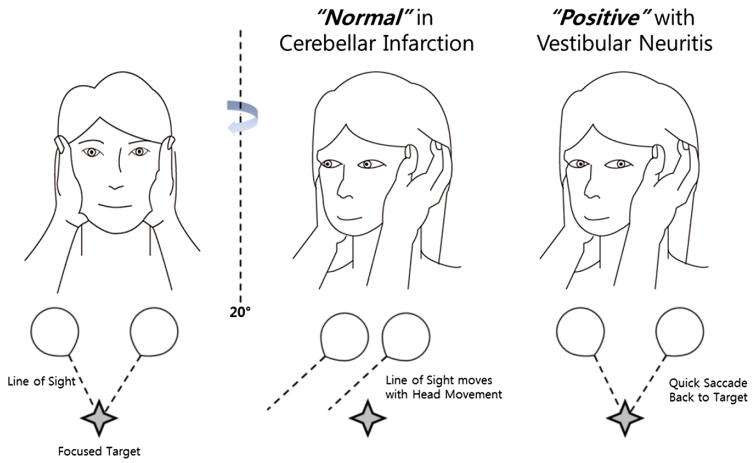

Fig. 2 The head impulse test

Table 2 Percentage of classification accuracy

Action	Percentage of accuracy	Standard deviation
Kneeing/pulling	90	0.98
Hammering/headering	78	1.06
Clapping/handshaking	83	0.91
Running/hugging	84	0.86
Elbowing/slapping	75	0.92

should be possible to diagnosis of vertebrobasilar stroke based on physiological device.

The electromyography (EMG) signal has a significant source of information for neuromuscular disorders recognition. Hence, Abadi et al. [8] used the feet and hands EMG data to detect normal and automatic aggressive actions through non-linear chaos properties and LMAN neural networks. Their methodology was proved with various activities EMG data. The normal activities were clapping, handshaking, hugging, and running, and the aggressive activities were elbowing, hammering, headering, kneeing, pulling, and slapping. The result showed that their methodology using neural network and LMAN classified the activities with EMG data with better accuracy (for example, 90 % accuracy for kneeing/pulling). Table 2 summarized the percentage of accuracy for activity classification.

Zhao et al. [9, 10] analyzed the performance characteristics of EMG using mathematical analysis tools and MATLAB software. They have collected EMG data of healthy people, and patients with cerebral infarction and cerebral hemorrhage. They have classified the characteristics of EMG signal with Fourier transform and AR model, and differentiated the patients either as cerebral infarction or as cerebral hemorrhage (Fig. 3).

Villara et al. [11] made recognition system for the early detection of strokes using genetic fuzzy finite-state machines and Time Series (TS) analysis. Also, proposed an algorithm for alarm generation using Symbolic Aggregate approximation (SAX). Test also performed to evaluate the approach presented and concluded that Symbolic Aggregate approximation (SAX) was a valid human activity recognition method with a reduced computational cost. Their proposed approach shown in Fig. 4. The tri-axial accelerometer data from left and right wrist are

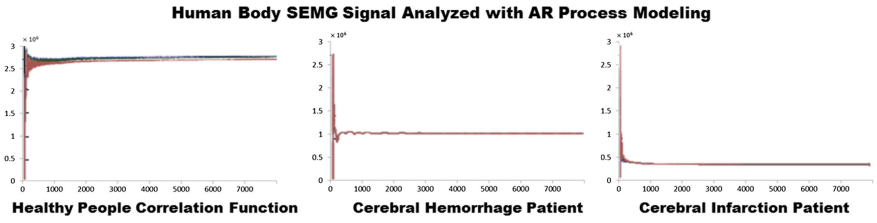

Fig. 3 Human body SEMG signal analyzed with AR process molding

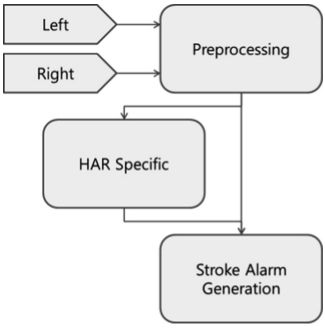

Fig. 4 The block diagram of a hybrid intelligent recognition system

pre-processed, then human activity recognition (HAR) take place, and finally the alarm generation is updated.

Many researchers are studying a stroke symptom to pre-detect stroke and rehabilitation. Therefore, if we are looking for accurate research methodology to pre-detect stroke using literature review, we can make a more accurate wearable device (i.e., smart watch, shirt and so on) using testing many subjects.

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Relation Between Glance-Times at an in-Vehicle HMI System and Number of Letters Displayed on It

Hiroaki Kosaka

Abstract This paper reports the relation between glance-times at the screen of an in-vehicle HMI (Human-Machine Interface) system near the driver's seat and the number of letters and characters dis-played on it. Our experimental results and discussion provide the fundamentals of a design method for HMIs operated by drivers to minimize glance-times. We conducted an experiment with a driving simulator to collect such data as time to read words displayed on in-vehicle HMIs while participants drove on an experimental course. The results indicate that for driving safety, the number of letters and characters displayed on an in-vehicle HMI screen should be less than 120.

Keywords Glance-time · In-vehicle HMI system · Driving simulator

1 Introduction

Recently, most cars are equipped with in-vehicle HMI systems such as car navigation systems, which display useful information on screens to drivers. However, obviously for safety concerns, drivers shouldn't be distracted by information on screens while driving. Some previous researches [1–4] proposed a system with a head-up display (HUD), which decreases the time needed to look away from the road. However, few cars are equipped with HUDs.

In Japan, the law prohibits drivers from gazing at screens while driving unless urgent information is being displayed. Drivers might cause accidents if they continue to gaze at a screen for ten seconds, even if they are legally permitted to do so. The length of time remains unclear at which drivers may legally and safely gaze at a screen to read urgent information.

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Here we consider what kind of urgent information drivers should learn immediately while driving. If a severe earthquake occurs, a car navigation system sounds an alarm and displays the earthquake's magnitude and its seismic center. We believe that the time to read the letters and characters on the screen increases as the number of letters and characters on the screen also increases.

In this study, we investigated the relationship between the number of letters and characters displayed on the screen and the time to read them while driving. We conducted an experiment where drivers had to read urgent information on a screen while driving and discuss the experimental results from the viewpoint of driving safety.

2 Experiments

We conducted an experiment where participants read urgent information while driving.

2.1 Apparatus

We conducted our experiment with a driving simulator that is composed of a desktop PC, a 46-inch monitor, and simulation software UC-Win/Road ver.10 from Forum 8 [5]. Such data as position and the speed of the driving simulator were collected. We installed a tablet PC (Surface Pro, Microsoft) on the left side of the driver's seat to display the urgent information. Figure 1 shows the driving simulator configuration, and Fig. 2 shows a scene of the experiment. We recorded the scenes using a video recorder while participants operated the driving simulator. Eye movements were monitored and recorded with an EMR-9 (Nac Image Technology Inc.).

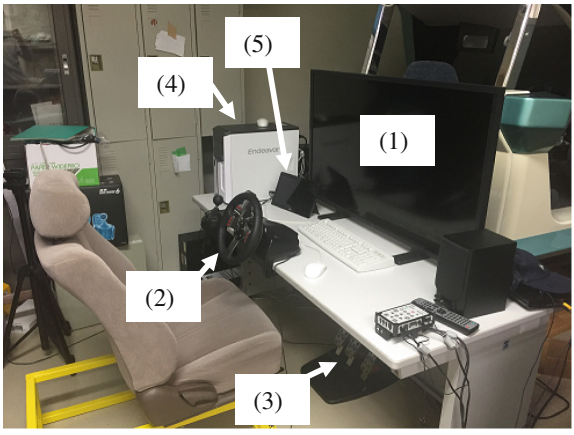

Fig. 1 Driving simulator configuration: (*1*) liquid crystal display for view in front of driver, (*2*) steering wheel, (*3*) pedals, (*4*) simulation PC, and (*5*) tablet PC

Fig. 2 Experiment scene: participant was shown urgent information in Japanese letters and characters shown in Fig. 3 while driving

2.2 *Urgent Information Displayed on Screen*

Participants were shown five pieces of urgent information on the tablet PC while driving. Figure 3a–e show the information that was written in 9, 20, 34, 78, and 120 Japanese letters and characters, respectively.

2.3 *Experimental Course*

Figure 4 shows the city area map used for the experiment. Participants started driving from "*Start*", passed I1, I2…I5, and stopped at "*End*" to follow the direction of experimenter. They read the urgent information while they drove on a straight road without any other cars, motorbikes, bicycles, or pedestrians.

2.4 *Participants*

Our participants were 13 male college student volunteers between 18 and 20 years old who possessed valid driver's licenses.

3 Results

We only included the data of 12 participants (P1, P2,…, P12) because we removed from our study one participant who did not completely read the urgent information while driving by analyzing his eye movement and reading performance.

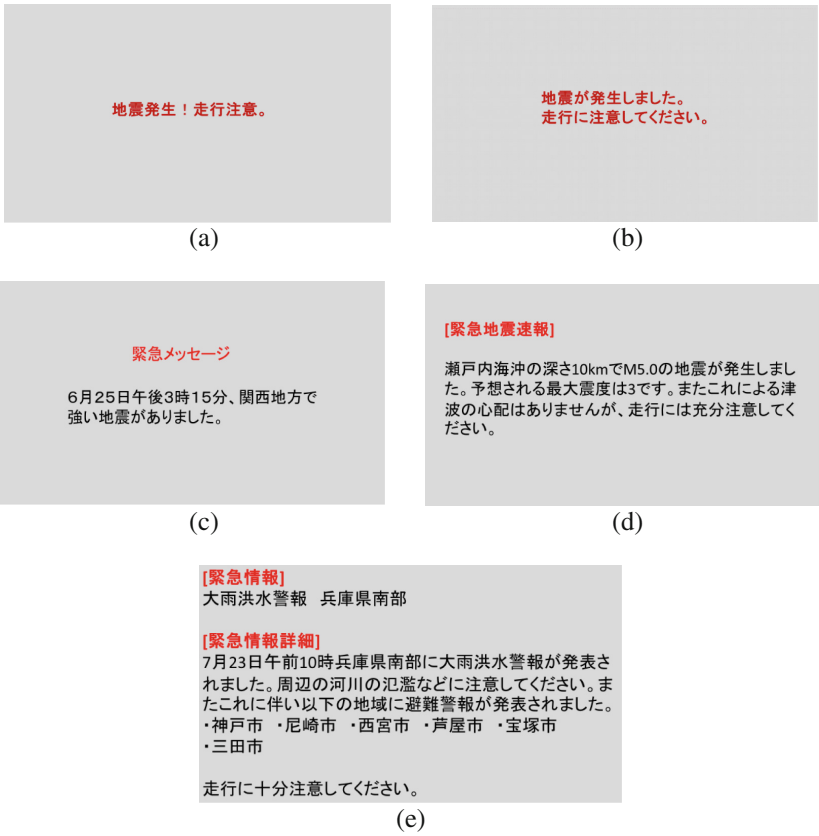

Fig. 3 (**a**–**e**) show urgent information displayed on the screen. String (**a**) consist of nine letters/characters. String (**b**) consist of 20 letters/characters. String (**c**) consist of 34 letters/characters. String (**d**) consist of 78 letters/characters. String (**e**) consist of 120 letters/characters

3.1 Relationship Between Glance-Times at Screen and Number of Letters and Characters Displayed on It

Figure 5 shows the relationship between the glance-times at the screen and the number of letters and characters displayed on it. The time monotonically increased in the same way as the number of letters and characters. We applied multiple regression analysis to the data shown in Fig. 5. A dotted line shows the regression line, which is given by $y = 0.13x + 1.06$.

Fig. 4 Participant begins driving from *Start*, turns right at intersections I1, I2, I3, I4, I1, I5, and stops at *End*

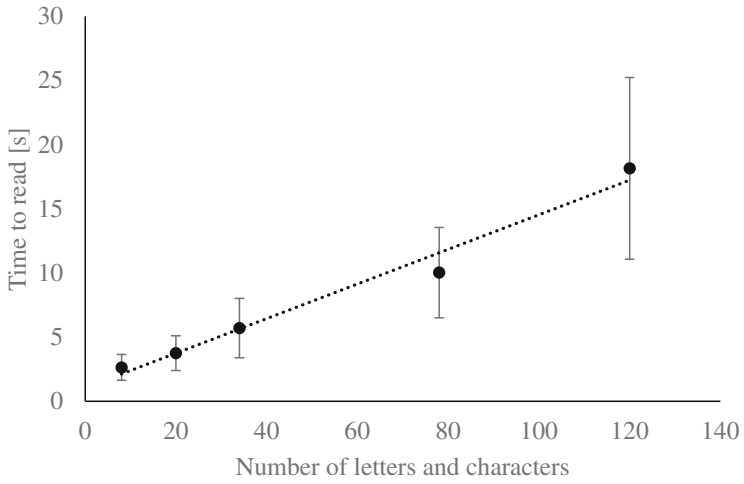

Fig. 5 Relationship between glance-times at screen and number of letters and characters displayed on it

3.2 *Relationship Between Number of Times Participants Glanced at Screen and Letters and Characters Displayed on It*

We analyzed the eye movements of participant P1 while driving. We defined the eye movements while driving and reading the urgent information on the screen, as shown in Fig. 6. We defined the number of glances at the screen as n and k-th screen glance-time T_{sgt_k}, total screen glance-time T_{sgt}, total front glance-time T_{fgt}, and task time T_{task} as

$$T_{sgt_k} = t_{4k-1} - t_{4k-2} \tag{1}$$

$$T_{sgt} = \sum_{k=1}^{n} t_{4k-1} - t_{4k-2} \tag{2}$$

$$T_{fgt} = \sum_{k=1}^{n-1} t_{4k+1} - t_{4k} \tag{3}$$

$$T_{task} = t_{4n} - t_0 \tag{4}$$

Figure 7 shows the relationship between the number of letters and characters dis-played on the screen and the number of glances at it. The number of glances to

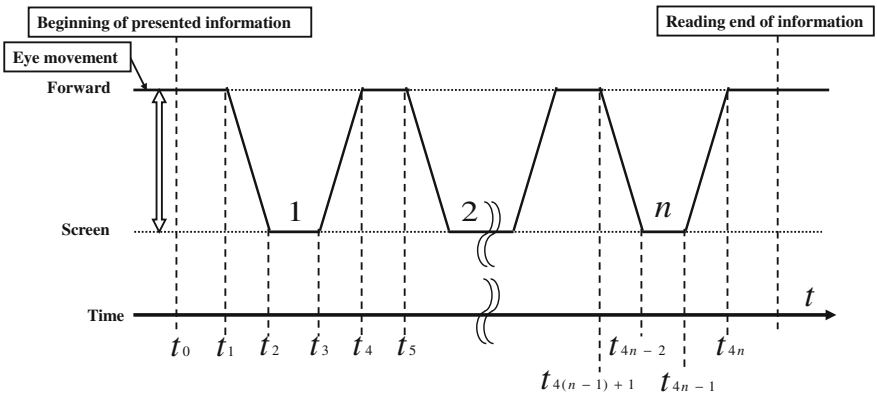

Fig. 6 Graph of eye movement when participant reads urgent information while driving

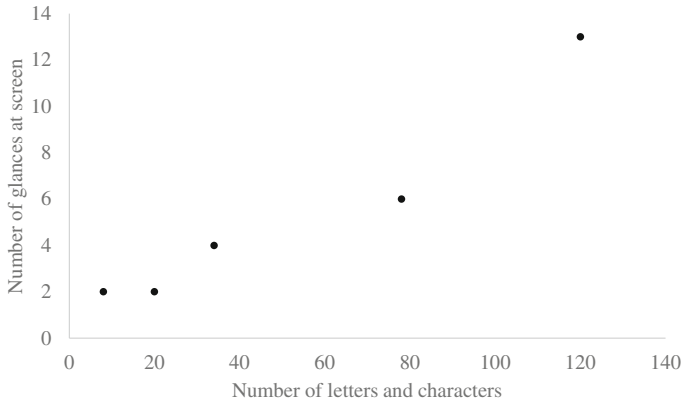

Fig. 7 Relationship between number of glances at screen and letters and characters displayed on it

read the letters and characters monotonically increases in the same way as the number of letters and characters.

3.3 Ratio of Total Screen Glance Time and Total Front Glance Times

We calculated the ratio of the total screen glance-times and the total front glance-times for the task times for P1 while driving (Table 1). P1 spent little time glancing ahead and spent most of his time looking at the screen.

3.4 Participant's Behaviors While Driving and Reading Urgent Information

All of the participants' car bodies swayed while driving and reading the urgent in-formation written by 120 letters/characters, suggesting that reading 120 letters and characters caused the sway.

Table 1 Ratio of total screen glance-times and total front glance-times to task time

Ratio of time	Percentage
T_{sgt}/T_{task}	71 %
T_{fgt}/T_{task}	11 %

4 Discussion

Next we discuss the experimental results from the viewpoint of driving safety. The maximum value of screen glance-times when participant P1 glanced at the screen was 2.0 s. P1 read the urgent information written in 120 letters and characters at that time.

In Japan, the National Police Agency recommends that drivers keep a safe distance between their cars and the one in front at a distance that equals the multiplication results of 2.0 s by car speed at that time. As mentioned above, we assume that drivers keep a safe distance between their cars and the one in front of them. If they are suddenly shown urgent information of 120 letters and characters, they cannot look up from the screen within two seconds, and if the car in front of them slams on its brakes, a rear-end collision might ensue. We conclude that the number of letters and characters displayed on a screen should be less than 120.

5 Conclusion

We conducted experiments where participants were presented urgent information in letters and characters while driving. We analyzed the relationship between the glance-times at the screen and the number of letters and characters displayed on it. We also investigated the relationship between the number of times when the participant glanced at the screen and the number of letters and characters displayed on it. We evaluated the car's behavior from the viewpoint of driving safety. Future work will increase the number of participants to objectively improve the reliability of the experimental results and propose indexes to measure car body sway and human errors.

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Upper Body Motion Tracking System with Inertial Sensors for Ergonomic Issues in Industrial Environments

Francesco Caputo, Egidio D'Amato, Stefania Spada, Fabrizio Sessa and Marco Losardo

Abstract Recently, motion tracking techniques to acquire human body movements have broadened their range of applications from sports training, to rehabilitation, to ergonomics issues. For industrial applications, motion capture systems are largely used to acquire workers movements to improve working conditions, comfort, safety, etc. Several tracking solutions have been provided to analyze trunk and upper limbs movement based on different sensing technologies such as optical systems, audio systems, radar systems, magnetic systems, inertial systems and mechanical motion systems. Motion tracking with inertial sensors has been an active research area due to its several advantages. In this paper the authors introduce a motion tracking method of arbitrary human upper body motion. Low cost wearable inertial sensors and CPU unit are used in the proposed approach to track the upper body movement in 3D space and in real time.

Keywords Motion tracking · Inertial sensors

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1 Introduction

During the last years, the global industrial products market has changed becoming more competitive and unstable due to several factors (legal, financial, environmental, etc.); in this contest OEM (Original Equipment Manufacturer) realized that, in order to create a competitive advantage to fit effectively the global market, they need to achieve excellence and to develop more flexible assembly lines and better methods for job planning on the same lines.

New standards on work organization also require new concepts for process design and for production: the human centered approach to improve manual assembly operations. In Fiat Chrysler Automobiles (FCA) this approach has been applied, during both Process design (by using advanced Human Simulations tools) and Process Industrialization/Production (by using the EAWS and ErgoUAS Methods for ergonomic optimization of assembly tasks and for optimal line balancing, therefore distributing the work load in the best way between workers along the lines).

Using these methodologies already in the design phase of a new car's manufacturing process, designers and engineers may have a preliminary estimation of the numerical indices used in the plants to check if assembly tasks are compliant to international standards (like European standards based on Niosh, OCRA, EAWS, etc.) (Table 1).

This is a key result because many of the above information, particularly those strictly related to human factors, are fundamental to satisfy mandatory (legal) standards in terms of safety and ergonomics, which define minimum requirements that machines and processes must meet in order to be placed on the market or used.

However, to achieve these results, experimental data and physical validation are also necessary. For this reason, an Ergonomics Laboratory ("ErgoLab") has been built in FCA in order to have a physical validation of design/virtual solutions using a detailed and scientific measurement of experimental data (biomechanical parameters) that are necessary to evaluate the above ergonomic indices. In the ErgoLab, ergonomics experts have measurement tools that are used for an ergo-characterization of assembly tasks, i.e. to acquire all the information that are

Table 1 Technical standard and related key ergonomic factor analyzed

Technical standard	Ergonomic factor
EN 1005-4 ISO 11226	Postures
EN 1005-3 ISO 11228-2	Forces
EN 1005-2 ISO 11228-1/2	Manual material handling
EN 1005-5 ISO 11228-3	Upper limbs

relevant to validate a work task according to the standard. Among all the tools in the ErgoLab, motion capture systems are used to evaluate worker's posture during an assembly tasks. However, to use these tools methodological developments are necessary in order to obtain consistent data values by overcoming limitations that these systems may show when applied in a real industrial environment.

2 Ergonomics Methods and Experimental Data Needs

Process Ergonomics activities in FCA are organized according to three main steps:

- Step 1—Design phase: design teams start to develop products and process solutions using 3D models. Ergonomics experts use virtual simulations to reproduce assembly tasks. Issues about postures, forces, manual material handling are evaluated by using specific tool (internally developed by FCA) fully compliant with European/Italian laws on health and safety.
- Step 2—Industrialization phase: suppliers start in developing car components, plant equipment, etc. Time information and detailed assembly sequences become available so FCA experts, coupling the EAWS ergonomic method with the UAS time analysis standard (Ergo-UAS method), may achieve optimal work task organization and line balancing.
- Step 3—Production phase: Production starts. Risk assessment and risk reductions activities are carried out always using mandatory standards.

During this process, many international ergonomic methods are applied (also according to safety laws) like NIOSH (for lifting operations), OCRA, EAWS, etc. In particular, EAWS is the ergonomics risk assessment method applied as a screening tool. It links corrective and proactive ergonomics, points out ergonomic problems and offers design solutions to overcome them. EAWS consists of four sections:

- working postures and movements with low additional physical efforts;
- action forces of the whole body or hand-finger system;
- manual materials handling
- repetitive loads of the upper limbs (Fig. 1).

To apply some of the above ergonomics methods, or to validate their results, experimental measurements of ergonomics factors may be requested, like posture and body angles acquisition during assembly task execution.

Several tracking solutions have been provided to analyze trunk and upper limbs movement based on different sensing technologies such as optical systems, audio systems, radar systems, magnetic systems, inertial systems and mechanical motion systems. Motion tracking with inertial sensors is a very interesting research area due

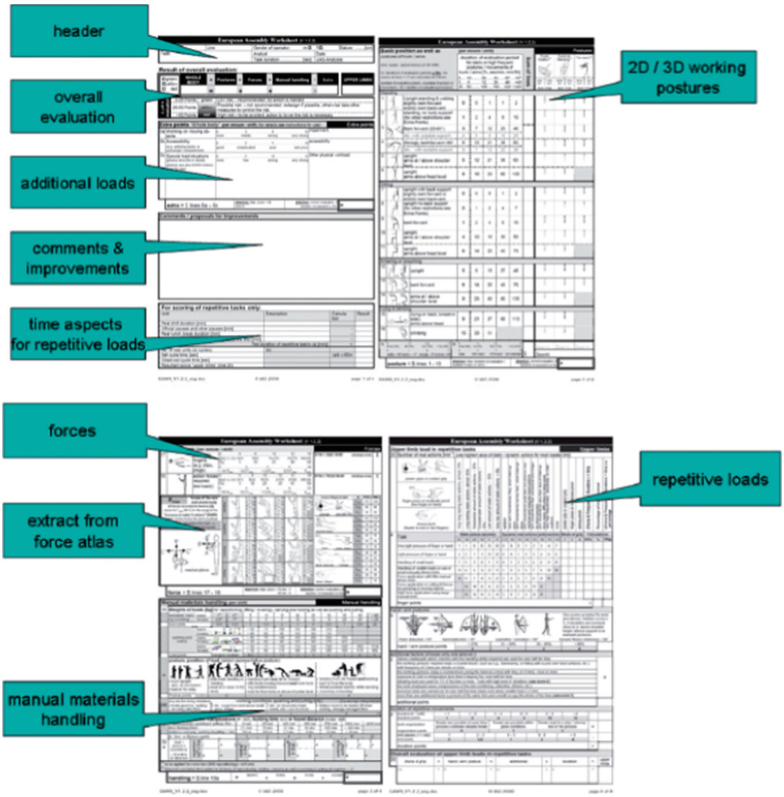

Fig. 1 EAWS sections

to its advantages. Several papers describe how to estimate the accurate orientation by fusing data from inertial sensors. The basic idea is to use a tri-axial gyroscope to determine the angular velocities, a tri-axial accelerometer to compute the orientation around the gravity vector and a tri-axial magnetometer to calculate the orientation in the terrestrial magnetic field. To avoid singularities in the estimation, usually the approach is based on the determination of a quaternion based orientation.

The paper is organized as follows. In Sect. 2, the procedure for the upper-body motion tracking is described, with details on the Extended Kalman Filter used to estimate the orientation of each segment. In Sect. 3, the hardware system is introduced explaining the calibration needed before performing tests. In the Sect. 4 the experimental demonstration is shown, with results on the orientation and on the estimation of the number of movements.

3 Upper-Body Motion Tracking

The basic idea of this paper is to create a low-cost system, simple to calibrate and enough accurate to evaluate standard ergonomics indices like EAWS, OCRA, NIOSH. The most important part of this indices is based on the upper-body pose and this system, coupled with an onboard camera to analyze the first person point of view, can simplify almost the whole ergonomic analysis.

Schematically speaking, the upper body can be divided in five important segments [1–3], neglecting the orientation of the whole hands: the trunk, two arms and two forearms. Considering the legs in a steady state, estimating the orientation of each segment allows to estimate the whole upper-body pose. For each segment, an Inertial Measurement Unit can be used to estimate the orientation in a fixed frame.

A Kalman filter is used to compute the estimation of the attitude, by combining a series of measurements affected by noise and other uncertainties. In this paper an Extended Kalman Filter [4, 5] has been implemented due to the non-linearities in the kinematic model.

The orientation of the fixed frame $X_E Y_E Z_E$ is such that the Z axis is parallel to the gravity vector, the x axis points towards the body at the initial time and the y axis creates a left-handed reference system with the other two axes.

Each segment has a local frame in agreement with its orientation that is overlapped to the fixed frame at the initial time. The orientation of each segment can be determined using euler angles that describe a rotation around the z axis (ψ yaw angle), a rotation around the y axis (θ pitch angle) and a rotation around the x axis (ϕ roll angle).

To avoid singularities, a quaternion based orientation for each segment is used. The transformation of an arbitrary vector $\underline{x}$ between the fixed frame ($\mathcal{E}$) and the local frame ($\mathcal{B}$) can be written as follows:

$$\underline{x}^b = \underline{\underline{C}}_{BE}(q(t))\underline{x}^E \tag{1}$$

where $\underline{q} = [q_1, q_2, q_3, q_4]$ is the quaternion vector and $\underline{\underline{C}}_{BE}$ is the rotation matrix defined as follows:

$$\underline{\underline{C}}_{BE}\left(\underline{q}\right) = \begin{bmatrix} q_1^2 - q_2^2 - q_3^2 + q_0^2 & 2(q_1q_2 - q_3q_0) & 2(q_1q_3 + q_2q_0) \\ 2(q_1q_2 + q_3q_0) & -q_1^2 + q_2^2 - q_3^2 + q_0^2 & 2(q_2q_3 - q_1q_0) \\ 2(q_1q_3 - q_2q_0) & 2(q_2q_3 + q_1q_0) & -q_1^2 - q_2^2 + q_3^2 + q_0^2 \end{bmatrix} \tag{2}$$

The transformation between q and the euler angles is:

$$\begin{aligned} \psi &= \tan^{-1}\left(\frac{2(q_1q_2 - q_0q_3)}{1-2\left(q_2^2 + q_3^2\right)}\right) \\ \phi &= \tan^{-1}\left(\frac{2(q_2q_3 - q_0q_1)}{1-2\left(q_1^2 + q_2^2\right)}\right) \\ \theta &= \sin^{-1}(-2(q_1q_3 + q_0q_2)) \end{aligned} \tag{3}$$

The Inertial Measurement Units (IMU) are equipped with a tri-axial accelerometer, a tri-axial gyroscope and a tri-axial magnetometer.

Gyroscope suffers of a non-white Gaussian noise, so estimating rotation from angular velocities is possible only by estimating the bias of gyroscope.

For each IMU the process model of the EKF can be described using seven equations: one for each component of the quaternion vector and three biases, one for each axis of gyroscope.

$$\begin{cases} \dot{\underline{q}} = \frac{1}{2}\underline{\underline{M}}\underline{q} \\ \dot{\underline{b}}_{\omega} = -\frac{1}{\tau}\underline{b}_{\omega} \end{cases} \tag{4}$$

where $\underline{b}_{\omega}$ is the vector of biases on each axis of gyroscope, and $\underline{\underline{M}}$ is defined as follows:

$$\underline{\underline{M}} = \begin{bmatrix} 0 & -(p-b_p) & -(q-b_q) & -(r-b_r) \\ (p-b_p) & 0 & (r-b_r) & -(q-b_q) \\ (q-b_q) & -(r-b_r) & 0 & (p-b_p) \\ (r-b_r) & (q-b_q) & -(p-b_p) & 0 \end{bmatrix} \tag{5}$$

p, q and r are the angular velocities measured from the gyroscope sensor and b_p, b_q and b_r are the biases for each axis.

The measurement model can be described through the estimation of accelerometer and magnetometer measures.

Let $\underline{a}_b = \left[a_x, a_y, a_z\right]^T$ be the acceleration vector in the body frame and $\underline{m}_b = \left[m_x, m_y, m_z\right]^T$ the earth magnetic vector.

The measurement model for the EKF on a single segment can be written as:

$$\begin{bmatrix} \underline{a}_b \\ \underline{m}_b \end{bmatrix} = \begin{bmatrix} \underline{\underline{C}}_{BE}\left(\underline{q}\right) & 0 \\ 0 & \underline{\underline{C}}_{BE}\left(\underline{q}\right) \end{bmatrix} \begin{bmatrix} \underline{g} \\ \underline{m} \end{bmatrix} + \begin{bmatrix} \underline{a}_l \\ \underline{0} \end{bmatrix} + \begin{bmatrix} \underline{\omega} \times (\underline{\omega} \times \underline{r}) \\ \underline{0} \end{bmatrix} + \begin{bmatrix} 2\underline{\omega} \times \underline{v} \\ \underline{0} \end{bmatrix} \tag{6}$$

Neglecting the linear acceleration a_l and the Coriolis acceleration $2\underline{\omega} \times \underline{v}$, because we consider pure rotations of the segment, the term $\underline{g} = [0, 0, g]^T$ is the gravity vector in the fixed frame, and $\underline{m}$ is the earth magnetic vector, written as $\underline{m} = [m, 0, 0]^T$.

Each segment orientation in the fixed frame, but for ergonomics measurements, we need relative rotation of each segment.

However, considering $\underline{q}_0$, the orientation of the trunk, $\underline{q}_1$, the orientation of the arm and $\underline{q}_2$ the orientation of the forearm (for symmetry we consider one arm), the relative transformation matrices can be written as follows:

$$\begin{aligned}\underline{\underline{C}}_{01} &= \underline{\underline{C}}_{BE}(\mathrm{q}_1)\left(\underline{\underline{C}}_{BE}(q_0)\right)^T \\ \underline{\underline{C}}_{02} &= \underline{\underline{C}}_{BE}(q_2)\left(\underline{\underline{C}}_{BE}(q_0)\right)^T \\ \underline{\underline{C}}_{12} &= \underline{\underline{C}}_{BE}(q_2)\left(\underline{\underline{C}}_{BE}(q_1)\right)^T\end{aligned} \tag{7}$$

3.1 Movemeter

Like a pedometer algorithm, the movemeter developed for this work is able to count trunk, arm and forearm movements.

Data acquired from inertial sensors are initially filtered than the attitude and the estimation of angular velocities (without biases thanks to the EKF) are used to evaluate movements. The basic idea is that usually human motion is never too slow, so the algorithm can use a threshold to understand the presence of a movement.

Afterwards, the angular acceleration is computed and delayed until it is equal to zero (motionless). At this time the algorithm uses the attitude to understand the magnitude of the movement and increase the selected counter.

A flowchart of the algorithm (Fig. 2) is shown to point out the different steps of our movemeter.

Some laboratory tests were performed to prove the effectiveness of the algorithm (Figs. 3, 4, 5).

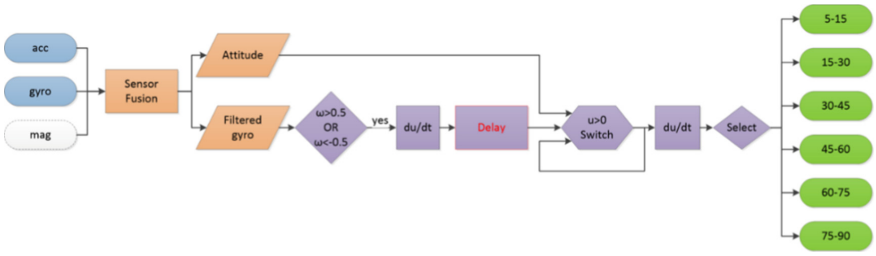

Fig. 2 Movemeter algorithm

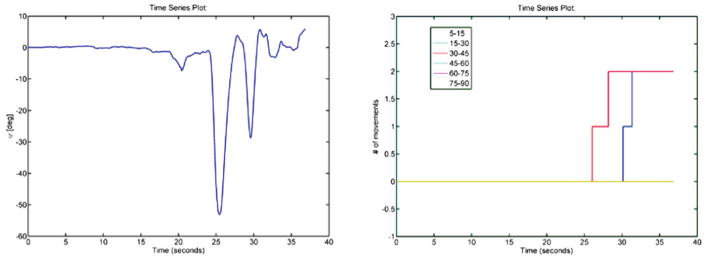

Fig. 3 Yaw movements (orientation on the *left*, movement counting on the *right*)

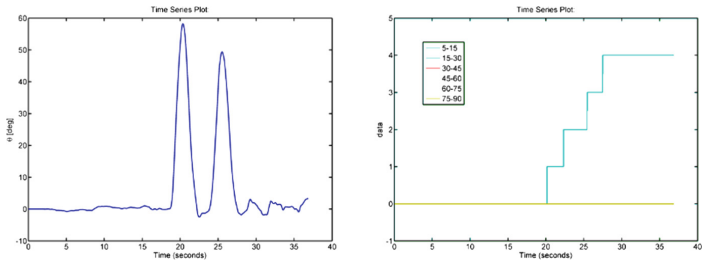

Fig. 4 Pitch movements (orientation on the *left*, movement counting on the *right*)

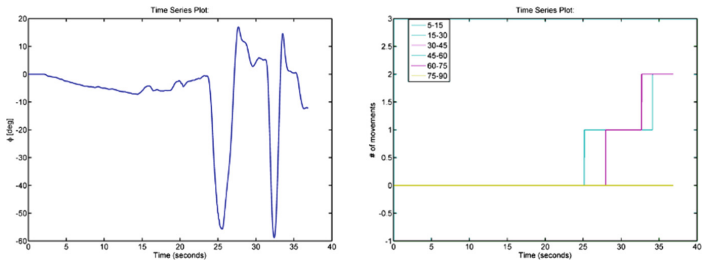

Fig. 5 Roll movements (orientation on the *left*, movement counting on the *right*)

4 Hardware Design

The following hardware has been used for our application:

- 4 IMUs, with ARM Cortex M4 processor (a STM32F303VCT), containing an Invensense MPU6050 (tri-axial gyroscope and tri-axial accelerometer) and an HMC5883L (tri-axial magnetometer), were placed on arms and forearms.
- 1 IMU, based on a Raspberry Pi 2 board plus an Invensense MPU9150 (tri-axial gyroscope, tri-axial accelerometer, tri-axial magnetometer), placed on the trunk (Fig. 6).

Fig. 6 Hardware system used for tests (from *left*: Raspberry Pi and two custom IMU boards)

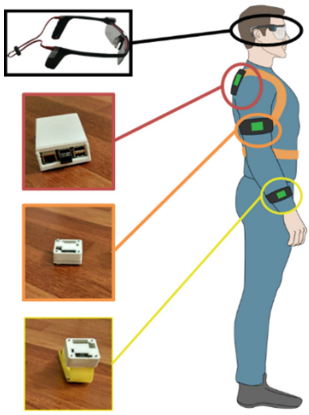

Fig. 7 Hardware system installation

Each peripheral board (arms and forearms) is linked to the main board (Trunk) through an USB connection. The frequency of data collection and communication is 100 Hz.

Each board acquires data from sensors and computes its attitude by using the above described EKF.

On the main board, a high level CPU was necessary to perform the real time acquisition of every attitude from peripherals, to compute the relative attitudes and count the movements.

To this system, an equipment made by smart glasses with an onboard camera can be added to help the ergonomic designer to analyze the pose using a first person point of view with synchronized data of trunk and arms orientation (Fig. 7).

5 Tests and Results

To prove the effectiveness of the developed algorithms, some tests in a real environment were carried out, using a prototype of the system instrumenting only the trunk and the right arm. The tests were performed simulating five times the same work cycle in order to validate the convergence of the algorithm.

Figure 8 shows the prototype system mounted on a worker during the tests.

In Figs. 9 and 10, five particular time steps in the work cycle are represented, showing the results obtained for pitch orientation of arm (Fig. 9) and forearm (Fig. 10).

Fig. 8 Hardware installation during system tests

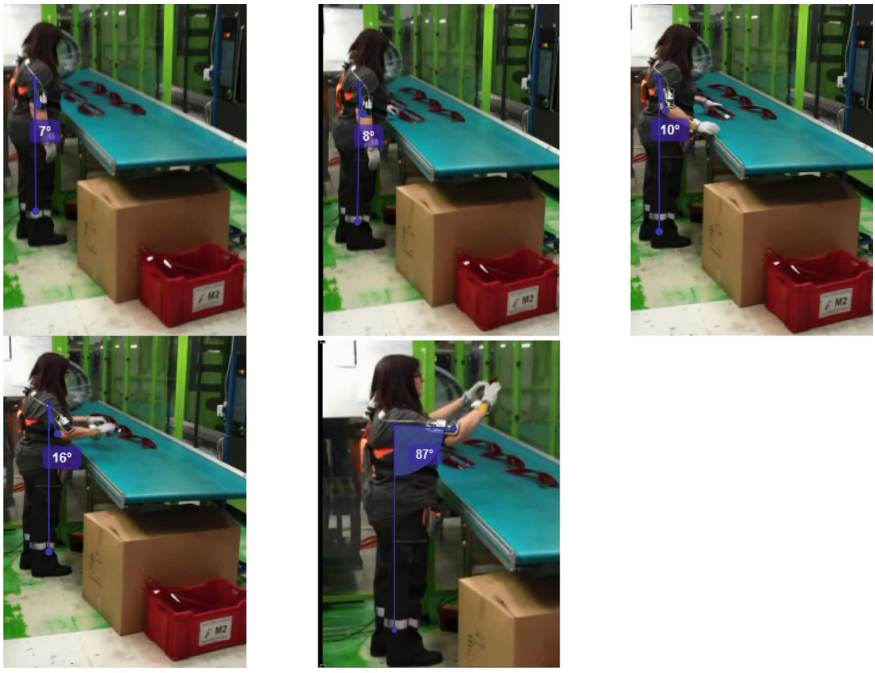

Fig. 9 Arm results for 20 s work cycle

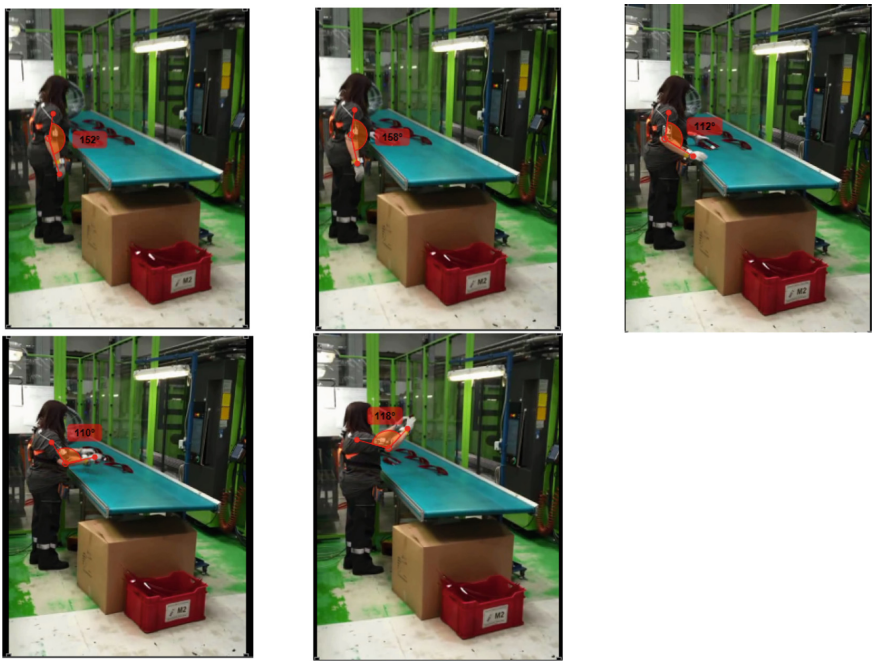

Fig. 10 Forearm results for 20 s work cycle

6 Conclusions

Experimental data acquisition is a fundamental activity to improve work organization in manufacturing environments to optimize processes and to reduce all kind of wastes and risks. Among these data, human movements are some of the most important values to analyze in order to improve comfort, safety and productivity of workers doing their tasks. Many solutions are available but their use in a real industrial environment may show limitation due to the fact that their underlying technology is not completely suitable for an industrial context.

In this paper our solution is based on a system with first person point of view video, with synchronized data on upper-body pose. The novelty is the capability to auto-compile several parts of the most important ergonomic indices and supply, at the same time, the ability to analyze the whole work cycle, very useful to an ergonomic designer to complete the analysis. This idea, combined with the low costs, the low invasiveness of the system (needed in industrial plant environments) and the ease of calibration, can help to improve the ergonomic analysis.

Results obtained by a preliminary test case show that the system is not influenced by the industrial context, besides algorithms are able to "find" real human movements reducing errors and false signals.

Further improvements in the system and a specific tool to evaluate results will easily lead users in a preliminary real time evaluation of ergonomics indices allowing process experts to optimize processes even in continuously changing production scenarios (new line balancing, new mix, etc.).

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Extended Use of Personal Factors in Adaptive e-Learning Environments: Moods in MOOC's

Tobias Augustin

Abstract Massive Open Online Courses (MOOC's) are a new kind of e-Learning environment, which enables us to address untold numbers of students. MOOC's allow students all over the world to participate in lectures independent of place and time. The sessions that are in some cases joined by more than 100.000 students are based on small units of teaching material containing videos or texts. However today's MOOC's are static environments, which do not take into account the diversity of the students and their situational context. Current MOOC's can be seen as mass processing but not as an individual treatment of individual students. Thus MOOC's need to be personalized in addition to massive. In order to personalize an e-Learning environment it is first necessary to collect data, or personal factors, about the student, his or her current environment and his or her situational context. This data should later be processed and used as input for adaptive functions. Basically there are many input factors imaginable, such as cognitive style, pre-knowledge, currently used device or personal goals. The input factors can be grouped into technical, personal and situational factors. Especially situational factors may help to support students in different learning situations. This paper describes an approach to detect the student's current mood as a situational input factor. The mood of a student in a learning situation might be an interesting feature that can be used as an instant feedback for the currently used teaching materials. The proposed approach is based on widespread availability of built-in cameras in devices that are used by students, such as smart-phones, tablets or laptop computers. The captured frames from these devices are processed by various algorithms for preprocessing, face detection, segmentation and classification. The classification algorithm operates on a large database of faces with basic emotional expressions that is used to determine the student's current mood from the captured frame. The output of the system may be used to adjust the difficulty level of tests or to determine the preferred media type.

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Keywords Human factors · eLearning · Adaptive systems · Face recognition · Emotion analysis · User-centered learning environments

1 Introduction

Adaptive systems are generally characterized by the capability of gathering personal or situational user data and the capability to adjust the system behavior regarding the user needs. In order to first get an accurate picture of the user, it is necessary to determine and detect the different factors influencing a user.

This work focuses on the detection of the user's mood in specific learning situations as one influencing factor. The aim of the proposed approach is to classify the mood of faces which are detected in camera images based on the eigenfaces method. The required cameras are nowadays available in most devices such as smart-phones, tablets or laptop computers.

The generated data can be used to adjust the behavior of the eLearning environment. Typically the success of learning situations depends on many personal and situational factors of the individual user. But the success of a learning session doesn't only depend on the current situation of the student, but also on the presented learning materials. A good teacher is always able to interact with a group of students. For example, it is possible to get attention from a group of tired students by using lively or funny examples. Static learning environments that usually follow a linear storyline are not able to interact with the students due to limited alternatives in terms of learning materials and missing knowledge in terms of the learner's current situation. It needs to be pointed out that detecting the learner's current mood is not the single, big solution, but one piece of the puzzle. There is more research needed to identify further personal, situational and technical input factors that have influence on a learning session. Furthermore courses need to be developed that don't follow one static storyline but have alternatives for each piece of information in difficulty level, used media and educational approach. The discussion towards standardized OER's might be a useful approach.

Figure 1 gives a general overview of the proposed system and its process flow. For the face classification we need to make a distinction between two major tasks. The first task is the face detection, which is used to find an area in a total picture containing the facial region. The face detection process is described in Sect. 4. This step is necessary for further processing with face recognition. The second major task, described in Sect. 5, is the face recognition, which is used to classify a face. Typically face recognition is used to recognize a match between a given face and a face from a database of known faces. Currently, the major case of application is to identify persons, e.g. in access control solutions. Here a very similar approach is used not to recognize the person in front of a camera itself but its current mood.

Besides the two major tasks, several additional tasks need to be performed. First a homogeneous and platform independent way for transporting the captured data from the client's device to the server side needs to be found as described in the

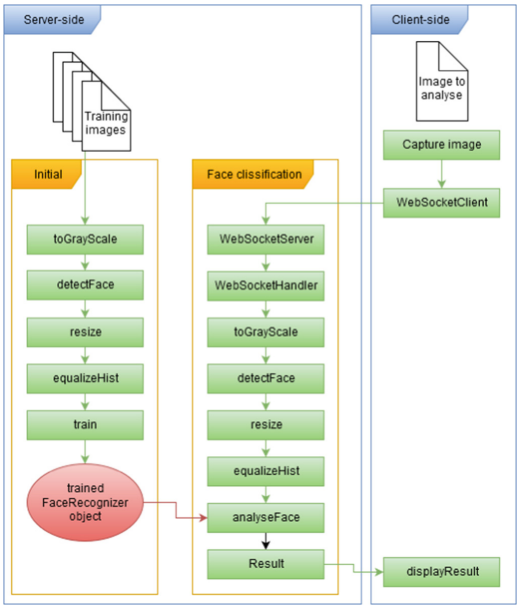

Fig. 1 General process overview

second section. This is essential to support most devices available on the market regardless of their platform and operating system. Additionally the client should not need to install additional software components as most current eLearning systems are web based.

After that a preprocessing at the server side is needed to normalize the transferred images regarding resolution, dimensions and color space. The details of applied preprocessing techniques are described in the third and subsequent sections.

2 Transport

This section describes the image capturing on the client side and the following transport mechanism to the server component for further processing.

As user acceptance for components working "out of the box" is increasing, we searched for a way to capture images at the client side and transport them to the processing server component without the need to install additional software or plugins on the client's side. Furthermore, we searched for a native, platform and operating system independent access to the device without the need to cover different camera models.

Since HTML5 was released in October 2014 it is possible to access the user's video and audio devices without the use of third party plugins. Now it is possible to access the user's camera device directly through a powerful JavaScript-API [1]. Most widely distributed web browsers, such as Microsoft's Internet Explorer,

```
var video;
function start(){
    video = $("#live").get()[0];
    var canvas = $("#canvas");
    var ctx = canvas.get()[0].getContext('2d');

    navigator.getUserMedia= ( navigator.getUserMedia
                              ||navigator.webkitGetUserMedia
                              ||navigator.mozGetUserMedia
                              ||navigator.msGetUserMedia
                            );

    if (navigator.getUserMedia) {
       navigator.getUserMedia ({video: true,audio: false},
          function(localMediaStream) {
             var video = document.querySelector('video');
             video.src = window.URL.createObjectURL(localMediaStream);
                 timer = setInterval(
                function () {
                    ctx.drawImage(video, 0, 0, 320, 240);
                    var data = canvas.get()[0].toDataURL('image/jpeg', 1.0);
                    newblob = dataURItoBlob(data);
                    ws.send(newblob);
                }, 1000);
                ws = new WebSocket("ws://132.176.66.179:9999/8711");
          },
          function(err) {
             console.log("The following error occured: " + err);
          }
       );
    } else {
       console.log("getUserMedia not supported");
    }
}
```

Fig. 2 Client-side JavaScript Code for camera access and connection to WebSocket Server

Mozilla Firefox, Google Chrome and Apple's Safari support HTML5 and its new features. So it is very easy to implement a piece of JavaScript code that can be integrated in most web based eLearning environments and allows us to access the users video device. However, the device will ask the user for permission to start the camera, based on the security settings.

WebSocket is a web technology providing full-duplex communications channels over a single TCP connection [2]. WebSocket is designed to be implemented in web browsers and web servers, but it can be used by any client or server application. In this tutorial we will use a Java server and a JavaScript client.

Figure 2 shows a minimal example that checks if UserMedia is available, creates an instance of a WebSocket server connection to the server's IP-address on port 9999. Once the connection is established it sends an image from the camera to the server every second.

On the server-side we use the Java based webserver Jetty which provides a Web server and javax.servlet container, plus support for HTTP/2, WebSocket, OSGi, JMX, JNDI, JAAS and many other integrations [3]. The server-side implementation

```
package workingSet;
import org.eclipse.jetty.server.Server;

public class WebsocketServer{
    public static void startWSS() throws Exception  {
         Server server = new Server(9999);
            WebSocketHandler wsHandler = new WebSocketHandler() {
                @Override
                public void configure(WebSocketServletFactory factory) {
                    factory.register(DemoWebSocketHandler.class);
                }
            };
            server.setHandler(wsHandler);
            server.start();
            server.join();
    }
}
```

Fig. 3 Server-side Java implementation of the WebsocketServer class

is also quite simple. The Java class WebsocketServer shown in Fig. 3 opens a TCP port and registers a handler class that processes all incoming messages.

The WebSockerHandler class shown in Fig. 4 shows some functions with annotations that are called for different events. Once the connection is established and the client sends frames from the camera device to the server, the function on Frame(byte[], int, int) is called for every incoming frame. The implementation of the function converts the byte-Buffer to an IplImage which is shown in a canvas Frame on the server.

This compact example shows how the captured image data can be transferred from the client to the server with the use of HTML5 and WebSockets. To use this mechanism in a multi-user environment it is also necessary to make a distinction

```
package workingSet
import static org.bytedeco.javacpp.opencv_core.CV_8UC1;
@WebSocket(maxBinaryMessageSize = 500 * 500)
public class WebSocketHandlerT {
    private Session session;
    CanvasFrame canvasFrame = new CanvasFrame("Class WSS Handler");

    public void onClose(int statusCode, String reason) {
    public void onError(Throwable t) {
    public void onConnect(Session session) {
    public void onMessage(String message) {
    @OnWebSocketMessage
    public void onFrame(byte buf[], int offset, int length){
        ByteArrayOutputStream bOut = new ByteArrayOutputStream();
        bOut.write(buf, offset, length);
        IplImage originalImage = cvDecodeImage(cvMat(1,
                bOut.toByteArray().length,CV_8UC1,
                new BytePointer(bOut.toByteArray())));
        canvasFrame.showImage(originalImage);
    }
}
```

Fig. 4 WebSocketHandler class

```
String url = this.session.getUpgradeRequest().getRequestURI().toString();
int uid = Integer.parseInt(url.substring(url.lastIndexOf("/")+1, url.length()));
```

Fig. 5 Server-side UID extraction

between individual users. This can easily be achieved by appending a unique user ID to the endpoint URL on the client and extracting it on the server side as shown in Fig. 5.

3 Image Preprocessing

Now that the images for further analysis are available in the server-side Java stack this section describes how the image data is preprocessed for the following face detection. Further processing techniques, especially face classification algorithms are extremely sensitive regarding lighting conditions, used color space and image dimensions. The preprocessing is necessary to normalize incoming frames regarding resolution, dimensions and color space. Additionally a histogram equalization is applied to each frame. Some of these techniques need to be applied initially to incoming frames, more over some of them need to be applied after the following processing steps.

3.1 Color Space Transformation

Usually the resolution and color space of captured images depend on the used camera device. The techniques used for face extraction and face classification work on the basis of differences in light intensity, so they require grayscale images. Transforming a color image to a grey scale image can be done by applying the following formula pixel wise [13].

$$\text{RGB[A] to Gray:} \quad Y \leftarrow 0.299 \cdot R + 0.587 \cdot G + 0.114 \cdot B \tag{1}$$

The percentage distribution of the colors depends on the color sensitivity of human eyes. OpenCV provides the function cvCvtColor(originalImage, grayImage, CV_BGR2GRAY) that converts an Ipl color image to a greyscale image.

3.2 Resizing

To achieve good results from algorithms for face classification it is necessary to provide pictures with the same resolution for training images and those which are

analyzed. In this scenario we use images with a size of 200 × 200 pixels. This size is used for all training images and all images that are analyzed. As the face classification doesn't work on the complete images as provided the resizing is applied after the face extraction for the area that contains the face. OpenCV provides a function that resizes a given image to a given size.

```
resize(originalImage, resizedImage, new Size(200,200));
```

3.3 Histogram Equalization

Histogram equalization is a very simple method of automatically standardizing the brightness and contrast of facial images. This method usually increases the global contrast of many images, especially when the usable data of the image is represented by close contrast values. Through this adjustment, the intensities can be better distributed on the histogram. This allows for areas of lower local contrast to gain a higher contrast. Histogram equalization accomplishes this by effectively spreading out the most frequent intensity values (Figs. 6, 7, 8 and 9).

Fig. 6 An unequalized image

Fig. 7 The same image after histogram equalization

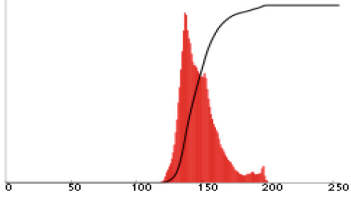

Fig. 8 Corresponding histogram (*red*) and cumulative histogram (*black*)

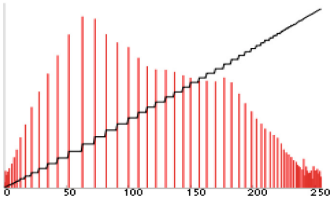

Fig. 9 Corresponding histogram (*red*) and cumulative histogram (*black*)

4 Face Extraction

This section describes the face extraction which consists of face detection in the first stage followed by a segmentation to provide a sub image that contains the detected face. There are several approaches to detect faces in images such as using the Hausdorff Distance [4] or Edge-Orientation Matching [5]. The breakthrough in face detection happened with Viola & Jones [6]. Using a cascade of "weak-classifiers", using simple Haar features, can—after excessive training—yield impressive results. This approach has proved to be very effective and reliable. The method, published in 2001, made it possible to implement face detection on gray scale images in real-time.

The approach is based on so called "Haar features" that represent features that are tried to match regions in the analyzed image. To find objects, features based on difference in light intensity are tested on different regions of the analyzed image. For example the eye area is usually darker than the cheeks and the eyes are darker than the bridge of the nose (see Fig. 10).

The Viola and Jones method is based on five different features. The features can be used in any scale and position to match a region in the original image. Therefore a huge amount of attempts needs to be performed. However the method uses two techniques to achieve fast and efficient processing, cascading and the so called integral image. In 2002 Lienhart et al. [6, 7] extended the method by Viola and Jones with a set of 14 features and were able to improve the processing time again.

Fig. 10 Two features shown in the *top* row and then overlayed on a training image in the *bottom* row. The first feature measures the difference in intensity between the region of the eyes and a region across the upper cheeks. The second feature compares the intensities in the eye regions to the intensity across the bridge of the nose [6]

4.1 Cascade

In most cases an image contains large regions that can easily be identified as background and only a few regions with potential faces. Only the regions containing a potential face are further analyzed. As a face can only be detected reliably by the use of many features, a mechanism is needed to discard background regions in a first step and to perform further detailed analysis on potential faces. Therefore, Viola and Jones used a decision tree based on the work of Amit and Geman [8] called cascade. Each node of this cascade has a binary classifier that determines whether or not the analyzed region can be treated as background (Fig. 11).

If a region is classified as background, the cascade is stopped and no further analysis is performed on this region. If the region is classified as potential face the region is processed by the next node of the cascade. Each region that passes all nodes is accepted as face. The essential advantage of the cascade structure is that early nodes contain less complex and fast classifiers while further classifiers become more complex and time consuming. In concrete terms the first node contains a classifier with two features and recognizes 60 % of the regions containing no face as background and almost 100 % of the regions containing a face as positive for further processing. The second node contains a classifier with five features and analyses all positive regions from the first classifier. This classifier is already able to detect 80 % of the regions as background that don't contain a face. In further steps three classifiers with 20 features, two classifiers with 50 features, five classifiers with 100 features and 20 classifiers with 200 features are used [6].

The complete cascade for face detection in XML representation is available as part of the Open Computer Vision Library [9].

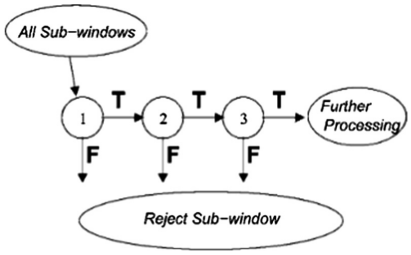

Fig. 11 Cascade used by Viola and Jones. A series of classifiers is applied to every region of the image. The initial stage eliminates a large number of negative examples with very little processing time. Subsequent stages work on a radically reduced amount of regions and eliminate additional negatives but require more processing time [6]

4.2 Integral Image

The second technique to achieve fast processing is based on an alternative way of image representation called integral image. With the use of this technique rectangular features, from which Haar-features are made of, can be calculated in a very efficient way. An integral image contains the cumulated values of the pixels. As the method is based on difference in light intensity, only gray scale images can be processed. Usually 8-bit gray scale images are used, so that a distinction between 256 different brightness values is done. The value of the integral image at a specific point results from the sum of all pixel values above and left of the specific point.

$$ii(x,y) \quad \sum_{x' \leqq x, y' \leqq y} i(x',y'), \tag{2}$$

where $ii(x, y)$ is the integral image and $i(x', y')$ is the original image. The integral image itself can be calculated in one pass with the following formulas, where s is the cumulative row matrix and ii is the integral image:

$$s(x,y) = s(x,y-1) + i(x,y) \tag{3}$$

$$ii(x,y) = ii(x-1,y) + s(x,y) \tag{4}$$

The coherence can easily be seen with a simple example of a 3×3 binary image, where i is the original binary image, s is the cumulative row matrix and ii is the resulting integral image.

$$i = \begin{Bmatrix} 1 & 0 & 1 \\ 1 & 1 & 1 \\ 0 & 0 & 1 \end{Bmatrix} \quad s = \begin{Bmatrix} 1 & 1 & 2 \\ 1 & 2 & 3 \\ 0 & 0 & 1 \end{Bmatrix} \quad ii = \begin{Bmatrix} 1 & 1 & 2 \\ 2 & 3 & 5 \\ 2 & 3 & 6 \end{Bmatrix} \tag{5}$$

The advantage of this method is that after the initial integral image has been calculated the sum of all pixel values of a square from the point of origin to the specific point can be looked up with only one access. Once the integral image has been calculated, it is possible to retrieve the sum of pixel values of any rectangular area of the image.

5 Face Classification

For the face classification we use the Eigenfaces approach which is typically used to recognize faces based on a database of known faces and to recognize the person. Here we don't want to identify the person in front of a camera but want to predict his or her current mood. Therefore it is necessary to build classes of training images that are grouped by the mood of a person and not by the person herself/himself.

The method for face identification was developed by Turk and Pentland [10, 11] and is based on the Principal Components Analysis (PCA). The idea is based on an approach by Sirovich and Kirby [12] which uses the PCA to represent pictures of faces highly efficient using low dimensional vectors.

The main difference compared to other approaches is that Eigenfaces doesn't attempt to detect and measure prominent features, such as eyes, nose and lips, and their relative position to each other. As it turned, out these approaches ignore important information that relies on the overall composition of a face. Eigenfaces analyses the face in its entirety and tries to find the relevant parts to make them comparable to other data. The idea behind Eigenfaces is to represent and compare the variation in a group of pictures of faces, absolutely independent of individual features. So the aim is to find the principal components or more specially the covariance matrix of a set of faces. This set is called training set and contains a group of known faces, called training faces. Usually faces in a training set are grouped regarding a specific person but here we group training images according to the shown emotion as we want to classify the emotion shown in the input image.

5.1 Initialization

For the initialization a set of M known faces is given. All images in the set are greyscale images and have the same resolution.

For further processing the images are represented as vectors. For a low resolution picture of 512 * 512 pixels the method accrues a vector with 218 dimensions or a point in a 218 dimensional space. As pictures of faces are similar in many regions it can be seen that the relevant face space is a relative low dimensional subspace. To find this subspace the most relevant vectors need to be found. These vectors are the eigenvalues of the covariance matrix of the training set. From an image the matrix Γ_M or the vector Γ_V can be built:

$$\Gamma_M = \begin{Bmatrix} 0 & 1 \\ 1 & 2 \\ 2 & 3 \end{Bmatrix} \quad \Gamma_V = \begin{Bmatrix} 0 \\ 1 \\ 1 \\ 2 \\ 2 \\ 3 \end{Bmatrix} \tag{6}$$

The training set contains M training images $\Gamma_1, \Gamma_2, \Gamma_3, \ldots, \Gamma_M$. From these M face vectors we first build the average face D:

$$D = \frac{1}{M} \sum_{i=1}^{M} \Gamma_i \tag{7}$$

From the obtained average face and the training images the difference images can be calculated:

$$\Phi_i = \Gamma_i - D \tag{8}$$

From the difference images we can build the covariance matrix C, whose M eigenvectors are searched:

$$C = AA^T \tag{9}$$

where A is a matrix with difference images as columns and A^T is its transpose.

Here a simpler approach is needed to identify the eigenvectors as the calculation is not practical. For a 512 * 512 pixel image a 262,144 × 262,144 matrix would arise. Solving this problem isn't feasible, so a trick needs to be applied. This can be done by solving a less complex problem, by reducing the $(B * H)^2$—matrix to a $M * M$ matrix, as $M \ll (B * H)^2$. Therefore the eigenvectors of $C' = A^T A$ instead of $C = AA^T$ are calculated. AA^T can have up to $(B * H)^2$ eigenvalues and eigenvectors. $A^T A$ can have up to M eigenvalues and eigenvectors. The M eigenvalues of $A^T A$ (along with their corresponding eigenvectors) correspond to the M largest eigenvalues of AA^T (along with their corresponding eigenvectors).

From the eigenvalues v_i of the covariance matrix C the corresponding eigenfaces u_i can be calculated using the following formula:

$$u_l = \sum_{k=1}^{M} v_{lk} \Phi_k, \quad l = 1, \cdots, M \tag{10}$$

As only the first eigenfaces show a significant difference, usually M eigenfaces are sufficient for face classification. In most cases even M eigenvectors are too many, so that only the best K eigenvectors are used. Sirovich and Kirby [13] showed that it is possible to use only the 40 best eigenfaces of a training set of 115 faces resulting in an inaccuracy less than 2 %. It can easily be seen that $K < M \ll (B * H)^2$ and therefore it is not necessary to calculate the eigenvalues for AA^T instead of just $A^T A$. Each face from the training set can be represented as a linear combination of the eigenfaces:

$$\Phi_i - D = \sum_{j=1}^{M} w_j u_j \tag{11}$$

To build classes of persons or in this case moods it is necessary to determine a weight vector for every face from the training set. Therefore they are disassembled to their eingenface components first.

$$w_k = u_k^T \Phi \quad (k = 1, \ldots, M') \tag{12}$$

And results in the weight vector $\Omega^T = [\omega_1, \cdots, \omega_M]$. All faces belonging to one class are averaged to obtain the face class.

Unknown input face images that are intended to be analyzed also need to be disassembled to their eingenface components. Based on the Euclidean distance we can now determine the matching face class with the shortest distance.

6 Discussion

The proposed approach shows that it is possible to implement a reliable mood detection component based on various proven techniques. Some of the underlying techniques such as the face detection by Viola and Jones are state of the art. Some others such as standardized HTML5 mechanisms or WebSocket communication are emerging techniques and help to make the shown process as simple described here. A new aspect is the use of eigenfaces not for training groups of individual persons in different poses and under various conditions but for training groups of emotions from different persons in different poses under various conditions. Due to the use of advances, preprocessing by analyzing only the facial region of an image that is normalized the approach is relatively robust concerning changing environmental conditions. However the face classification using eigenfaces based on a training set grouped by emotions is the weakest module concerning reliability.

An alternative to holistic approaches, such as the discussed eigenfaces method are landmark based approaches. Based on the relative position of facial landmarks the potential shown emotion is determined. One of the main advantages of these approaches compared to holistic approaches is that no large scale database and time consuming initial training of the classifier is required. But on the other hand these approaches are less reliable due to inaccurate position determination of the single landmarks.

In summary, it can be stated that landmark-based approaches are quite easy to implement and can be used ad hoc in various environments without a training process. Compared to holistic approaches disadvantages can be expected in terms of reliability but also benefits through lower development costs and immediate operational readiness.

In general it needs to be considered that detecting a mood is only one of many possible input factors to an eLearning situation. Mood detection can help to improve an eLearning session but it is only one of a lot of factors on the way to real adaptive scenarios.

In addition to that it needs to be considered that the detection of situational or personal factors is only one first step in the development of adaptive eLearning scenarios as it is furthermore necessary to develop strategies how to react on particular input factors and interactions of multiple factors.

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Part IX
Safety and Health

Physiological Analysis of Stoop Lifting Based on Heart Rate for the Malaysian Population

Rosnah Mohd. Yusuff, Nor Hafeezah Kamarudin, Ariff Mubarak Kamal Ariffin, Siti Anom Ahmad and Mohd. Amin Mohd. Soom

Abstract The growing problem of work related back injuries has contributed to the rising cost of health care, human suffering and loss of productivity. In Malaysia, back pain injury awareness is still low, but the number of casualties as a result of back pain is increasing. In this study, the physiological aspects of stoop lifting posture on heart rate for the Malaysian population were studied. Different lifting heights, frequency, twist angle and weight of loads were studied to identify and recommend the appropriate lifting tasks to be used by the workers. An experimental work was conducted involving 36 subjects between 20 and 40 years old with no history of back pain. The subjects performed stoop lifting posture to lift loads of 10, 15, 20 and 23 kg to a lifting height of 70 cm and 130 cm, with the frequency of 1 lift, 3 lifts and 6 lifts per minute and twist angle of 0° and 90°. The results of the study showed that heart rate is linearly related to height of lifting, weights, frequency and angle of twisting. These findings can be used as a guide to design lifting tasks for the Malaysian population.

Keywords Heart rate · Physiology · Lifting task · Stoop lifting

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1 Introduction

Musculoskeletal diseases especially back pain problems have been increasing every year. It implies the symptom complex where pain is localized to the lumbar spine or refers into leg or foot and where other specific conditions causing such pain have been excluded. In 1981, the National Institute of Occupational Safety and Health (NIOSH) recognized the growing problem of work-related back injury. According to the Department of Labor (DOL) report in 1982, back injuries accounted for nearly 20 % of all injuries and illnesses in the work place, and nearly 25 % of the annual workers' compensation payments. On top of that, low back pain and injuries attributed to manual lifting activities continue to be as one of the leading occupational health and safety issue [1, 2].

In Malaysia, based on the statistic reported by Department of Occupational Safety and Health Malaysia, 675 cases were reported in 2014, with only 10 reported cases in 2005 [3].

Currently, there is limited work that has been carried out on the physiological effects of lifting on the Malaysian population. Most work were concerned on the prevalence of musculoskeletal diseases.

1.1 Manual Lifting

Manual material handling has been considered as a major occupational hazard to workers. Among the various kind of manual material handing tasks, load-lifting is thought to be the common cause of various musculoskeletal injuries, especially low back problem [2]. Lifting activities require involvement of the various human joints in a complex manner. The external force applied by the load to be lifted is shared by the low back, hip and knee joint. The sharing may depend on many factors like age, sex, strength and also posture adopted during the lifting activities.

Physical ergonomic elements such as the combination of load and postures, awkward working postures, postural activities, heavy weight lifting, prolonged periods of standing or walking, long working hours per shift, repetitive movements or monotonous work and poor working condition are associated with low back pain injuries [4].

Posture used during lifting activities seems to contribute most to the issues of back pain. Normally, people or workers tend to use squat posture and stoop posture during performing manual material handling (MMH) activities, especially lifting activity. Studies have been done to find the best posture that should be used to minimize the effect of back injury [5–11] and [12]. Squat lifting was found to be more tiring than straight leg posture [5]. Stoop lifting method is viewed as best in circumstance where the load is too wide to be placed between the knees since stoop

method minimizes the moment arm of the load to the low back [6]. In terms of physiological cost, the stoop method of lifting was found to be the least and the squat method most demanding.

1.2 Physiological

Physiological criteria concentrate on constraining energy expenditure to levels that do not result in excessive whole-body or localized fatigue [7]. Physiological criteria constrain the metabolic stress and fatigue associated with redundant lifting tasks [1, 2]. The level of acceptable energy expenditure is reliant on the duration of activity. Heart rate, rate of oxygen consumption and percentage of maximum oxygen uptake can potentially be used as the criteria. The rate of oxygen consumption is the most widely recognized measure of energy expenditure. A rate is picked that corresponds to a majority of the population being accommodated. Dynamic lifting tasks oblige different muscle groups to move both the load and the body [1]. Because of this, large energy expenditure is needed to supply the muscles with adequate oxygen for contraction. Without oxygen to discharge adenosine triphosphate (ATP), prolonged dynamic activity cannot be maintained. When metabolic demands of dynamic and sustained activity surpass the energy producing capacity of a subject, muscle contraction is influenced and entire body exhaustion is generally experienced.

Physiological assessments are the basic approaches to assess the effects of manual lifting task. The heart rate varies for different activities and increases when engaged in vigorous activities due to increase in oxygen supply for muscle metabolism [8]. The physiological evidence reported that using squat posture required high absolute oxygen consumption and maximum oxygen consumptions for stoop lifting is reported to be 14.3 % lower than squat lifting and ventilation maximum capacities for stoop lifting is reported to be 18.7 % lower than squat lifting. The maximum heart rate capacities for stoop lifting is reported to be 6.5 % lower than for squat lifting [9, 10].

Manual lifting is typically carried out in most industries in Malaysia, especially in manufacturing and agriculture. The energy capacity of the Malaysian population has not been studied for various lifting tasks. This study can provide some guidelines in designing the lifting tasks for the Malaysian population. Heart rate measurement can indicate the amount of energy expended while doing work, therefore the severity of the tasks can be determined and appropriate lifting tasks can be designed without exceeding the limitations of the workers. Generally, this study focuses on the identification of energy expenditure by measuring the heart rate before and after the lifting task.

2 Methodology

2.1 Subject Selection

A total of 36 healthy male and female volunteers between the ages of 20–40 years, with no history of back pain were recruited. The average height and weight of the respondents were 162.2 cm and 59.6 kg respectively. The demographic data of the subjects shown in Table 1.

The procedure for conducting the experiment was approved by the Ethics Committee of Universiti Putra Malaysia and they have to sign the consent form prior to the data collection. Respondents were briefed on the procedures and were given sufficient time to practice and familiarize with the task before actual data were recorded.

2.2 Subject Preparation

Actiheart is a chest-worn monitoring device that records heart rate, inter-beat interval (IBI) and for calculating and measuring activity energy expenditure was used. The Actiheart which is attached directly to ECG surface electrodes (4 mm diameter, 10 cm inter-electrode distance) were placed on the chest adhered at V1 or V2 (4th intercostals) and V4 or V5 approximately 10 cm away on the left side which is comfortable for the subjects as in Fig. 1.

After the electrodes placement, the signal test function in Actiheart software to check the quality of the R wave signal were done before the actual and long term recording of the subjects.

Table 1 Demographic data of the subjects

Data	Min	Max	Mean	Standard deviation (SD)
Age (year)	20	40	24.5	4.3
Height (m)	149.3	177.0	162.2	7.6
Weight (kg)	41	102	59.6	14.7

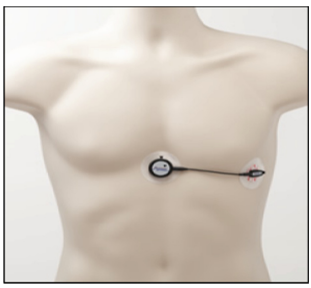

Fig. 1 Electrode placement on the chest of respondents

2.3 Experimental Setup

The material and method were setup for this experiment including posture, variables and the equipment used for this experiment.

Lifting Posture. Stoop lifting posture as in Fig. 2 was used for the lifting tasks designed in this study. Subjects were required to bend forward while maintaining their legs straight during the lifting task [12]. Most authors claimed that stoop lifting method is hazardous to the lower-back but still is a frequently used lifting method [5–13]. Stoop lifting method is viewed as best in circumstances where the load is too wide to be placed between the knees since stoop method minimizes the moment arm of the load to the low back [5].

This posture utilizes the hip and trunk muscle groups which are better than the knee muscle and allow better body control as well as better balance. It also lowers the rate of energy expenditure and minimizes the change in potential energy of a lifter's body.

Variables. Weight Loads (L)—10, 15, 20 and 23 kg and placed at the centre of the lifting box. Height of the loads (H)—Two level of height 70 cm and 130 cm. Lifting Frequency (F)—1, 3 and 6 lifts per minute. Only two twisting Angles (A) were considered: 0° and 90°.

Equipment. Load, adjustable table, Actiheart, lifting box and weighing scale.

2.4 Design of the Experiment

There are three types of variables involve namely fixed variables, dependent variables and independent variables.

The fixed variables are:

1. Type of lifting posture
   (a) Subjects were required to use stoop lifting posture to lift the loads.
2. Distance of subject from the table
   (a) The distance of the subject and the table is set to be 0.25 m.

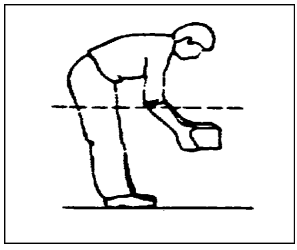

Fig. 2 Stoop lifting

3. Angle of twisting
   (a) The angle of twisting of subjects is set to be 0° and 90°.

The dependent variables are:

1. Heart rate before and after lifting activity
   (a) Subject's heart rate will be recorded using fingertip pulse Oximeter before and after lifting activity
2. Energy expenditure
   (a) Energy used to lift the loads will be recorded and determined by using Actiheart.

The independent variables are:

1. The weight of the loads lifted
   (a) All subjects need to lift loads of 10, 15, 20 and 23 kg
2. The height of the loads lifted
   (a) There are two levels of height which were 70 cm and 130 cm.
3. Lifting frequency
   (a) Lifting frequency was set to be 1, 3 and 6 lifts per minute.

3 Result and Discussion

The results of this study showed the heart rate response during the lifting activities at each combination of height and weight loads together with different lifting frequency.

3.1 Heart Rate for Stoop Lifting Varying with Lifting Table Height, Lifting Frequency, Loads and Angle of Twisting

Table 2 indicated the mean heart rate for stoop lifting varying with the height of table, lifting frequency, loads and angle of twisting.

Figures 3, 4, 5 and 6 below showed the trend of heart rate when the loads and lifting frequency were increased.

Figure 3 shows the heart rate when the height of table was set to 70 cm and the twisting angle was 0°. From this figure, generally the heart rate was increasing

Table 2 Mean heart rate for stoop lifting varying with table height, angle of twisting and lifting frequency

Height of table (cm)	Angle of twisting (°)	Lifting frequency	Stoop			
			Heart rate			
			10	15	20	23
70	0	1	92	96	101	104
		3	100	104	106	109
		6	108	109	114	118
	90	1	95	100	102	105
		3	104	108	108	110
		6	113	119	120	123
130	0	1	97	101	102	104
		3	104	109	111	116
		6	111	119	122	124
	90	1	102	107	107	116
		3	107	112	114	119
		6	117	124	131	135

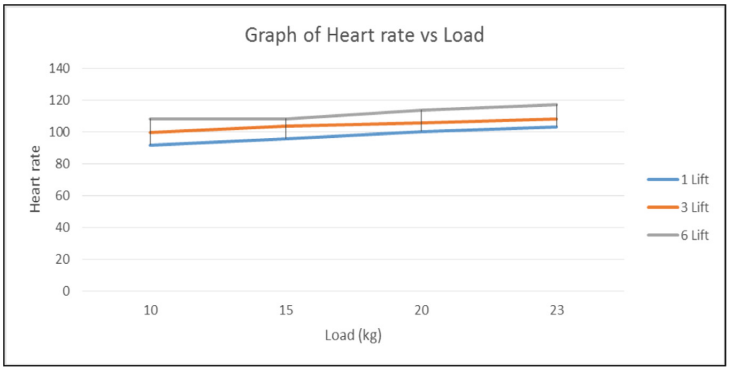

Fig. 3 Comparison of mean heart rate for stoop lifting varying with lifting frequency and loads at the height of 70 cm and angle of twisting, 0°

when the weight of load lifted was increased. Not only that, the heart rate also increased when the lifting frequency was increased. The increasing of heart rate is due to the increasing difficulty of the lifting task. The maximum heart rate obtained for 1 lift and 3 lifts per minute, were 103 and 108 beats per minute respectively during lifting 23 kg of load. For 6 lifts per minute, the trend of heart rate was just like in 1 lift and 3 lift. The maximum heart rate in this state was 117 beats per minute.

Figure 4 shows heart rate of subjects in an experiment using same height as in Fig. 3 but with the twisting angle was set to 90°. Based on these two figures, the heart rate was increased when the twisting angle was changed from 0° to 90°. The

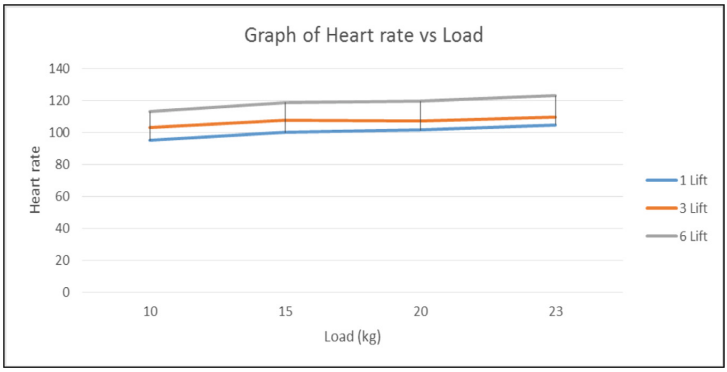

Fig. 4 Comparison of mean heart rate for stoop lifting varying with lifting frequency and loads at the height of 70 cm and angle of twisting, 90°

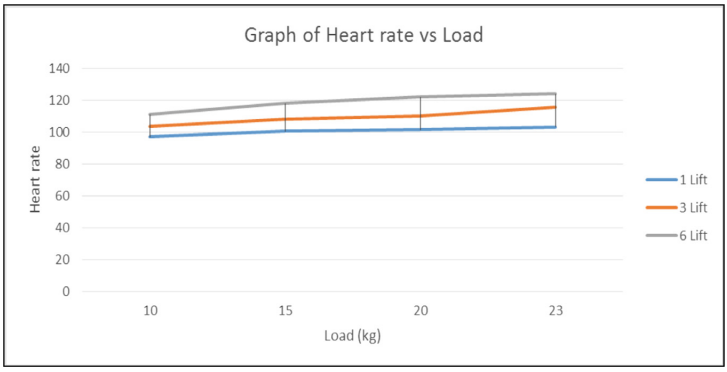

Fig. 5 Comparison of mean heart rate for stoop lifting varying with lifting frequency and loads at the height of 130 cm and angle of twisting, 0°

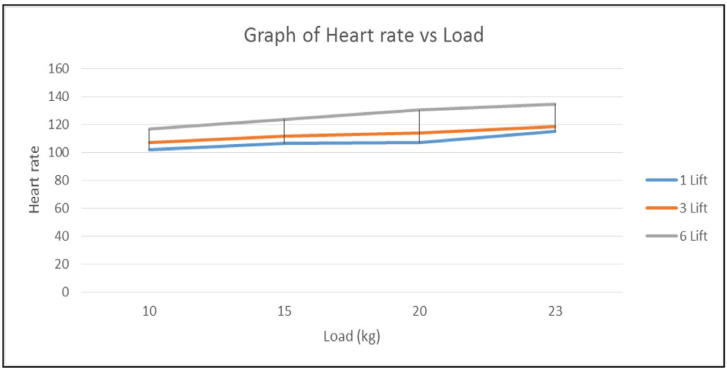

Fig. 6 Comparison of mean heart rate for stoop lifting varying with lifting frequency and loads at the height of 130 cm and angle of twisting, 90°

average heart rate for 6 lifts per minute at 10, 15, 20 and 23 kg with 0° twisting angle were 108,109, 114 and 118 beats per minute respectively, while for 90° twisting angle, the average heart rate recorded were 113, 119,120 and 123 beats per minute.

Figures 5 and 6 represent the heart rate when the height of table was set to 130 cm with different twisting angle of 0° and 90°. For height table of 130 cm, the average heart rate recorded for all weights and angle of twisting were all above 100 beats per minute, except for 1 lift per minute for 10 kg weight. Both figures obtained the same trend as in previous figure. Referring to 6 lifts per minute data, the heart rate when lifting 10, 15, 20 and 20 kg with 0° twisting angle were 111, 119, 122 and 124 beats per minute while for 90° twisting angle were 117, 124, 131 and 135 beats per minute.

4 Conclusion

Based on the preliminary experiment, the weight of the loads, the height to lift the loads, the angle of twisting and frequency of lifting showed the lifting capabilities of the respondents and energy used during the lifting tasks. The angle of twisting and lifting frequency influenced the result of heart rate of each participant during the lifting task. Heart rate increases when the weight of load lifted, angle of twist and frequency of lifting were increased. Subjects need more energy when the heart rate was increased. The heart rate also increased when the height of table was increased. The increasing heart rate showed that the lifting task was becoming more difficult to do when the height was increased. The twisting angle also affects the heart rate. The increasing heart rate from 0° to 90° during the lifting task showed the increased twisting angle is more difficult and tiring to the subjects. The lifting frequency also affected the heart rate of the subjects. When the lifting frequency increased, heart rate also increased. The study showed that heart rate is linearly related to height of lifting, weights, frequency and angle of twisting. These findings can be used as a guide to design lifting tasks for the Malaysian population.

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Evaluation of Physical and Motor Function in an Aging Population—Methodology Design

Marek Bures

Abstract The paper is focused on issues regarding degenerative changes in older industrial population. Proposed research will focus on measurement of dexterity and motor skills, hand strength and range of motions. The paper reviews actual research studies in previously mentioned areas and forms a methodology for new research. The dexterity tests will be performed by Purdue Pegboard Test, Grooved Pegboard Test and Complete Minnesota Dexterity Test. For hand grip the Jamar dynamometer will be used and range of motions will be measured by standard goniometers. The questions about testing positions, number of repetitions, hand dominance, warm-ups and breaks during measurements are discussed and answered. Within this proposed research a mutual relation between dexterity, strength a range of motions will be evaluated. Also actual normative data for European population will available.

Keywords Aging population · Dexterity tests · Grip strength · Range of motions · Normative data

1 Introduction

Mainly Europe but also some Asian countries are affected by the demographic trend facing towards population aging. According to the statements by the European Commission [1], three basic trends are responsible for this development:

1. The continued rise in life expectancy owing to a significant improvement in the health and quality of life of Europeans.
2. The increase in the age group over 65 up to 2030 when the children of the "baby boom generation" reach retirement age.

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3. A constantly low birth rate (low fertility) due to numerous factors.

Some studies e.g. [2] show that the mortality, which has fallen substantially since the 1970s among older people, is the main reason of population ageing, rather than low fertility. According to EU statistics [3] the old-age dependency ratio in Europe (i.e., the ratio of people aged 65 years or older to people aged 15–64 years) is projected to increase from 26 to 52.5 % between 2010 and 2060, so that for every person aged 65 years or older, there will be only two people aged 15–64 years (instead of four as previously). The largest increase is expected to occur during the period 2015–2035, with year-on-year increases above 2 % points. This phenomenon will have a massive effect on working population. Many countries in these days form strategies how to provide dignified working condition for people working longer than till 60 or 65 years of age. The general problem in these days is the employment of people over 50 years old. The employment rate for older workers (aged 55–64) in EU 27 is currently less than 50 %. Only 15 countries around the world have the employment rate of older workers higher than 50 %.

With increasing age, there are human physiological changes, more frequent occurrences of health problems and chronic diseases. For this reason there is a necessity to adjust work environment in order to prevent early retirement and sick leave of older workers. The most frequent causes of incapacity are musculoskeletal and mental disorders, including depression. The most common physiological changes accompanying aging according to the various researches include:

- change of anthropometric dimensions,
- a reduction in physical fitness and muscle strength,
- respiratory problems,
- decrease in maximum heart rate, and thus the performance of the worker,
- worse motor skills,
- reduction in range of motion in joints and its pain,
- deterioration of the senses (sight, hearing)
- change in mental function and
- immunosuppression.

For the future research we have selected three areas from the previously mentioned. We will focus on mutual interactions between degenerative changes in the areas of:

- physical fitness and muscle strength,
- motor abilities and
- range of motions.

What is the progress of physical changes in these areas is already known from previous worldwide researches. The aim of current research idea is to explore mutual relations. Previous studies usually focus on changes only in each areas separately. A comprehensive evaluation of several factors at once has not been done yet. For example, one of the assumptions is that the reduction in the range of motions may have influence on reduction of motor abilities. Another goal of this

study will be confirmation of already known normative values on European population, Czech Republic residents precisely. Most of current normative values came from American or Asian studies. Some of them need to be actualized already as founded by several researchers.

On a selected sample of subjects a measurements of manual skills and dexterity (motor testing), muscle strength and joints range of motion will be performed. For motor skills measuring three well known dexterity tests will be used. Purdue Pegboard Test and Grooved Pegboard Test will serve for fine dexterity evaluation. Complete Minnesota Dexterity Test will serve for manual dexterity evaluation. The hand grip strength and finger strength will be measured by Jamar Plus + dynamometer. Finally the joints range of motion of the hands, torso and neck will be measurement by standard goniometers. As a first step the literature review of current measurement procedures was performed in order to establish clear rules for measurement with respect to future comparison of the results. This paper is focused on this methodological description.

2 Methodology

2.1 Dexterity Testing

These tests are most often used in health care in neuropsychiatry, after injuries or illnesses to assess the severity of the patient's condition [4, 5]. Furthermore, they are used to measure progress during rehabilitation, which point to the effectiveness of treatment. Dexterity tests are also used by industrial companies in convalescence and for workers returning from sick leave. They are also very popular in the selection process, in particular on the positions of assembly workers or for positions requiring manual dexterity [6]. There are a several dexterity tests that have been developed and improved throughout the time. Yancosek et al. [7] provides an overview of fourteen dexterity tests and compares them in terms of their validity, reliability, costs, time demands and other factors. These factors include whether the test evaluates bilateral or unilateral hand movements or whether the test is used to measure the fine dexterity, manual dexterity or both of these skills.

2.1.1 Purdue Pegboard Test (PPT)

In our study we will use the Purdue Pegboard Test model 32020 from Lafayette Instrument Co. PPT assess fine motor hand function using three common objects, pegs, washers and collars, to be inserted on a pegboard. The test consisted of four subsets. In the first three subsets, subjects has 30 s to fill the holes with pegs initially with the dominant hand (defined as the hand used for writing), then with the non-dominant hand, and finally with both hands simultaneously. In the last

subset, subjects have 60 s to assemble in sequence a peg, a washer, a collar, and finally another washer with both hands [8].

According to the PPT manual and nature of the test it is advice to perform this test in sitting position. Another issue is the number of test repetition. According to the Manual it is recommended to repeat each test four times for greater reliability. Yancosek and Howell [7] noted that three time repetition is enough for sufficient results. The exceptions are patients with multiple sclerosis where [9] demonstrated that one repetition is enough. The subject acting in proposed study will be completely healthy the test will be performed three times.

2.1.2 Grooved Pegboard Test (GPT)

In our study we will use the Grooved Pegboard Test model 32025 from Lafayette Instrument Co. GPT is another in a series of manual dexterity tests which like PPT measures fine dexterity of hands respectively fingers. This test consists of desk with 25 holes in which the pegs are being inserted. Each peg has a ridge on one side and therefore must be oriented correctly to fit into a hole on the pegboard. This lock-and-key feature of the peg and pegboard necessitates visual attention to task and thumb and index finger manipulation of the peg which makes this test special. GPT consists only of two variants of tests. First test evaluates the dominant hand, second test focus on submissive hand. Time needed to fill all holes with pegs is measured.

The GPT manual didn't indicate whether the test subject has to sit or stand during the test. Because the nature of the test and similarity with PPT (GPT requires even more precise and fine handling of pegs) it was decided that the subject will also sit during the test. Also the number of repetition isn't discussed so again as in case of PPT the repetition of the test will be three times. There aren't many studies containing normative data for this kind of test [10, 11] so the results of our study will have considerable contribution.

2.1.3 Complete Minnesota Dexterity Test (CMDT)

Complete Minnesota Dexterity Test or also called Complete Minnesota Manual Dexterity Test serves for evaluation of manual skills, specifically the ability to move small objects at different distances. Unlike previous tests this one is focused on manual dexterity of hands, arms and overall hand-eye coordination instead of fine dexterity of hands and fingers. The test used in our study will be a model 32023A from Lafayette Instrument Co. which consists of two boards with holes and 60 short round blocks, red colored from one side and black from the other. The actual test consists of placing these round blocks into the holes of the board, turning them and combination of these movements. This produces a series of following five subtests:

1. placing test,
2. turning test,
3. displacing test,
4. one-hand turning and placing test and
5. two-hand turning and placing test.

In literature we can meet variations like Minnesota Rate of Manipulation Test (MRMT) a Minnesota Manual Dexterity Test (MMDT). There are basically two versions of a similar assessment tool (CMDT). The MRMT older and is no longer produced. Both versions consist of five timed subtests. A distinction between the two versions is that MRMT contains two boards, whereas MMDT uses a single board. However, Surrey et al. [12] raise legitimate concern for the use of the MMDT based on their results that revealed significant differences in scores between the placing and turning subtests between the two test versions ($p < 0.001$). Furthermore, they point out that the MMDT uses the normative values and instructions established for the 1957 version of the MRMT. Given their findings, research to establish new norms and evaluate psychometric properties should be done related to the currently available version of the MMDT.

Several studies also focused on the question which position the subject should take. Despite the test manual advice the standing position [13] found out that there is no difference in results whether the subject is standing or sitting. In our study we will select the standing position. According to the nature of the test and size of the test board it is better to stand during the test in our opinion. However the test manual advises that the table height should range from 71 to 81 cm. This is very low for standing work position. Ideal working height for standing operation from ergonomic point of view is between 90 and 100 cm depending on male or female. This will be our testing height.

For all CMDT subtest a time for completion is measured. After a trial test is performed next two, three or four rounds are performed. According to the test manual four rounds are recommended (the lower the number of attempts, the less reliability). As natural we will perform three repetitions.

2.2 Hand Grip Testing

The hand grip is used during normal activities throughout the day, including eating, dressing, personal hygiene, writing or computer use, but also in specific activities, such as playing a musical instrument or sports. People with injured hand, arthritis or other disease which reduces grip strength very quickly realize how difficult it is to perform the most common operations.

Measuring the grip strength is like dexterity tests used in orthopedics and physiotherapy to determine the severity of injuries, to record progress in recovery and in general to monitor changes in health status. It is also used in the diagnosis of

neuromuscular disorders such as stroke, cervical herniated discs, carpal tunnel syndrome or tennis elbow.

In our study we will focus on measurement of palmar grip, key grip and tweezer grip. As a measuring tool, one of the most famous instruments, Jamar + dynamometer, will be used. It includes an adjustable handle which can be adjusted into five different positions, each offset by a half inch from 1.375 to 3.375 in. The first position has a margin 3.49 cm, the second 4.76 cm, the third 6.03 cm, the fourth 7.3 cm and the fifth 8.57 cm. The device enables to measure maximal voluntary grip force (MVGF) up to 90 kg.

There are many studies that studied the influence of grip span on maximal grip force. Firrell and Crain [14] sought to determine on which dynamometer position the subject will have greatest strength. Based on measurements in standard position they found out that the overwhelming majority (89 %) developed MVGF on second position of dynamometer. Interestingly, the subjects who had MVGF the third or fourth position hadn't a bigger hand or longer fingers than those for which the MVGF was measured on the second position. Blackwell et al. [15] tested the effect of different handle positions of Jamar dynamometer on grip strength and fatigue of musculus flexor digitorum superficial. They conducted a test of only first four positions since the fifth position was mostly unreachable for the participants. It was found that there were statistically significant differences in the grip strength of all handle positions except the second and third and second and fourth positions. Minimum grip force was performed on first and fourth position (minimum and maximum range), while the greatest strength was performed on the second and third position.

When measuring the maximum grip strength it is customary to follow standard procedure recommended by the American Society of Hand Therapists (ASHT). The recommendations regarding the test position are as follows [16]:

- subject is seated during the test,
- arm is abducted and in neutral rotation,
- elbow at a right angle,
- forearm in a neutral position and
- wrist in a neutral position.

Another aspect that must be considered is the warm-up respectively muscle heating. Some studies like [16] performed warm-up before the actual measurements. Innes [17] states that a specific warm-up when the subject isn't performing maximum grip strength but only submaximal leads to the development of higher MVGF. The three minute warm-up described in this study includes flexing the shoulder joints, elbow joints and wrist and then repeatedly squeezing the rubber ring. As there will be also a range of motion measurement in our study, it will be performed before the hand grip measurement thus serving as a warm-up.

It is also necessary to consider how many rounds of the testing will be performed and whether the warm-up round will be included in evaluation. User guide for Jamar + dynamometer recommends three repetitions. Hanten et al. [16] conducted

also three rounds of measurements which were preceded by a warm-up of each hand. Mathiowetz et al. [18] recommended for greater reliability and validity also three measurements as well as [17].

Except warm-up the grip force is also influenced by rest periods between measuring rounds. A time interval between the test rounds is necessary for muscle fatigue elimination. Blackwell et al. [15] indicates that muscle fatigue is defined as a reduction of MVGF while the inability to maintain power at a constant level even with increased effort. During theirs measurement of MVGF they gave 3 min break between the rounds to the participants. Hanten et al. [16] provided 15 s of the rest between rounds. Innes [17] found that including 60 s rest period between successive measurements show no statistically significant differences between MVGF.

2.3 Range of Motions

Joint mobility is necessary for performing the movement in the corresponding range and is influenced by numerous factors. From the anatomical point of view it depends on the shape of the joint, soft tissues in its vicinity and tension and vacancy of joint capsule and ligaments. Among other factors affecting range of motion (ROM) is undoubtedly age and gender but a certain effect has also a mental condition or fatigue. Within the industrial practice ROM are very important in workplace design and design of various equipment and tools [19, 20].

In our research the attention will be paid to the upper extremities (wrist, elbow, shoulder) and spine (cervical and lumbar) mainly because these joints are often being overloaded in industrial practice and particularly upper limb are mostly used for different handling. As a measuring tool a standard goniometers will be used. The ROM will be measured according to the methodology of American Academy of Orthopedic Surgeons (AAOS) which is the most common.

There are three possible systems how to record the measured values of ROM. The system of 0° to 180°, the system of 180° to 0° and 360° system. The most frequently used system is 0° to 180° which is also called neutral zero method. The initial joint position for ROM measurement is 0° and the movement continues by curve up to 180°. This recording method was first described in 1923 and was adopted by AAOS and other associations. ROM measurements in the joints will be repeated until the difference between two measurements will be up to 4°. The resulting value will then be the average of these two values [20].

Already mentioned study performed by Stubbs et al. [20] evaluated a sample of 55 males aged 25–54 and divided into three age groups. All participants were right handed. The measurement was performed bilaterally which is not a rule at all by other studies. Most normative data even ignores the right and left hands and normative data provided by the AAOS are no exception. A statistically significant difference ($p < 0.05$) between the right and left limb was demonstrated for each age group in several joints. In the age group 35–44 years was found to be statistically significant differences in the elbow flexion, wrist extension and extension of the

shoulder joint. Flexion at the elbow and wrist extension had ROM bigger on left (submissive) arm. At right (dominant) arm a greater ROM extension of the shoulder joint was found. In the third age group 45–54 years was greater ROM in elbow flexion on the left hand. In terms of age statistically significant difference were found between the three age groups in multiple joint motions. In any case the oldest group had the smallest mean values in the ROM. Data confirmed the general view that with increasing age the ROM decreases in most joints.

While Stubbs et al. have dealt only with the influence of age and partly laterality in ROM, Chung et al. [21] examined the effect of age and gender. Research sample included 1134 workers aged 16–64 years living in Taiwan, while 698 were males and 436 females. The results again showed that the ROM decreases with increasing age, but the rate of decline depends on the age as well as on the measured joint and the type of movement. Most decrease in ROM with increasing age was observed in the cervical spine and wrist. Comparison of the ROM results between males and females showed that statistically significant difference exists at 22 joints moves from 28 measured, while females demonstrated bigger ROM in the cervical spine, upper and lower extremities. ROM of the joint motion of the lumbar spine was significantly greater by males than females except for lumbar extension. In the upper extremities females showed greater ROM by wrist and elbow (respectively forearm) than males. The opposite it was only at the shoulder joint which showed a statistically significant increase in the males ROM.

Influence of age and gender on the ROM was also explored by Doriot and Wang [22] who measured the ROM of upper extremities, cervical and lumbar spine using optoelectronic motion system VICON. The sample consisted of younger groups of males and females aged 20–35 years (11 male, 11 female) and older groups of male and female aged 65–80 years (10 male, 9 female). The results were compared between the two age groups and between males and females. The older group of subjects had again smaller ROM compared to the younger group. The greatest differences were in ROM of the shoulder, cervical and lumbar spine. For lateroflexion and extension of cervical spine a decrease of more than 40 % was found, for lateroflexion and rotation of the lumbar spine the decrease was about 33 % and for external rotation of the shoulder even 42 % decrease was found. On the contrary, there was no significant decline in the elbow and wrist joint with increasing age. When comparing the measured values between male and female the only statistically significant difference was found for the forearm pronation, ulnar duction, extension and right lateroflexion of the lumbar spine. Females had a greater ROM in the forearm pronation and ulnar duction, the males in the extension and lateroflexion. However the differences between male and female are generally smaller compared to the differences between younger and older group of subjects. The sample in this study was however very small and therefore it is necessary to take these results with a reserve.

3 Conclusion

This paper focused on degenerative changes which occur with age. Three of probably mostly measured changes which are hand dexterity, hand grip strength and range of motions are discussed. These have been selected intentionally as they are very important in serial production or in workplace design. New methodological design for starting research has been proposed on the basis of previous research studies and results. This research should bring new knowledge about mutual relationships between previously mentioned degenerative changes. It is clear that hand dexterity will be affected for instance by range of motions or hand strength but specific quantification will be the subject of research. Mathematical equations on those relations will be formulated in the future.

As a secondary output new normative data for European population will be available. Many of the current studies have been performed on American or Asian residents. Proposed research will validate those data and compare them. Also some normative data are of older date and should be actualized. As mentioned by [7] perhaps the current reliance on technology, such as computers, mobile phones, tablets etc. has affected baseline dexterity values in all populations. Dexterity abilities may have improved radically due to the increased use, or declined based on the automation of work processes that were previously reliant on manual skills. Either way, research is needed to update the reference values.

The first phase of the research will focus on females. Two age groups from the Czech population aged 25–34 and 55–64 will be measured and evaluated. Subsequently the males of same age groups will be measured. Those age groups have been selected on purpose to demonstrate the biggest differences. Age groups of 35–44 and 45–54 for both genders will not be neglected. The results will be a part of future papers.

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Toward a Connected Health System for Older Adults: Lessons Learned

Vera Stara, Richard Harte, Mirko Di Rosa, Lorena Rossi and Gearóid ÓLaighin

Abstract This paper aims to provide some lessons learned during the development of the Wireless Insole for Independent and Safe Elderly Living (WIISEL) system that can be generalized for all connected health devices for older adults. The analysis of the different results confirms that there is a clear challenge for modern technologically driven healthcare systems to meet the complex needs of an ageing society. We observed three major themes which should be taken into considerations when tackling the barriers to the uptake of technology enabled care: 1. Face cultural resistance and concerns toward technology enabled care; 2. Improve engagement of users in design; 3. Built or Increase users trust in connected health by spreading awareness and knowledge among end users about technology's benefit and utility.

Keywords User-centered design · Usability · User experience · mHealth · eHealth · Older adults

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1 Introduction

The rapid evolution of the connected health sector is nowadays providing cost-effective healthcare solutions by allowing healthcare personnel to utilize telecommunication technology to manage and monitor patient data. This growth is related to the world's ageing population with older adults representing a user group who could benefit from connected health solutions, both to maintain and increase home independence and quality of life [1].

This paper aims to provide some lessons learnt from the implementation of a connected health system prototype in the field: The Wireless Insole for Independent and Safe Elderly Living (WIISEL, GA 288878).

The WIISEL is a system designed to continuously assess fall risk by measuring gait and balance parameters associated with fall risk in the older adult population. It consists of a pair of electronic electrically isolated insoles with Bluetooth transmission, a Qi wireless charging tool, a Smartphone with a WIISEL specific app, a desktop Gait Analysis Tool, and an administrative web application. The insoles and the smartphone are both worn by users during their waking hours. Data collected by sensors are sent primary to the smartphone and then uploaded to a server for processing and analysis through the Gait Analysis Tool. The complete system architecture is illustrated in Fig. 1.

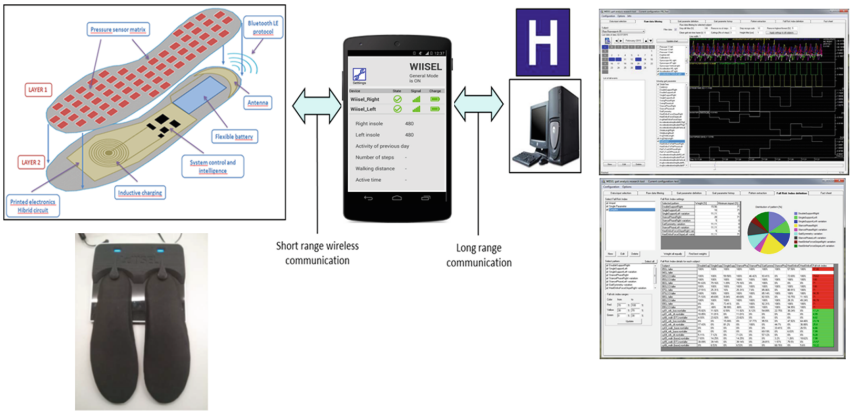

Fig. 1 The WIISEL system architecture

2 User Centered Design Approach in the WIISEL System Development

As a connected health device designed for unsupervised use by the older adult, the WIISEL development has required the close involvement of end-users during the design and testing process in conformity with the User-Centred Design (UCD) approach. Multidisciplinary and experienced teams were engaged in Italy (INRCA), Ireland (Ballyvaughan Primary Care Centre) and Israel (TASMC) to implement the following UCD phases during the development of the system (Table 1).

At first, a set of specific user requirements were defined in order to create a degree of fit between the system concept and users' thoughts. Two focus groups were conducted with 18 potential user's (age = 78.8, std = 3.4) and 18 stakeholders (age = 43.2, std = 9.4) in order to identify technical aspects of a wearable system which are important to user satisfaction and adherence. The stakeholders group included geriatricians and neurologists but also allied health professionals such as nurses and physical therapists.

In general, a good attitude toward technology was recognized. Namely, all participants were enthusiastic about the system, stating that it would be important to focus on design, usability and comfort of the insole to become acceptable to an older adult user. Concerns were raised regarding the use of touch screen technology and challenge it could pose to a non tech savvy older adult population. The need to develop a usable and friendly user interface was quickly identified. Moreover, many questions raised from participants about the exposition to potential harms and the intrusiveness of the system in the home and on the person.

Table 1 The involvement of end users across multiple centers

Phase		Maturity of the system	No. of users involved			
			Italy	Ireland	Israel	Total
User requirements		Early system concept	6 end users and 6 stakeholders	6 end users and 6 stakeholders	6 end users and 6 stakeholders	36
Multistage human factors inspection		1st prototype		12 end users, 10 stakeholders, 20 young volunteers		42
User testing	3 days pilot testing with end users	2nd prototype	5 end users	5 end users	5 end users	15
	14 days validation testing with end users	3rd prototype	12 end users	11 end users	16 end users	39

Using the feedback from this phase, a 1st prototype was developed and critically examined through multistage human factors inspections and user testing which scrutinised both the smartphone interface usability and insoles ergonomics and comfort. Details of all methods fielded and results are described in Harte et al. [2, 3]. After this phase, which involved testing with 42 participants in Ireland, a second prototype was produced.

Finally, a two-stage user testing phase exposed 54 older adults (age = 70, std = 6.38) to the system in order to capture feedback which might enhance the user experience. Having attended their respective clinical sites in Italy (INRCA), Ireland (Ballyvaughan Primary Care Centre) and Israel (TASMC) for system fitting and introduction, all participants were instructed to wear the system on a continuous basis during daily hours. The protocol consisted of a structured laboratory assessment with the insoles (day 1) followed by 2 days of using the system in the participants home environment for pilot testing and 14 days for validation testing. No specific instruction were provided for specific tasks to be performed in the home in order to preserve natural living conditions and performance. Usability and acceptance issues were in depth analyzed by means of the Quebec User Evaluation of Satisfaction with Assistive Technology—QUEST 2.0 questionnaire [4] and the System Usability Scale (SUS) [5].

From the analysis of the QUEST 2.0 (Fig. 2.) it emerges that effectiveness is the biggest problem affecting acceptance followed by ease of use and dimensions of the devices. Effectiveness suffered due to the connection problems encountered when trying to sync the insoles to the smartphone; this was the most commonly reported functional problem in both pilot and validation testing. The lack of experience/confidence with touch screen technology caused many problems due to frustration related to unlocking the screen, touch to enter the app login procedures and recognition of the exact button to press within the app. It is plausible that this frustration determining the low score for ‘ease of use’. This data is confirmed by

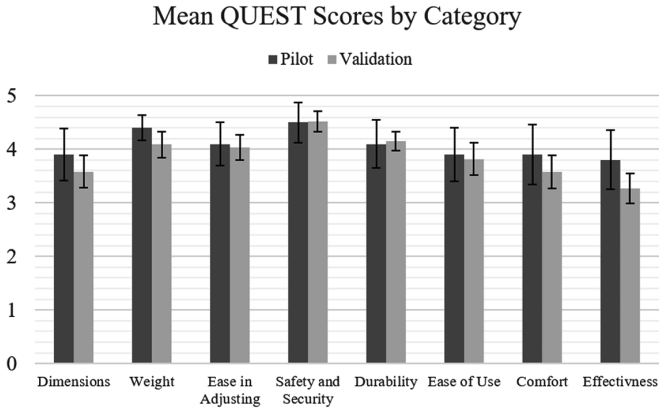

Fig. 2 QUEST scores show in validation and pilot trials

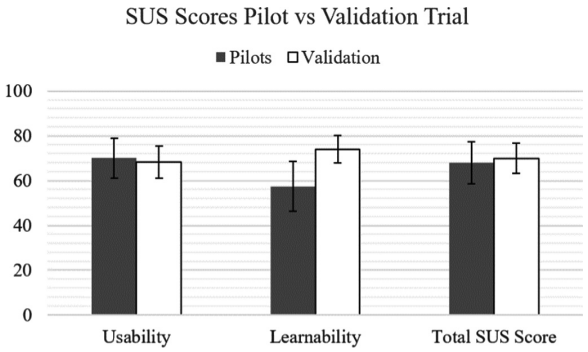

Fig. 3 SUS scores show in validation and pilot trials

SUS results: the WIISEL system scored relatively average in terms of usability, highlighting the challenges in introducing a technically complex connected health system to an older adult population. Frustration with the connection sequence and the touchscreen and problems with the insole comfort were constantly identified as barriers to a satisfactory user experience.

Nevertheless, the system achieved an SUS score of 70, surpassing the Sauro average of 68 [6]. As shown in Fig. 3 learnability showed significant improvement ($p = 0.04$) between validation and pilot trials, while overall SUS showed marginal improvement. Effective and efficient user manuals, clearer instructions and some remote counselling and encouragement overcame the problems of learnability outcomes.

This confirmed that technology acceptance outcomes are influenced by appropriate training and support [7] especially in older adults due to the lack of knowledge of ICT devices.

Data coming from the user testing phase highlights the strategic importance of instructional phases within the evaluation process to reduce uncertainty and unfamiliarity with new technology as well as the significant impact of at least three design iterations for producing an average system in terms of usability.

3 Lessons Learned

The analysis of the different results collected during the design and development phases of the WIISEL system confirms that there is a clear challenge for modern technologically driven healthcare systems to meet the complex needs of an ageing society. We observed three major themes which should be taken into considerations when tackling the barriers to the uptake of technology enabled care.

3.1 Face Cultural Resistance and Concerns Toward Technology Enabled Care

Research and development of connected health technologies has potential psychological, ethical and social implications. Security, intrusiveness, lack of control, confidentiality and usability concerns can be considered severe hindrances to the uptake of connected health systems worldwide. These devices are generally designed for unsupervised use to facilitate independent control of the individual's healthcare in their own home. For the majority of people, the home is a space threaded with memories and meaning, informing and informed by the resident's identity. Particularly, it represents a symbol of independence and a place of comfort and security for older adults. Therefore, they usually fear of a lack of security and to be exposed to potential harms. Moreover, the passive and 'always on' nature of the device generates concerns about continued electricity consumption and a sense of minor control in their environment. Given the complexity and idiosyncrasy of the home space, great efforts should be done to not modify or erode this sense of identity, and to respect perception and attitude to privacy and private lives in order to avoid the sense of stigmatization in adopting such technologies [8].

During research and development of connected health system the protection of people starts with the safety and reliability of the equipment. With the aim to reduce intrusiveness, sensors are becoming more and more not-invasive, reliable and sustainable thanks to miniaturisation and concealment. Indeed dimensions of the devices had a major impact on user experience in the WIISEL study. Furthermore, the control of technologies is more within the user's power or placed in the hands of their carers.

Breaches in security, intrusiveness and confidentiality can lead to a lack of trust in the technologies as well as usability concerns. Modern devices and systems are often perceived as complex, difficult to control and error-inducing. Consequently, perceived ease of use, clear instructional material and technical support are necessary to allow the user to overcome the demands of the new technology which may contain many unfamiliar features, options and information. These demands are also increased by age-related decline (i.e. vision decline, hearing loss, motor skill diminishment), and cognitive effects (i.e. trouble remembering names, trouble remembering the flow of a conversation, an increased tendency to misplace things), making connected health devices tricky to use [9, 10]. Optimal design for the older adult user group can be achieved by following the UCD process. Benefits of adhering to such an approach are manifold and vary from the recognition of a comprehensive the role of usability to the admission of human factors and user experience as part of product quality [1].

3.2 Improve Engagement of Users in Design

Involvement of end users is a key strategy for recognizing and removing the barriers that currently obstruct the diffusion of technological innovations among older adult. However this involvement must be carefully planned to influence, drive and refine the design, addressing the whole user experience within an iterative development process.

Different viewpoints coming from multidisciplinary and experienced team can strengthen the design approach and create early awareness of constraints, realties, enablers and barriers in the definition of the user profile in their needs, expectations and limitations. Furthermore, this strategy leads to conceptualize how parts of user lives could be improved by technology, an approach which seeks coordination between elements of engineering, healthcare and social psychology.

Typically users involvement relates to participation in activities related to specifying, elaborating, prioritising, reviewing and verifying the requirements as well as testing the developed features.

Benefits derived from this strategy are copious [11]: improved quality of the system arising from more accurate user requirements; avoiding costly system features that the user did not want or cannot use; improved levels of acceptance of the system and greater understanding of the system by the user resulting in more effective use. Direct contact with potential users, enables designers to learn from older people what functionalities and attributes are important in new products, what motivates them and what factors would hinder a positive user experience with a proposed product.

3.3 Build or Increase Users Trust in Connected Health

Is it possible to build or increase trust in connected health? Older adults are usually less exposed to the use of new technologies because they have left the workplace before the widespread introduction of modern computer technology, particularly mobile devices. Effectively, this lack of experience and knowledge determines a lack of motivation and trust in using mobile technology. In addition to this phenomena, other reasons previously analyzed (i.e. safety, privacy, intrusiveness and usability) may act as contributing factors in the rejection of mobile devices, overriding any perceived personal benefits.

Despite the recognition of the impact of users needs, many existing technologies are poorly matched to the real need faced by many people aged 65 and older. It must be emphasized that older adults experience needs related to safety, independence, maintaining good functional status, being part of everyday life in their family and community and maintaining the ability to move freely. Consequently, people over 65 make use of technologies that accomplish these needs and reject those with unclear evidence of personal benefit [12–15].

A key strategy to built and increase trust in connected health is to spread awareness and knowledge among end users about technology's benefit and utility. Many older adults are not aware of the benefits of the connected health systems and have no understanding of how technology can impact their day-to-days activities [16]. Meaningful learning and training activities can be applied to cover this gap and it can be imparted through written materials, computer based programs, or face to face communication [10]. However, while the need for training is a recurrent theme there are still poor frameworks to achieve specific training goals and guidelines within the connected health sector.

Another remarkable barrier preventing trust in connected health solutions is related to the lack of adequate reimbursement or incentive programs by institutional payers and national authorities. The identification of sustainable business models to finance connected health infrastructure, applications, devices and services, and digital inclusion policies are mandatory actions to be planned at a worldwide level.

At this purpose, a better understanding and evidence of the impact of current connected health products and services in the healthcare sector could define how policy can globally help to develop, scale or replicate existing good practices.

4 Conclusions

In this paper we have discussed some major lessons learned during the development of the WIISEL system that can be generalized for all connected health devices for older adults.

First, when approaching this segment of population it is worth to consider any cultural resistances and concerns that could act as hindrance for the uptake of technology enabled care. In particular, security, intrusiveness, lack of control, confidentiality and usability issues can lead to a lack of trust in such technologies.

Second, involvement of end users is a key strategy for recognizing and removing these barriers but must be carefully planned to influence, drive and refine the design within the iterative development process.

Finally, we are strongly convinced that is possible to build or increase trust in connected health through both meaningful learning/training activities and sustainable business models and digital inclusion policies.

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Ergonomic Intervention in the Sector of Waste Collection, with the Use of Deparis Guide Method: Case of the Municipality of Monastir in Tunisia

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Abstract Despite the evolution of tools, equipment and work-organization, the collection of waste remains a difficult and dangerous sector. In the town of Monastir, in 2013, the number of operators assigned to the direction of cleanliness and environment was 63 and they ensured in average 1800–2000 tons of collected waste per month up to 3000 tons during the summer season. The current intervention had followed a request of the Mayor of the Municipality of Monastir which focused on the reorganization of the activity of collection of household and similar waste, with the objective to improve both the efficiency and the safety of work and the health of collectors and drivers of vehicles. We based our intervention on the 1st level of the Sobane Strategy: the Déparis guide on its initial version. The focus group was composed of ten actors in the business of waste collection, including key operators (drivers and garbage collectors) but also representatives of local of supervision and also of management (responsible for the municipal park district coordinator). The diagnosis had focused on physical work environments (buildings, equipment, tools, air hygiene, urban transport) but also on team organization and psychosocial factors. Consultation between the team work allowed to retain a number of proposed corrective actions focusing on machines and tools work, but also actions to re-design the work organization. Among these propositions we mention the design and development of new work spaces in the municipal park taking into consideration both the needs but also the activities of operators and the organization of collective work. Over 80 % of the actions proposed by the working group were retained and implemented. Other more complicated aspects of the work situation were chosen as subject of future ergonomic intervention (e.g. computerization of the organizational process of the park) or further reflection objects in budgeting (installation alarm systems).

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Keywords Human factors · Waste collection system · Occupational risks · Prevention · Work organization

1 Introduction

Currently, developed and developing countries, face the challenge of periodically increase of waste production related, both, to population growth, urbanization, industrialization, and excessive consumption characterizing modern daily life [1]. Despite technical development performed, waste collection remains, a painful and one of most dangerous work sector [2]. Indeed, waste collection workers are exposed to o higher risk of occupational accidents, with injuries afflicting 35 % of garbage collectors each year [2, 3]. Besides, these workers are concerned by different professional diseases related to physical and biological risks especially bio-aerosols and volatile agents (respiratory, skin, infectious, musculoskeletal problems …) [3, 4]. The collect of solid domestic waste, involves the collection of various products, such house, hold, construction or yard waste, toxic products, abandoned and suspicious needles … and involved many considerable heavy lifting as well as other manual handling of containers, work above shoulder. Thus, security, health and well being of drivers and garbage collectors can be influenced negatively [2–4].

This paper presents an ergonomic intervention led with waste collection department of the Monastir municipality and which aims, through a global and participative approach, to diagnose the factors and situations of risk to which are exposed operators during waste collection and to identify and put in place adapted actions in order to ameliorate working conditions, safety and wellbeing of workers.

2 Context, Request and Field of Intervention

In Monastir—a small tourist city of the center of Tunisia—waste production, is about 2000 tonnes per month and reaches 3000 tonnes per month during the summer period. Before this collection, only plastic wastes are partially sorted for recycling. Solid collected wastes are directly sent into landfills which is 8 km from the city. Between fourteen and twenty-one journey to this discharge is practiced daily by collection vehicles.

Until 2012, 80 % of the garbage collection has been entrusted to subcontracting societies and the hygiene and environment department of the municipality ensures only 20 % of this collection. In 2013, following the suppression of subcontracting in Tunisian public service, in accordance with the agreement signed between the Workers's Central of the Union of Tunisian Workers (the most represented trade union body) and the Tunisian government, the municipality of Monastir was forced to make the entire collection of garbage.

Table 1 Workers, vehicle and machine distribution of garbage collectors team

Staff	Type of vehicle or machine (Number)	Drivers	Garbage collectors
1st team: "packer trucks"	Packer trucks (05)	07	21
2nd team: "bodywork"	Tractor (01) Chassis (01) Bodywork (07)	01	01
3rd team: "door to door"	Tractor (02) Truck (01)	03	08
4th team: "Specific interventions"	Truck (04) Bulldozers (02) Bob cat (01)	07	04
5th team: "Rickshaw"	Rickshaw (11)	00	11
Total	35	18	45

To deal with these new demands, the municipality of Monastir increased the number of permanent workers from 35 in 2012 to 63 in 2013, improved of waste collection equipment available to these workers with a total of vehicle which reached 35 (packer trucks, tractor, chassis, bodywork, Truck, bulldozers, packer trucks, Rickshaw) and reorganize the function of the hygiene and environment department. Following this reinforcement of human and material resources and reorganization, the activity was distributed near five teams whose composition is presented in Table 1.

Regarding the hierarchical organization of the hygiene and environment department, it is split into five sub-working groups which ensures the garbage collection of the five administrative boroughs of the city. All these sub-teams are under the responsibility of a single general coordinator directly dependent on the municipal park manager. According to the chart of the municipality management organigram, the latter is directly dependant of the general secretary, himself under the direct orders of the mayor. Each sub-team is under the responsibility of the coordinator of the district, and associate one or more vehicle drivers, who organizes the work of garbage collector that accompany them.

Apart from the case of the team of rickshaws, coordinators of district are themselves vehicle drivers.

In this context of a new human management policy, we received a request from the Mayor of the Municipality of Monastir with the objective to improve both the efficiency of work and the safety and the health of refuse collectors and drivers of vehicles.

3 Methods

To join between the demand about the improve both of, the efficiency, working conditions and waste collection worker's safety, we have adopted the "Déparis" (participative screening of the risks), consultation guide which is a screening tool

corresponding to the first level of professional risk management strategy SOBANE [5, 6]. This guide has the advantage of being suitable for small-medium enterprises and to approach the work situation in its entirety both in terms of workspace, working conditions (noise, heat, chemical agents …) as well as all physical, organizational, psychosocial which may interfere with the health, safety, well-being, but also the quality of work, productivity [5, 6]. According to the Déparis guide, the 18 sections of the characteristic work situation are approached at a meeting organized with a working group including in particular workers' representative, coaching, and representative of management … [5–8].

In this study, the Arabic validated version of the guide, introduced in many enterprises in very different industrial contexts, mainly in Maghreb countries, was adopted [8].

The intervention was conducted in accordance with the guide-use-recommendations. First of all, the ergonomist, in order to expose and explain the process and interest of Déparis consultations, met mayor, municipal officials and the directorate of municipal park, who was in charge of hygiene and environmental team.

After agreement of these officials, a working group of nine workers was created. The group was coordinated by the ergonomist and associated the director of municipal park, the security manager, the occupational health physician, the general secretary of the union base, a district coordinator, the driver responsible for the district of hospitals, clinics and tourist area, a truck driver and two garbage collectors, the first is part of "the packer vehicle team" with tenure of over 20 years and the second is part of "team door to door" with seniority not exceeding the 5 years. In most cases, these participants were selected following consultation with colleagues, based on professional experience, knowledge of different aspects of the activity, motivation and critical and constructive aspect.

After a brief period of work observation conducted by the ergonomist, the Déparis meeting was held in August 2013, in a municipality office within the park, over a period of almost two hours. During this meeting, the coordinator briefly reminded the objectives of the appointment and resumed the content of the eighteen facets of the work situation screened by the guide. Theses sections were related to: Premises and working areas; work organization; work accidents; electricity, fire and explosions, controls and signals, work material, tools, machines; work postures; efforts and handling operations; lighting; noise; chemical and biological risks; thermal environments; vibration; autonomy and individual responsibilities; work content; time constraints; relationships between workers and with the hierarchy; psychosocial environment.

During the meeting, each participant expressed his point of view clearly. Each topic was presented in a grid with a small description of the ideal situation. In the same table, in a space against these descriptions, coordinator noted actions proposed by each participant to be improve the situation and validated after discussion by the entire work group. Situations and actions, not having been agreed by the group, were noted by the coordinator in the third part of each section dedicated for "aspects requiring further studies".

The last part of the meeting was dedicated by the group to conclude an overall judgment on the priority of decided changes and the assessment were made using a three-tier system of colors and smiles: satisfactory situation (☺); average or acceptable situation to improve if possible (😐) and unsatisfactory situation may be dangerous and to improve necessarily (☹).

Finally, a listing of classified actions and additional studies decided during the meeting were was synthesized in a summary table containing the responsible, the delay and the cost of each action for a short, medium and long term acts plan.

4 Results

Table 2 summarizes the judgments issued by the working group on the eighteen sections about work situations during Déparis meeting. In total forty-nine actions were proposed by the group to improve working conditions of the hygiene and environment team, 34 % of them were not associated to any cost, and 44.9 % were associated to little cost (adapted to local budget). These actions included five short-term actions, 34 medium-term (deadlines under three months), and nine long-term actions (over three months). In the next part of this paper, we will detail

Table 2 Statement of accounts of overall judgments on facets of work situations

Facets:	
1. Premises and working areas	3
2. Work organization	2
3. Work accidents	3
4. Electricity, fire and explosions	3
5. Controls and signals	2
6. Work material, tools, machines	3
7. Work postures	3
8. Efforts and handling operations	1
9. Lighting	1
10. Noise	1
11. Chemical and biological risks	3
12. Thermal environments	2
13. Vibration	1
14. Autonomy and individual responsibilities	1
15. Work content	3
16. Time constraints	2
17. Relationships between workers and with the hierarchy	1
18. Psychosocial environment	3

1: Satisfactory situation (green smily ☺); 2: Average or acceptable situation (Orange smily 😐); 3: Unsatisfactory situation may be dangerous (red smily ☹)

the work situation judged unsatisfactory and the emergency actions proposed to improve them.

4.1 Unsatisfactory Situations and Proposed Actions

Main unsatisfactory working areas, even dangerous and requiring urgent improvements have been: Premises and working areas, work accident, electricity, fire and explosions, work material, tools, machines, work postures, chemical and biological risks, work content and psychosocial environment.

Premises and Working Areas. The garbage collection is carried on public roads and residential areas of different districts of the city of Monastir. But several annexed activities are accomplished in the municipal park such as preparation, cleaning and maintenance of equipment and vehicles.

During Déparis meeting, the work groups claimed primarily that working areas in the park were particularly unsatisfactory mainly because of the defective changing rooms and sanitary units and the congested work space and traffic lanes. In order to improve this situation, proposed actions were, first of all, the construction by the direction of new showers, toilets, changing rooms and equipped refectory. Additionally, to ameliorate traffic in the park, both for persons and vehicles, participants proposed that maintenance service removes waste, garbage cans, and confiscated items and delineate areas dedicated to the parking of gear and vehicles; the park director reorganize the traffic circuit and limit the ones of packer trucks only to lanes of at least nine meters wide; the gradient restricts access to the park to service cars and machinery only; and the security manager displays the appropriate icons to indicate the emergency exits. Moreover, outside the park, the group proposed that the municipality administration obliges contracted hospitals and hotels, to build suitable garbage premises, ensuring easy access for packer trucks drivers and allowing avoiding turbulence areas.

All these actions were estimated moderately inexpensive with a maximum realization delays fixed to six months.

Work accidents. Participants estimate this situation unsatisfactory and may be dangerous, mainly due to risk of road accident for garbage collectors, but also the fact that, most of the time, personnel protective equipments were not available in sufficient numbers, and even for available work clothes they are not used by workers. Immediate proposed actions were that park manager informs drivers of any changes in road signals in different roads and avenues of the city; put at their disposition sufficient quantity of protective vests and control their mandatory port by all workers. Staff representatives, under the control of park manager and occupational physician have to select adequate individual protective equipments especially clothes and gloves for all garbage collectors and masks for respiratory protection for garbage collectors ensuring collection of hospital waste and clinics. This selection, must be made within a maximum time limits of two months so that the chat service, under the control of the general secretary and the mayor, ensures

these purchases in delay of six-month. Finally, the working group proposed that administration buys first-aid kits in all cabins of dumpsters and trucks, and send the security officer for training about analysis of occupational accidents; after, this last assure a training program for all collectors and drivers on procedures in case of accident.

Work, Tools, Machines. During the Déparis meeting many dysfunctions of work material were noted especially the incompatibility of bins with packer trucks. These incompatibilities lead to supplementary efforts and constraints gestures for garbage collectors. To improve the situation, the general coordinator of the hygiene and environment team was charged to check, monthly, the good condition of work equipments and the compatibility of technical characteristics of bins commended and packer truck before any purchase. Moreover, the administration has to assure the buys of ergonomic shovels and brooms during the year and the park manager was charged to verify the redistribution of garbage adequately with standards of dumpsters to prevent the destruction of bins.

Posture of Work. Contrary to ergonomics expectations, participants in the meeting agreed that the efforts and handling operations were globally satisfactory, but work postures were unsatisfactory and needs urgent actions. Some of postural constraints are related to work with elevated shoulders, torsion of trunk, prolonged leaning. One of the explanations given by participants was encasement of garbage inaccessible places, the unsuitability of bins with trucks as well as the equipment non-conforming with ergonomic standards, imposing constrained postures. Key proposed solutions were rotation of workers and coordination of collaboration between sub-teams. The park manager was designated as the responsible of the weekly rotation. The drivers of the team "door to door" were charged to inform the park administration about the existence of objects weighing more than 25 kg for their transport by the blackheads team. Training about work postures was decided for garbage collectors and was in charge of the security agent and focused on the arrangement of waste bags to avoid extended posture forward to over 40 cm of the body. Finally, maintenance department was responsible of the reparation of damaged or broken wheelie bins to facilitate their movement and their regular check; and park manager was in charge of increasing bins number in collection points around clinics, hospitals and hotels.

Risks of Electricity, Fire, Explosions, Chemical and Biological. The Preventive measures against risks of electricity, fire and explosions and those against chemical and biological ones, were evaluated as unsatisfactory especially because of non-signalization of toxic and explosive products, the absence of individual protective equipment and training about their use when they are available. Most proposed actions were the training of workers and administrative staff about these risks and how to use fire extinguishers, techniques and procedures in case of accident (fire, projection or ingestion of toxic product …). The security agent was charged of the isolation and signalization of toxic products, electrical risk, safety instructions and emergency exits. Moreover, administration was charged of building and equipping showers sinks with cold and hot water, of purchasing the vaccine of hepatitis and tetanus and personal preventive equipment

after the consultation of occupational physician, and this last was designated as responsible of the hepatitis B and tetanus immunization, for all workers, in a delay under three months.

Content of Work and Psychosocial Environment. During the meeting several participants expressed a shared feeling between the importance of the work accomplished by the health team, and the non-recognition of this work by users (citizens and residents of the city of Monastir). In addition, an agreement of working group was noted about an unsatisfactory psychosocial environment, linked both to conflict situations within the department, but also with other teams, users and city residents. The absence of communication between the different services, the lack of clear plan of careers progression and the verbal or physical aggression by users was reported as problematic elements. Thus, some improvement actions, in the medium and long term, were proposed including administration's sensitization of citizens on the importance of the work of garbage collectors, and its motivation of workers throughout social actions, also its clear notice of promotion possibilities for operators. But following a global agreement of the group it was decided that the psychosocial environment requires further study with further analyses.

4.2 Carried Actions

Short and medium terms actions include the maintenance of sanitary units, repairing cages of tracks and maintenance of signals of trucks tippers, demanding letters to be sent to the director of hygiene and Environment every change of road signals and the denial of access to the city park to all foreign vehicles. The medium-term realization actions include the selection and delivery of PPE to all workers, the inspection of new tools of work, the reorganization of the trucks circuit, installing new communications medium at the municipal park, strengthening security against fires, sensitization of citizens and arrangement of the park and hazardous and toxic waste areas.

Long-term actions include purchase of equipment and water fountains, building a new sanitary block, the creation of an internet network, the construction of hospitals and hotels of a suitable new areas for garbage, repairing the soil surrounding the bins, the tenure of temporary workers in the park and installing an alarm system.

5 Conclusion

Mass production of domestic waste is increasing in communities, generating an intensification and transformation of teams responsible of the collection of this waste activities. The group's work created during the intervention must be consolidated and supported, in order to install an operational model based on an effective communication between actors.

The ergonomic study, performed in the municipal park of Monastir in August 2013, had objectives to identify the hazards and risk situations of work accident and occupation disease and to propose recommendations to reduce or eliminate the hazards and risks identified, reflected the real situation of work as experienced by operators and therefore reduce the direct and indirect cost of accidents at work.

This study also improved the preventative culture in the Municipality and established a dynamic program to manage professional risk thought participative screening of the risks DEPARIS.

Ergonomic studies of hazardous areas are important in the current economic environment. In fact, the interests of trade union structures are geared towards the preservation of job positions and the improvement of working conditions.

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Increasing Awareness About Sport in Turkey

Erdal Zorba

Abstract Regardless of their ages, races, and gender all people benefit from active participation in sport and recreation activities because all of these activities aim to promote active participation. Sport for all (hereafter SfA) aims for taking this idea a step further. Sport for all activities demands voluntary active participation to sport for all activities of participants. Besides, voluntary work in maintenance of these activities, giving support to the projects and other events are also important as they help to create and promote a unique network of sport enthusiasts. The aim of this paper is to how Turkish Sport for All Federation (hereafter TSFAF) works to disseminate sport and active life style to the whole country through various organizations along with introducing some activities and their effectiveness in terms of raising awareness.

Keywords Turkish sport for all federation · Culture of sport · Awareness about sport · Active life

1 Introduction

The term sport For All is defined as making use of spare time of everyone desiring to do sport by doing sport notwithstanding their social status, class, race and disability and enabling their attendance by the Council of Europe Sports Progress Committee [1].

When this definition is analyzed, it is understood that everyone in a society needs to take advantage of this right and making sport widespread is adopted as a principle in social groups ignored either this or that way. For instance, prisoners and criminals are deprived of freedom for a length of time they retain the rights of education, culture and sport. Because sport right is among social rights and freedoms defined with rights of education, health and security. Moreover, SFA is based

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on the ideal of democratization of sport and bestow this right to the greatest number of people as far as possible [2].

SFA aspires to practice entertainment and health at the same time within itself. It should not be forgotten that the word *sport* derives from the word "de sport" meaning *joy* in French. Joy, entertainment and games are the main factors that motivate a sportsman aimed at self-improvement. Another fact is that the most favorable result will be got when the activities of SFA are performed in line with a principle of not much exhausting effort and relaxation and fun [1].

The idea that people doing sports are healthier than the ones who do not is scientifically proved and socially accepted. The basic philosophy of SfA is based on this idea: raising healthier generations that like doing sports, live actively and eat properly. Regular sport activities such as competing at a high level or walking at a park are quite useful for bringing individual and society together, creating better life quality and improving health [1]. In other words, increasing community health care, building bridges between people from different cultural or racial background are among the objectives of SfA as well [3]. In addition, SfA is an international program aiming to make leisure activities easy enough for everyone to benefit, like, have fun and keep healthy.

1.1 A Historical and Global Look to SfA

Although the term sport for all was first coined by the Council of Europe in 1966, SfA concept dates back to older times. In the 19th century, some Scandinavian countries and Germany gave considerable support to popular gym. Yet since the beginning of 20th century, it has started to be regarded as a more serious activity. In 1920s German society was encouraged to do sport by government Weimar. Federico Gaelzer, an expert on physical education and sport, organized games, cultural and sport festivals in streets and open spaces. Up to that time, such activities had been done indoors like schools and clubs. Gaelzer, however, also changed the nature of these organizations through putting more emphasis on attendance rather than competition [2]. He organized a footrace in Sao Paulo in 1923, which has turned into an annual international organization and is still organized. In 1931 the Soviet Union initiated a program under the name of "Ready for Labor and Defense" which aimed at physical education [2]. For centuries, sport has been seen as the aim of making use of spare time out of serious times. The Council of Europe has tried to extend the meaning of this word, and has seen it as a part of universal character of itself. UNESCO has started to play an active role on sports since 1975 as well [1]. In 1974 a campaign named "Trim during Holidays" was initiated in Sweden. In 1976 sport activities targeting on family members became popular in Spain whereas sport activities for people over the age of 50 were also popular in Belgium. It can be inferred from these historical developments that SfA is not a new concept but it has been systematized recently by the efforts of national and international federations.

2 SfA in Turkey

The idea of SfA in Turkey was stated in Ataturk's speeches between 1923 and 1937. The official recognition of SfA, however, is based on the Article 59 of the Constitution of 198 which states that "*Government takes the precautions that will improve physical and mental health of Turkish citizens of all age. It encourages sport to reach the masses*". Turkish Sport for All Federation was established officially on 12th June, 1990 [4].

2.1 Mission and Vision of Turkish Sport for All Federation

The main objective of the establishment of the Sport for All Federation is to create opportunities for people from all age, race, gender and class to participate in sport activities. Our objectives are;

- to organize festivals, games and recreational competitions
- to promote healthy diet and values as a life philosophy
- to disseminate sport culture
- to raise awareness against smoking, alcohol and drug use [2]

In order to achieve these aims, TSFAF has 81 agents, one for each province in Turkey. TSFAF has 13 commissions to carry out its organizations and programs [5].

In addition to the objective given above, TSFAF has various goals some of which are given as follows;

- to bring our people together in mutual understanding and give a chance to individuals to improve themselves,
- to teach and disseminate sport culture and the spirit of Olympism,
- to organize events such as symposiums, conferences, regional or international seminars that popularize the idea of Sport for All,
- to organize in-service training programs and teaching seminars for SFA members,
- to raise leader trainers for SfA and Fitness to improve the quality of life in society,
- to carry out and support scientific researches about SfA practices,
- to cooperate with other federations when necessary,
- to organize fun organizations and competitions without strict rules.
- to take part in regional, national, and international events [2].

2.2 Goals that Are Achieved

- Books about SfA, lifelong sport and healthy diet are written.
- TSFAF and Fenerbahçe SK became partners in order to help children who work at streets.
- The website is re-organized and become more user-friendly, and enriched with various international connections.
- TSFAF has applied to The Association for International Sport for All (TAFISA) for a membership and it has been accepted.
- In coordination with youth and sport provincial directorates, services related to sports are planned for some certain groups (prisoners, old people, disabled people and children working on the streets etc.) and these services are put into practice supposing the budget conditions.
- Different recreational events and animation programs are given place during beach games. International beach handball tournament held in Köyceğiz each year is supported.
- Annual Arhavi festivals held in Artvin are supported.
- Various kinds of regional upland festivals are both supported and organized.
- During all festivals and events, activities are started in some branches which are not common in our country but can be done by everybody easily (skipping rope, sports tug of war, Frisbee, capoeira etc.).
- Various conferences and symposiums are held in demanding cities and universities about lifelong sport and fitness, life standard and sport for health and wellness.
- TSFAF participated in the European Union meetings in Brussels in order to take place in a Project which is about life Standard of Turkish people.
- Organizations and festivals are held in southeast, east Anatolian and east black sea regions where basic facilities related to sports are relatively poor.
- For the first time in Turkey, International Sport for All festival is held in Iğdır with attendance of Iran, Azerbaijan, and Georgia.
- Sport Culture Symposium from the Eyes of Different Disciplines is held in Ankara University in cooperation with UNESCO.
- Different thematic conferences have been organized in cooperation with TAFISA.
- International Sport for All and Sport Tourism Conference has been held.
- 1st level sport for all and wellness coaching courses have been opened for the first time in Turkey. First one was in İzmir and the second one was in İstanbul.
- TSFAF started to buy mobile fields in order to distribute these fields to cities, municipalities and universities and the first field is given to Antalya. It is planned to distribute other fields to different cities which are ready in terms of basic facilities.
- 13 TV programs are prepared each of which lasts for 30 min at least to be shown on a national channel.

2.3 The Future Aims of TSFAF

The biggest problem about the process of sport activities in our country is that, basic sport strategies of the country are not determined and it is not determined whether all kinds of organizations and services related to sport are for the good of Turkey. Therefore, the first step should be the development of a contemporary, scientific, measurable and applicable state policy with the help of all community institutions about sports education, servicing and application. In these policies, first, the relations and priorities of all relevant parameters such as the development of sport culture, sport education, success, organizations, sport economy, public health etc. should be clear [4].

Today, the concept of sport is increase in variety day by day. And this variety is parallel to spread of the sport culture. As for competitive and performance sports, it is clear that the idea of reaching to the top in terms of type, period and frequency of training is dominant. In other words, you may have to make a concession from your life style, nutrition style, behavior and life. The first and only aim of the competitive or performance sports is not generally sport for health. Athletics is a foremost example that explains the situation because the ambition to win pushes the athletes to use doping most of the time and the consequences can be very bad. So, it is very important to spread the sport culture.

It should be taken into consideration that making the sport culture widespread is as important as a competitive success. In the new sport policy, it is emphasized that spreading of sport culture should have priority over success gained in competitions. The growth of sport culture will lead to better social outcomes such as general public health, moral development of young generations, filling spare times with useful activities and making sport industry more powerful. At this point, TSFAF should be supported financially so that various kinds of projects should be put into practice by TSFAF [5].

Today, some of the performance sports leave their real goals and try to serve in the area of exercise for health. This situation caused serious problems in the spread and success of these sports. Even, it is more difficult today, to find qualified athletes in these branches.

In order to solve health problems through exercise, different exercise types have been designed in Europe and America. Some of these exercises are plates, fitness, yoga, tiçi, rope skipping, capoeira, Frisbee, and fist ball. It is quite likely that many other exercise types can be designed or derived in near future. Undoubtedly the appearance and purpose of all of these new exercises is based on good intentions, yet without supervision, they can turn into money pit. As it is said "*power is not power without control*", these institutions should be supervised. On the other hand, effectiveness, quality and competency of these institutions can be analyzed [6, 7].

The areas such as plates, yoga or aerobic are the ones which do not have competitions. For example; plates is kind of floor exercise done with various equipment's fir physical treatment. So only improvement workshops and certificates can be organized not coaching [8]. The program of SfA and wellness coaching

can be enriched with different education and application programs for elder, pregnant, sedentary, disabled people etc. are available. We can put these into an order like, office exercises, exercises for pregnant, old and disabled people, and exercises for illnesses because of immobility, exercises for the equipment in parks and gardens and floor exercises done with various materials.

3 Suggestions and Results

The first step should be the development of a contemporary, scientific, measurable and applicable state policy with the help of all community institutions about sports education, servicing and application. In these policies, firstly; the relations and priorities of all relevant parameters such as the development of sport culture, sport education, success, organizations, sport economy, public health etc. should be clear.

It should be taken into consideration that making the culture of sport widespread is as important as a competitive success. The growth of the sport culture will lead to very good result such as, general public health, moral development of young generations, filling spare times with useful activities and making sport industry more powerful [4]. At this point, TSFAF should be supported and different projects should be put into practice via this federation. So, Turkey sport for all federations should a pioneer federation in our country because it aims the missions above and this federation takes the reason of foundation directly from 59th item of fundamental law.

Today, some of the performance sports leave their real goals and try to serve in the area of exercise for health. This situation caused serious problems in the spread and success of these sports. Even, it is more difficult today, to find qualified athletes in these branches.

The areas such as plates, yoga or aerobic do not have competitions. For example; plates is kind of floor exercise done with various equipment's for physical treatment. So workshops and certificates can be organized for coaching. When the program of SfA and wellness coaching are studied, different education and application programs for olds, pregnant, sedentary, disabled people etc. are available. They can be put into an order like, office exercises, exercises for pregnant, old and disabled people, and exercises for illnesses because of immobility, exercises for the equipment in parks and gardens and floor exercises done with various materials [9].

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The Experimental Study of Temperature Effect on Human Blood Flow Based on the Controllable Temperature Cabin

Yao Chen, Huiting Qiao, Baoqing Pei, Yubo Fan and Li Ding

Abstract Human body's endurance for high temperature or low temperature is limited. The change of environment temperature can directly affect the body surface temperature, and then affect the blood circulation system, thereby affecting the efficiency and safety of human. There are only a few reports about the relationship between temperature and blood circulation system so far. In order to explore the specific relations, we established a controllable temperature cabin. Based on the cabin, 15 healthy young male subjects' blood flow velocity, heart rate and blood pressure were tested. The results show that the blood flow velocity at carotid artery decreases when the environment temperature increases from 15 to 25 °C, and then increases along the environment temperature increases from 25 to 40 °C. Heart rate and blood pressure presents the similar trend as the blood flow velocity along the variation of environment temperature.

Keywords Controllable temperature cabin · Blood circulation system · Human factors

1 Introduction

There exist many high-temperature operations and low-temperature operations in the daily life, the military labor or the industrial production. In these operations, the single effect of temperature or other complex factors will lead to low efficiency, increased operation accidents, stress disorder, and even death. Common high-temperature operations include coking, steelmaking and rolling in the metallurgical industry, and also include the operations in the printing and dyeing industry [1] and so on. The high temperature in these conditions will have an obvious harmful effect on human's physiology and psychology, and then interfere with the

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improvement of work efficiency. While in the low-temperature operations, such as in the cold storage, the workers will have some symptoms of knee pain and back pain, resulting in stiff limbs and then lowering the working efficiency [2]. Furthermore, the astronauts also face the problems of low-temperature operations in the extravehicular activities. For example, the extravehicular activity spacesuit glove suffers a lot from its surrounding environment (high temperature, vacuum, the universe dust collision, radiation, etc.), and then directly leading to a great loss on the efficiency of astronauts' extravehicular activities [3]. Thus, the change of temperature directly affects human's work efficiency and safety.

The change of environment temperature has a direct impact on body temperature, while the body temperature is the necessary condition of human's metabolism and normal life activities. Furthermore, hyperpyrexia or hypothermia will cause hematological abnormalities, metabolic disorders, cardiovascular function changes, pulmonary hemorrhage and the decline or even the loss of the nervous system functions. Some researchers had studied the effects of temperature on blood circulation system. H. Barcroft et al. found that the blood flow of forearm changed correspondingly when putting the forearm into the water at different temperatures [4]; CW. Song et al. explored the influence of local heating or cooling on human skin's microcirculation blood flow through the Laser Doppler Flowmeter [5]; Yinguo Zhang et al. found that the effect of hypothermia on blood pressure variability was sensitive to the heart rate variability by using surface physical cooling method to reduce the rectal temperature gradually [6]; Zhu Lin et al. found that temperature had a great impact on rabbits' blood circulation after the microvascular surgery, by using the $Na^{99m}TcO_4$ trace imaging (TTI) [7]. However, there are only few researches aimed at exploring the relationships between environment temperature and human body blood circulation system so far, and how the environment temperature adjusts the blood circulation system is not clear. So, in order to explore the specific relationship, we established a controllable temperature cabin and tested 15 healthy young male subjects' blood flow velocity, heart rate and blood pressure based on the cabin.

2 Methods

2.1 Experimental Platform

In order to complete the experiment, we established a controllable temperature cabin. The size of the cabin was 7.5 m^2 (3 m * 2.5 m), and its temperature can be real-time monitored by an electric control box (NAK119 W, ®Suzhou Xinya Technology Co., Ltd, accuracy: ±0.1 °C) with the adjustment range from −10 to 50 °C. In the cabin, 36 temperature i-buttons (DS1921, ®Beijing LANCE Technology Co., Ltd, accuracy: ±0.1 °C) were evenly arranged to record the indoor temperature. We did a pre-experiment and verified that the cabin temperature reached stable after 20 min

Fig. 1 The closed controllable temperature cabin

when adjusted to a specified temperature. The controllable temperature cabin can be isolated from the outside environment completely and it can also be real-time monitored and controlled, which is the basis for the following experiments. The closed controllable temperature cabin was shown in Fig. 1.

2.2 Subjects

The experiment data were collected from fifteen 20–25 years old males [height: 173.93 cm (±20.86); weight: 68.23 kg (±41.76)]. All subjects are healthy and have no history of cardiovascular diseases. Written informed consent was obtained from all participants. The study was approved by the Ethics Committee of Biological Science and Medical Engineering School in Beihang University.

2.3 Experimental Process

Before the start of the experiment, the cabin temperature was adjusted to 15 °C, and then the subject entered into the cabin. 20 min later, the cabin temperature reached stable, and then the relevant tests began. We used the ultrasonic Doppler blood flow detector to test the blood velocity at carotid artery and saved the screenshots to record the blood velocity data. At the same time, the heart rate and blood pressure were recorded through a pulse oximetry and an electronic blood pressure meter.

Fig. 2 The experimental apparatus. The ultrasonic Doppler blood flow detector (**a**). The pulse oximetry (**b**). The electronic blood pressure meter (**c**)

5 min later we stopped all the tests and then adjusted the cabin temperature to 20 °C. 20 min later we started the next tests as the above-mentioned steps. Then we subsequently adjusted the cabin temperature to 25, 30, 35 and 40 °C, and then did the relevant tests mentioned above.

2.4 Experimental Apparatus

In this study, we used the ultrasonic Doppler blood flow detector (DVM-4300, ®Hadeco Technology Co., Ltd, accuracy: ±0.1 cm/s) to test the blood velocity, shown in Fig. 2a; we used the pulse oximetry (CMS50D, ® CONTEC Technology Co., Ltd, accuracy: ±2 bpm) to test the heart rate, shown in Fig. 2b; we used the electronic blood pressure meter (CONTEC08A, ® CONTEC Technology Co., Ltd, accuracy: ±0.3 mmHg) to test the blood pressure, shown in Fig. 2c.

3 Results

Table 1 shows the average data at each environment temperature (15, 20, 25, 30, 35 and 40 °C), which reflects the average blood velocity, the average heart rate and the average blood pressure in the 5 min of testing.

Figure 3 shows a typical change of the blood velocity at carotid artery from a certain subject at 15 °C.

According to Table 1, we obtained the environment temperature-blood flow velocity diagram shown in the Fig. 4. As we can see, the blood flow velocity at

Table 1 The average blood velocity, the average heart rate and the average blood pressure in 5 min at each environment temperature

Environment temperature (°C)	15	20	25	30	35	40
Blood velocity (cm/s)	65.3 ± 16.4	62.1 ± 15.3	59.6 ± 14.4	62.3 ± 14.9	65.7 ± 15.2	69.4 ± 15.3
Heart rate (bpm)	84 ± 10.0	79 ± 11.5	76 ± 10.8	82 ± 11.5	88 ± 10.5	93 ± 10.9
Systolic pressure (mmHg)	122.8 ± 7.7	119.4 ± 8.1	115.2 ± 8.2	117.1 ± 7.5	119.5 ± 7.8	121.8 ± 7.7
Diastolic pressure (mmHg)	78.7 ± 8.0	76.9 ± 8.6	74.7 ± 8.0	74.3 ± 8.7	75.0 ± 8.4	76.1 ± 6.8

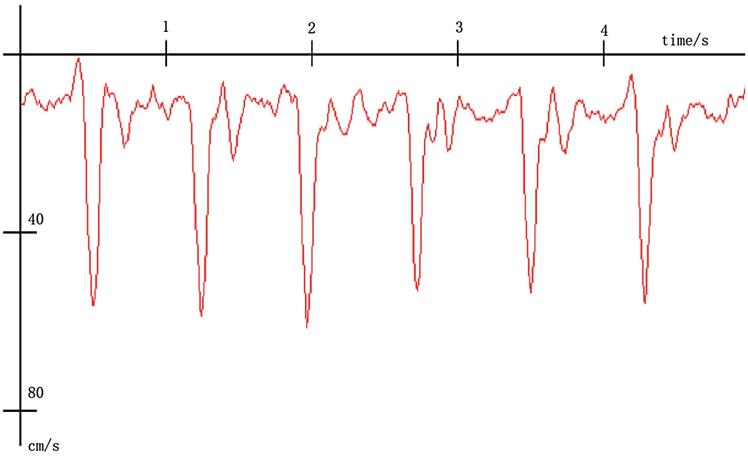

Fig. 3 A typical change of the blood velocity at carotid artery from a certain subject at 15 °C

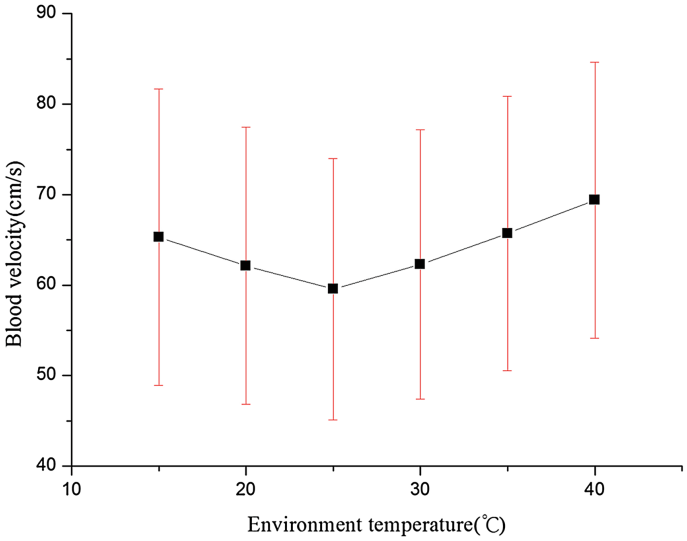

Fig. 4 Environment temperature-blood flow velocity diagram

carotid artery decreases when the environment temperature increases from 15 to 25° C, and then increases along the environment temperature increases from 25 to 40 ° C. The minimum mean blood flow velocity at carotid artery appears when the environment temperature is about 25 °C, and the size is 59.6 cm/s. The maximum mean blood flow velocity at carotid artery appears when the environment temperature is about 40 °C, and the size is 69.4 cm/s. The maximum speed increases by 14.1 % compared to the lowest. We also found that the part of the diagram from

15 to 35 °C is symmetrical with 25 °C. In addition, blood flow velocity at carotid artery changes 4.9 % responding to the 5 °C changes of environment temperature.

According to Table 1, we also obtained the temperature-heart rate diagram shown in the Fig. 5. As we can see, the heart rate decreases when the environment temperature increases from 15 to 25 °C, and then increases along the environment temperature increases from 25 to 40 °C. The minimum mean heart rate appears when the environment temperature is about 25 °C, and the size is 76 bpm. The maximum mean heart rate appears when the environment temperature is about 40 °C, and the size is 93 bpm. The maximum heart rate increases by 18.3 % compared to the lowest. We also found that the part of the diagram from 15 to 35 °C is symmetrical with 25 °C. In addition, heart rate changes 6.2 % responding to the 5 °C changes of environment temperature.

According to Table 1, we also obtained the temperature-systolic pressure and temperature-diastolic pressure diagram shown in the Figs. 6 and 7. As we can see, the blood pressure presents similar trends with blood velocity and heart rate. The minimum mean systolic pressure appears when the environment temperature is about 25 °C, and the size is 115.2 mmHg. The maximum mean systolic pressure appears when the environment temperature is about 15 °C, and the size is 122.8 mmHg. The maximum systolic pressure increases by 6.2 % compared to the lowest. The minimum mean diastolic pressure appears when the environment temperature is about 30 °C, and the size is 74.3 mmHg. The maximum mean diastolic pressure appears when the environment temperature is about 15 °C, and the size is 78.7 mmHg. The maximum diastolic pressure increases by 5.6 % compared to the lowest.

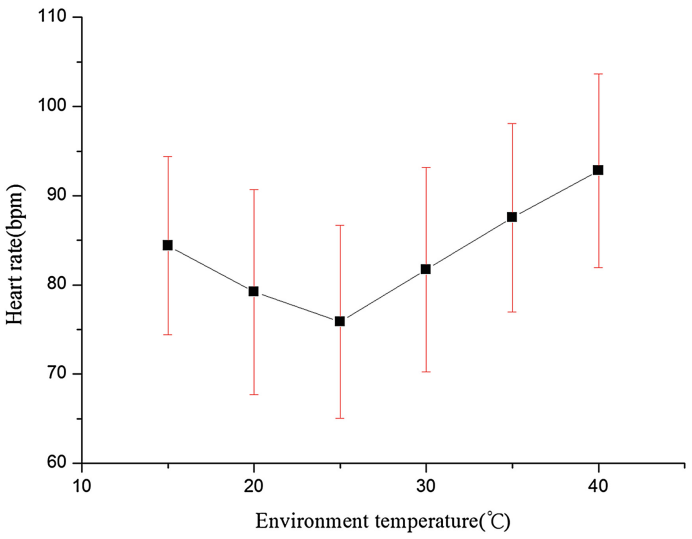

Fig. 5 Environment temperature-heart rate diagram

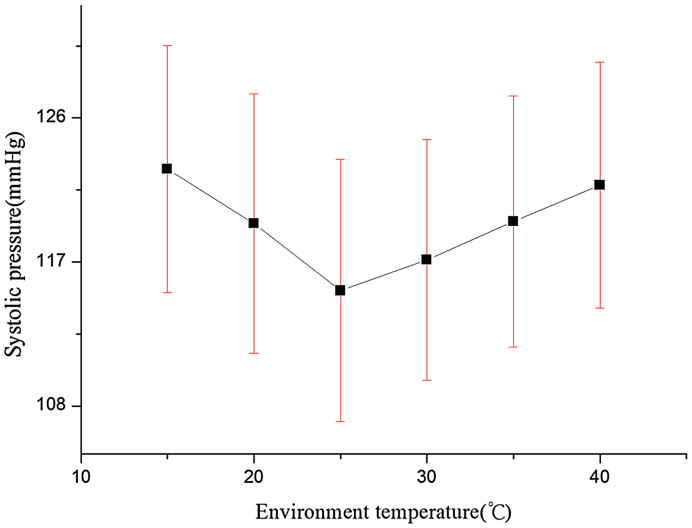

Fig. 6 Environment temperature-systolic pressure diagram

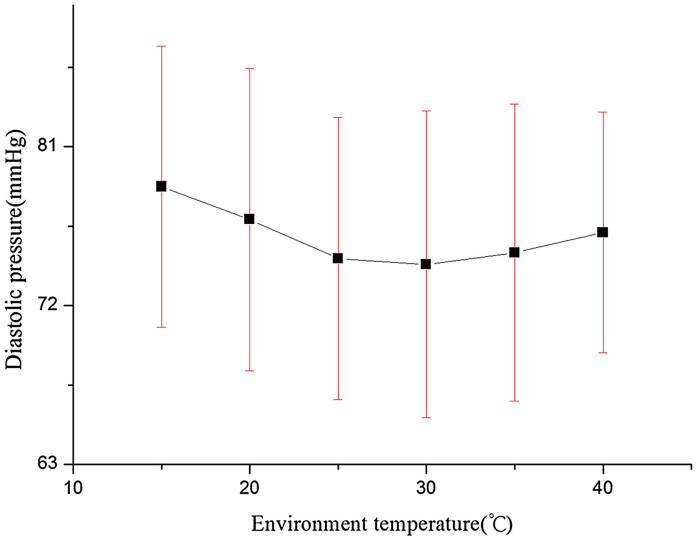

Fig. 7 Environment temperature-diastolic pressure diagram

4 Conclusions

i. In this study, we successfully established the controllable cabin which can be real-time monitored and controlled with the adjustment range from −10 to 50 °C.
ii. We executed the experiment on fifteen subjects and explored the effect of environment temperature on human blood flow.
iii. We found that the blood flow velocity at carotid artery decreases when the environment temperature increases from 15 to 25 °C, and then increases along the environment temperature increases from 25 to 40 °C. Heart rate and blood pressure presents the similar trend as the blood flow velocity along the variation of environment temperature. However, the environment temperature has a larger impact on blood flow velocity and heart rate compared to blood pressure. Therefore, the environment temperature indeed affects the blood flow circulation system regularly, and we can use this regulation to better guide the production and life, improving work efficiency. This study indicates the effect of environment temperature on human blood flow, while the mechanism of the environment temperature effect required further investigation.

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The Study of Evaluation Method for Safety Activity at Railroad Station Service in Consideration of User's Security Feeling

Kazuki Kiyota, Yuya Tanabe and Yusaku Okada

Abstract We decided research object station service, and use the report that is sentence written by employee when they encounter event that making user's uneasiness of an accident happens and so on. By reference to evaluation method of non-technical skill enforcement (SPLINTS and maker system for US Navy ODD), we made evaluation method by next 6 Categories how much words written in the reports: (1) Usual times Situation, (2) Event occurs Situation, (3) Process of Think and Do, (4) Result Prediction, (5) Consideration for Users, (6) Consideration for Colleague. And we make Advice Collection that Advice for activities about enhances safety awareness that are derived from the evaluation.

Keywords Railway safety · Non-technical skill · Incident report

1 Introduction

Japanese railway companies have a problem with reduction of the number of customers. Declining birth rate and aging population cause it. Under the circumstances, their objective is securing their constant profitability. Customers bear the profitability, so railway companies carry out a wide range of measures and programs to maintain and increase the number of customers. The examples of the measures and programs are as follows,

- increasing comfortability by construction of new vehicles and remodeling stations
- improvement of convenience by direct operation with other routes
- improvement of attraction by development and invitation of enterprises along the line
- pursuing the goal that customers ride train with sufficient sense of security.

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This paper focuses on the 4th measures. These measures include measures which are related to not only accident avoidance but also safety, reliance and comfort of customers.

Generally, accidents and troubles cause declining satisfaction of customers. However, incidents whose damage is smaller than accidents even cause it. According to "Research On The Characteristic Of Transportation Usage Focused On Negative Incidents" [1], the more customers experience negative incidents, the less they are satisfied in public transportation. Customers decrease by bad manner of an employee particularly. Therefore, the measures above have some effect on securing their constant profitability.

In order to become a reliable business conduct, railway operators are involved in a variety of activities about both hardware and software. The examples of activities about software are enlightenment of employee about safety, propulsion of incident report and risk prediction training. However, activities that reduce human error often reach a dead end. This is caused by mismatch of current status and activities and shortage of explanation to employee. Employees directly contact with customers and give a sense of security or insecurity. Especially, station employees are the most related with customers. Therefore, if the manager understands the thought of station employees, the activities have more effectiveness.

Nowadays, the works of them are changing because of the automation. In addition, the service that customers need is also variegated. Accordingly, the conventional countermeasures are not accepted. It is necessary that the manager always grasp the thought, value and intention of the station employee. Moreover, railway operators should take proper countermeasures for social values.

2 Past Research

According to the above, managers should grasp the station employees' thought and decide the action plan based on it in order to secure constant profitability with no customer's sense of insecurity. There are some methods which investigate how widely the safety culture related with the approach is diffused.

- assessment tool based on Safety Culture Maturity Model
- Health and Safety Climate Survey tool (HSCS)
- Safety Culture Assessment Tool (SCAT)
- ASCOT (Assessment of Safety Culture in Organization Team) Guidelines
- Hospital Survey on Patient Safety Culture.

These are the examples of the method. These methods evaluate the "safety culture" in organization with questionnaire or subjective assessment. The result is one of the indicators to determine where they should place importance and what kind of safety activities they should conduct. However, these have little objectivity

and there is a little relevancy between assessment and countermeasure. The purpose of this paper is development of new method that has high objectivity and can lead to concrete countermeasure easily.

3 Development of the New Evaluation System

3.1 Six Categories

In this paper, we analyze Potential Incident Report in order to grasp the thought of station employees about safety activity and human error. The contents of the report are incident they encounter, the event that may give customers anxiety, the way they deal with the incident in, and the result of their action. The purpose of the report is the prevention of recurrence and occurrence of the incident and accident, so their understanding or value about safety is expressed on it. We evaluate the reports in the six categories that are developed by referring to SPLINTS. SPLINTS is one of the method that evaluate non-technical-skill. The six categories are "Usual times Situation", "Event occurs Situation", "Process of Think and Do", "Result Prediction", "Consideration for Users" and "Consideration for Colleague". The method of this evaluation is searching keywords in free description on it. We set the keywords related with the categories beforehand. We score the report based on the number of the keywords. The contents of these categories are shown below.

Usual Times Situation.

Content. This category means whether the situation of the report is different from the usual situation. Time of the day and day of the week is also in this category.

Reason of Setting This Category. Yukimachi claims that the difference between the situation and usual situation is useful for making countermeasures. Moreover, if employee can write the difference, he understands the basic concept about safety activity, which means that individual cannot prevent human error.

Event Occurs Situation.

Content. This category means how the situation was, what kind of work they did and how the surrounding was when the incident occurred.

Reason of Setting This Category. We set this referring to "collecting information" in non-technical-skill. This means whether they supervised the surrounding carefully. In addition, when we make a countermeasure, we consider this category and "Usual times Situation" simultaneously to make more useful countermeasure.

Process of Think and Do.

Content. This category means what they thought about the incident, what they decided to do and what they act actually.

Reason of Setting This Category. We set this referring to "collecting information", "recognition", and "decision" in non-technical-skill. We can understand whether they were able to decide correctly by means of concrete information about thought and decision.

Result Prediction.

Content. This means whether they were able to predict the result of the incident if they did not deal with it correctly.

Reason of Setting This Category. We set this referring to "recognizing information" and "future prediction", in non-technical-skill. The more they experience, the more precise they can predict the result of it. Therefore, this category is related to the advice about educational system.

Consideration for Users.

Content. This means whether they considered customers.

Reason of Setting This Category. We set this referring to "recognizing information" and "future prediction", in non-technical-skill. The purpose of this paper is offering the sense of security to customers, so this category is important.

Consideration for Colleague.

Content. This means whether they communicated with others when the incident occurs.

Reason of Setting This Category. We set this referring to "communication" and "teamwork" in non-technical-skill. In the station, some works are done by individual, and the others are done by more than one person. We judge whether they respond appropriately in this category.

3.2 Scoring Method

We give a score to the report based on the six categories. We set the keywords previously (Table 1).

According to this table, two categories get 3 points per 1 keyword and the others get 1 point per 1 keyword. We do not evaluate a report. We evaluate plural reports submitted in a group. The example of the evaluation is below (Table 2).

Table 1 Six categories and keywords

Category	Keywords	Score (/1 word)
Usual times situation	Always, usually, sometimes, daily, rarely, only…	1 point
Event occurs situation	When, in, occur, arrive, departure, for, guide dog…	3 points
process of think and do	Think, decide, act, do, make, take, ask, write, inform…	3 points
Result prediction	Result, accident, possibility, if, may, nearly…	1 point
Consideration for users	Customer, user, passenger…	1 point
Consideration for colleague	Deputy, mayor, chief clerk…	1 point

Table 2 The example of the evaluation

	Usual times Situation	Event occurs Situation	Process of Think and Do	Result Prediction	Consideration for Users	Consideration for Colleague
2010	0.6	2.5	1.1	0.3	1.2	0.9
2011	0.8	4.9	1.0	0.6	0.9	2.1

	Usual times Situation	Event occurs Situation	Process of Think and Do	Result Prediction	Consideration for Users	Consideration for Colleague
2010	1	1	1	1	1	1
2011	1.33	1.96	0.91	2	0.75	2.33

The numbers in the upper table is points per incident report. The numbers in the lower table is the numbers modified upper numbers. The lower is more readable than upper (Fig. 1).

These graphs are made from the table. Railroad companies should focus on the category in which the point in 2011 is smaller than in 2010.

4 Development of the Advice List

We develop the list of advice to educate the station attendant and manager of the station. The advice is based on

- the ability and the way of thinking which is needed in evaluation method of non-technical-skills
- the way of thinking which is effective to prevention of occurrence of human error
- the way of thinking which is needed in the work in the station
- the suggestion which is found in interview to station attendant.

The advice consist of

1. the suggestion of action
2. why the advice is needed
3. the detail advice.

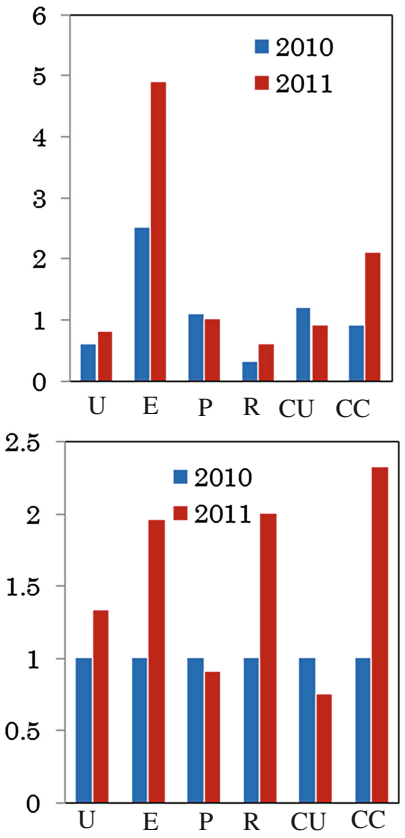

Fig. 1 The example of the evaluation

The example of the advice is below.

① *The workers should learn the allocation of the powers of concentration.* ② *It is said that human cannot continue concentrating on something for a long time. So they arrange the order of the operation, they think about timing they can relax their attention.* ③ *For example, in operation on the platform, they concentrate on 100 % when the train comes. On the contrary, they concentrate on 80 % when the train leaves. The veteran can do so, so the young worker should ask them.*

We develop the 63 advice like above and the table related with advice and six categories (Table 3).

This is the correspondence table. If the category of "Result prediction" is low, you should refer to the advice which is in the group of the "The ability of prediction", "Thought and action".

The figure is the flow of this system (Fig. 2).

Table 3 Advice and six categories

Advice	Usual times situation	Event occurs situation	Process of think and do	Result prediction	Consider ation for users	Considera tion for colleague
The number of reports decrease or does not increase						
The content of reports decrease or does not increase	Generally low					
Communication in workplace		Low				Low
Cooperation in workplace						Low
To get customer satisfaction					Low	
Employee's thought about railway service		Low			Low	
The ability of prediction	Low		Low	Low	Low	
To grasp the situation	Low	Low				Low
Thought and action			Low	Low		
The way of education and instruct	Generally low or sharp fluctuation					
To confirm the result of education	Generally low or sharp fluctuation					
How to communicate in education	Generally low or sharp fluctuation					
Other	Depend on the case of the situation					

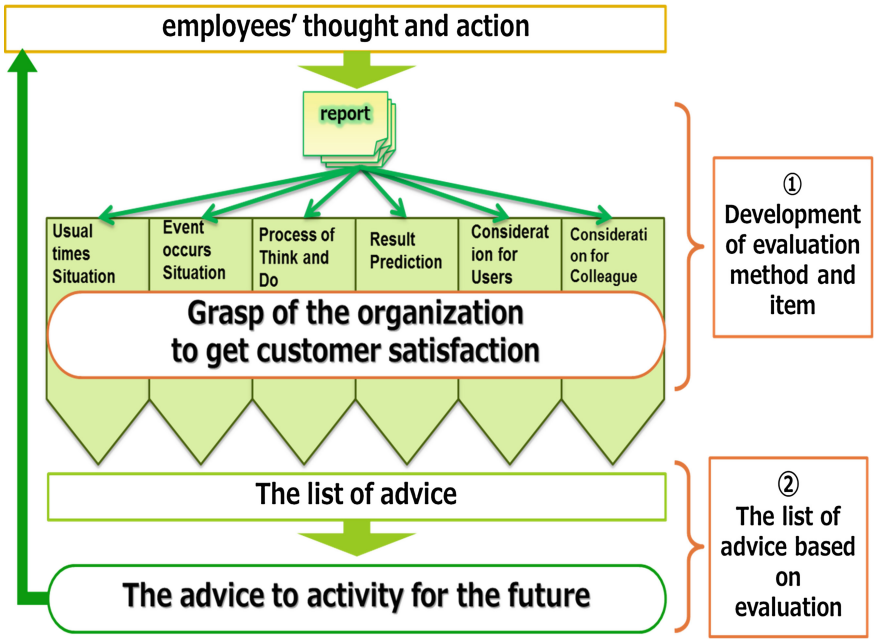

Fig. 2 The flow of this system

5 Conclusion

1. This system can objectively evaluate how much the safety sense of employee is prevailed.
   - Objectivity is guaranteed by evaluating reports in free description.
   - Clarity is guaranteed by categorizing reports in six categories.
   - Validity of the evaluation is not guaranteed yet. We need keep examining the validity.
2. This system can advise manager and employee about educational activity and cite management based on the result of evaluation.
   - Facility is guaranteed by format of the advice "the suggestion of action" "why the advice is needed" and "the detail advice".
   - Validity of the advice is not guaranteed yet. We need keep examining the validity.
   - If the validity is guaranteed, this system can complement existing method.

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User-Centered Design Applied to USAF Civil Engineering Explosive Ordnance Disposal Tools and Jigs

Bradford L. Shields, Vhance V. Valencia, Alfred E. Thal Jr., Joseph D. Wander, Michael E. Miller and Jeffrey C. Parr

Abstract This research employed a user-centered design process to examine the application of additive manufacturing (AM) to fabricate tools and jigs in USAF civil engineering (CE) operations. Within this research, numerous parts were designed and printed for use within CE operations, rapidly evolving the design based upon user feedback. The results of the part testing and the resultant surveys indicate that AM can impact the daily operations of a CE unit, improving operational effectiveness. Further, the research determined that AM has reached a point that the integration of AM into strategically coordinated units, along with proper education and training, can be beneficial for the CE career field. However, this research raises questions regarding the dissemination and rapid adoption of successful designs across DoD operations, without creating burdensome evaluation methods or proliferating an overwhelming number of less than ideal designs.

Keywords User-centered design · Additive manufacturing · 3D printing · Explosive ordnance disposal

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1 Introduction

An innovative technology rarely imposes as drastic a change in processes and procedures across numerous industries like additive manufacturing (AM), more commonly known as three-dimensional (3D) printing, which creates a desired product by additively bonding extremely thin, successive layers of material together to form a 3D object. Deemed a disruptive technology, AM has the potential to displace established design and manufacturing technology, forming an entirely new industry [1]. AM provides a more flexible and convenient approach to manufacturing, while ignoring the concept of economies of scale typical of traditional manufacturing. Historically, traditional manufacturing companies achieved lower unit costs and increased profits by focusing on the production of larger quantities of products. However, AM's flexibility in changing product designs enables customized prints and low-volume production that facilitates a consistent unit cost for producing an item, which is independent of the production volume. For use in both deployed and home station operations, the United States Air Force (USAF) civil engineering (CE) community intends to harness the transformational characteristics of AM in hopes of solving some of the problems accompanying the limited budgets and degraded infrastructure within today's environment [2]. Utilizing a user-centered design approach and a thorough understanding of the potential benefits of AM, the DoD is investigating the potential of AM as a ground-breaking technology within the DoD.

2 Background

USAF civil engineers stationed on USAF bases throughout the US and abroad provide the capability to construct, operate, maintain, repair, and dispose of base assets and infrastructure systems. They maintain an assorted range of infrastructure including, but not limited to, facilities, roads, runways, water distribution, electrical distribution, and grounds maintenance. These engineers also oversee the base fire response capability, Explosive Ordnance Disposal (EOD), and the base's Emergency Management and Readiness functions. Infrastructure systems and other response requirements carried out by USAF engineers comprise both large primary bases and smaller secondary bases, which are often located in remote and austere areas. Similar to research currently taking place by members within the USAF, every other branch, in their own rightful way, has taken steps to integrate 3D printing technology into daily operations.

2.1 Current Additive Manufacturing Military Applications

In the 1990s the US Army investigated AM, referred to then as stereolithography; however, due to the then-primitive technology's unreliability and minimal utilization

in industry, they put little effort into possible applications [3]. As AM technology grew and the availability of materials increased, the Army realized the potential impact of this technology and subsequently developed a plan to stay at the forefront of technology development. In 2002, the Rapid Equipping Force (REF) was developed to be an "on the ground" workshop located at large forward operating bases to provide technical expertise, assistance, and solutions to soldiers, permitting them to complete their mission. In 2012, changes to the REF resulted in the development of two expeditionary labs (Ex-Labs), which are "easily deployable, custom-manufacturing shops equipped with state-of-the-art equipment such as 3D printers, computer numerical control machines, and fabrication tools" [4].

The development of the Ex-Labs represents a rapid integration of 3D printing into US military operations and has resulted in multiple custom fabrications and product solutions being designed and printed in deployed environments [5]. For example, a faulty wheel design and tire inflation system on the Mine Resistant Ambush Protected Vehicle was identified, designed, and printed by the Ex-Labs and engineers who operated the station. The crucial ability to use the equipment in theatre, with reach back to engineers at home station locations who help identify requirements, design prototypes, and provide technical expertise, has proved pivotal in saving time and money compared to alternate options [5]. Due to their success, the Army is establishing more Ex-Lab units to provide better capabilities to their units around the world. The newer assets will include hybrid generators and solar power to help make the Ex-Lab units independent of civil infrastructure [6]. Along with identifying possibilities for 3D printing solutions in deployed environments, the US Army's REF is developing an online tool to give soldiers the ability to submit suggestions for the use of 3D printing. Army leaders expect the younger generation of soldier to embrace use of 3D printing and could improve the way the Army operates [6]. Altogether, the Army is moving forward with integrating AM into their operations; as the technology grows, they will continue to identify, test, and incorporate the technology as efficiently as possible.

Based on the Army's success, the US Marine Corps decided to procure their own deployable assets for operational use [6]. Several areas for possible cost and time savings due to 3D printing included inventory and warehouse space reduction, logistical transportation and shipping cost reduction, and manufacturing and design costs for training aides [7]. Most recently, 3D Systems® was contracted by the US Marine Corps to incorporate the growing capabilities of AM technology into their operations. The end goal is to develop quick response teams, similar to the Army's Ex-Labs and will provide the USMC the skill to "rapidly replace damaged components in the field, especially under critical circumstances" [8]. During a wargame scenario, Marine Corps engineers were expected to use a deployed 3D scanner to model and create a CAD file for a damaged robot. Once the needed parts were printed, the USMC engineers were to repair the robot and complete the assigned operation. By analyzing how quickly a part can be perfected and printed in an operational setting, an evaluation of the technology will be conducted by 3D

Systems® and the USMC. Other assets within the USMC inventory are being tested using 3D printing technology as well.

For the USAF, the AM focus has completely been in the realm of aircraft operations and maintenance technology. Due to the average age of the aircraft in the USAF inventory and the maintenance intensity they require, any time- or cost-saving technology is extremely valuable to the overall operation. In fact, AF leadership has identified 3D printing technology as a strategic priority critical to the success of AF operations in the future [2]. Within the Air Force Research Laboratory and the Air Force Institute of Technology (AFIT), AM is receiving considerable research funding to find additional applications within the USAF; however, to date, only a minute percentage of operational USAF units have implemented any sort of AM technology within their active processes. The USAF has focused its research for AM on operational aircraft, as it operates the most expensive pieces of equipment and these aircraft are the "tip of the spear" for the USAF mission. However, research conducted at AFIT previously identified deployment kits as a possible application for AM.

Air Force Captain Seth Poulsen, a 2015 AFIT graduate, explored the possibility of including AM machines within kits for downrange deployment. During his research, he reached out to Air Force CE leadership and conducted surveys to determine the possible uses for AM within a deployed CE squadron [9]. While the results of his study suggested substantial opportunities for possible applications within CE's downrange mission, it did not identify specific items for printing. The study determined that while it is beneficial to isolate possible areas in which AM could be advantageous within CE, it could only theoretically conclude that the technology would prove to be successful. The final conclusion of his research recommended a pilot study wherein a 3D printer would be integrated into a deployed kit for downrange use. By getting the technology into an operational environment, the study stated it would educate Airmen about the printer's abilities and lead to the identification of actual uses. In the end, the research provided proof that CE leadership believed there was a unique application for AM within their operations; the technology simply needs to be introduced to Airmen who have the technical skills to find the specific applications.

Overall, the four branches of the United States military are still developing an understanding the potential of AM and what it holds for future operations within their services. Based on the literature review conducted on the current military applications for AM, it appears that implementation of the technology is being carried out separately by each branch with little cross communication taking place to share each branch's implementation successes and failures. To move forward into the new era of technology, the entirety of the U.S. military must come to understand the value that AM brings to the unique nature of the mission at hand; additionally each branch must realize that potential value and utilize it best for what that particular service brings to the fight. The foundation is being laid to identify the requirements for each service and to determine how to use AM to help solve the

problems facing each of the different services; however, fully understanding and quantifying the real value of AM is imperative for the proper application of the technology into real world operations.

2.2 The Value of Additive Manufacturing

With the implementation of computers and automation in the manufacturing industry, processes have become more precise, timelines are accelerated, and lower production costs occur [10]; however, traditional manufacturing is limited when it comes to affordably producing customized, low-volume products on an individual basis. The inability of traditional manufacturing to efficiently produce low volume, highly customizable products is exactly the reason why new technologies, specifically AM, have emerged and will be able to compete with the traditional manufacturing processes.

The disadvantages of traditional manufacturing are a result of a lack of design flexibility, extreme up-front costs, significant labor wage gaps, and a lack of investment. Many products in today's market require customization based on the customer and the need for a more efficient use of materials. Traditional manufacturing techniques are unable to meet these demands. Additionally, high-volume production sometimes has hundreds of steps in the cycle and therefore limits the ability of the manufacturer or designer to make any changes to the design [10]. Even with the concept of "extended enterprise supply chains," which farms out pieces of a large assembly to smaller factories, the large up-front costs, inventory requirements, and time lost prohibits any ability to change even a small part. As a result of changing technology and consumer demand, manufacturers have fought to achieve a balance between scale of production and flexibility.

That balance is found through the production of specific items using AM. Unlike traditional manufacturing, which is limited based on geometry and mass production, AM is not restricted by the economies of scale concept. The "just-in-time" application of AM allows users to iteratively change designs based on user need, store designs on a hard drive or global network, easily transport designs on a thumb drive or through e-mail, and then produce the item at the time it is needed. The unit cost for producing a product using AM does not change based on the number of items printed; therefore, customization and low-volume prints do not incur additional costs. The value of AM is in the "just-in-time" application of customizing, printing, and sharing designs without the restrictions of high cost and large distances. Additionally, while AM printers currently print at an average speed of about 4 h per inch in the z-coordinate direction, the relative speed of production compared to traditional manufacturing is seen as another value of AM. Overall, there will always be value found through the mass production of items using traditional manufacturing methods; however, AM's ability to cost effectively produce low

volume, highly customizable items based on user needs and preference provides an alternate avenue for solving some of the unique challenges faced by today's DoD personnel.

3 User-Centered Design

3.1 Systems Engineering

Within any design process in which the system requirements are not well understood, implementing a systematic, iterative, and user-centered procedure is paramount to ensure the final system adequately covers all factors of the design needed by the customer. The application of this systematic approach to the design, manufacturing, deployment and disposal of man-made artifacts is defined as systems engineering. Within the systems engineering approach, important technical processes include, but are not limited to stakeholder (including user) needs and requirements definition, system requirements definition, and design definition processes [11]. Different process models have been developed to visualize and conceptualize how to conduct the design process. These include relatively linear models, such as the waterfall and "Vee" process model, which are applied when the requirements are known or can be determined and iterative design models, such as the spiral process model, which is applied to reduce the risk imposed by uncertain requirements [12]. Within the human factors literature, since it is difficult to easily anticipate the requirements for the items we interact with, it is common to apply a specific spiral process model, often referred to as the user-centered design process [13].

Spiral Process Model and User-Centered Design Process. The spiral process model was originally developed in 1968 (Fig. 1). The model was "intended to introduce a risk-driven approach for the development of products or systems" [11]. The Spiral model makes the process of requirements, design, and conception cyclical while adding a phase for risk analysis. In this process, a system concept is developed, risk associated with the concept are determined, a prototype is developed and assessed to develop requirements for the system and the process is iterated, often developing more complex and realistic prototypes are developed, leading to a final design, evaluation, and product release.

The spiral has four separate phases: Planning, Risk Analysis, Engineering, and Evaluation [14]. The phases allow the design team, for any prototype development, to continually walk through each process in the chain to ensure it meets all the desired specifications. Based on the spiral design, the angular component represents the progress of the design, while the radius of the spiral represents cost [14]. At the end of each cycle, prior to moving to the next cycle, the design team is mandated to evaluate their prototypes and alternatives, solicit suggestions and changes from stakeholders, evaluate the inputs, and decide what changes to make.

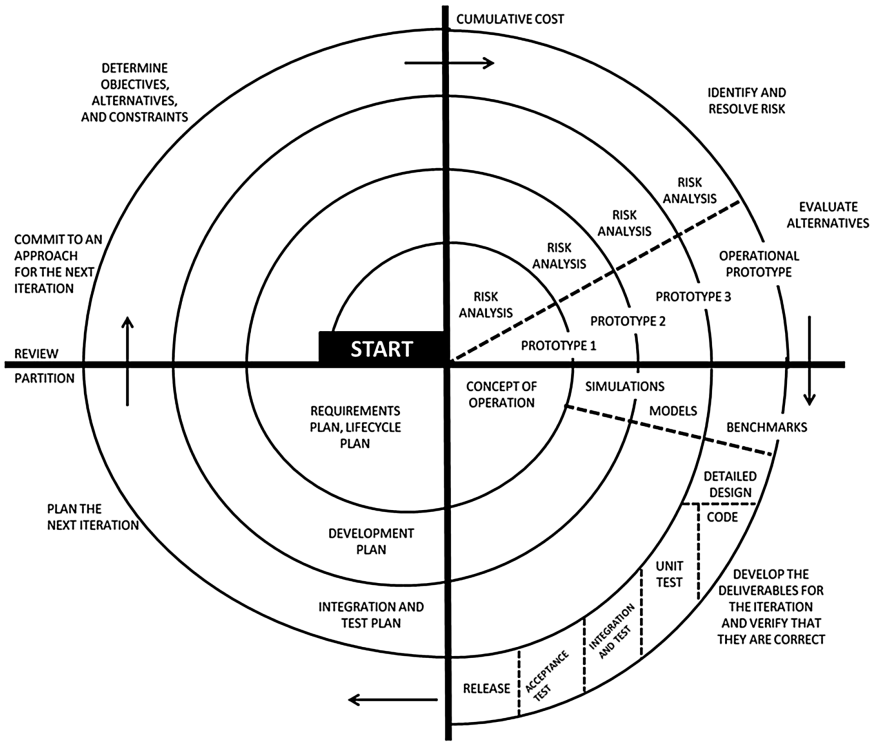

Fig. 1 Spiral process model

Software developers and design teams agree the spiral model's focus on risk analysis is an advantage for both the project manager and the user, that it works well for large and mission-critical projects, and that it is iterative and extremely flexible. Disadvantages of the model include that it is sometimes costly to use, requires highly specific expertise, is incompatible with smaller projects, and exquisitely dependent on the risk analysis phase [14]. Even with its liabilities, the process quickly became the model of choice for design teams walking through a cradle-to-grave design process [11].

The user-centered design process is an iterative design process, commonly applied in user interface design [13]. This process focuses early on the users and their needs instead of technical considerations. A front-end analysis is conducted, often including an assessment of user tasks, empirical evaluations of the existing system, and environmental description. The design is then evolved iteratively, often beginning with participatory design, which includes user input to the design. The human interface to the product is prototyped, followed by usability testing and evaluation, which is applied early and repetitively during the design process. Like

the spiral model, this model attempts to reduce risk, with the user-centered design process focused primarily upon the risk of producing a design that will not be desired by the end user. Within the systems engineering process, this research used a semantic differential survey technique for quantifying and analyzing the usability of the printed parts during the evaluation phase of the spiral model.

3.2 Usability

Usability, sometimes interchanged with the term *operability*, "deals with an individual's ability to accomplish specific tasks or achieve broader goals while 'using' whatever it is that is being investigated, improved, or designed" [15]. The analysis of usability relies both on the performance of the product, user preference, and other human factors required to operate the product. Human factors include human capabilities and the cognitive needs and limitations of humans [15]. Usability depends on the user population's knowledge, skills and abilities as well as the design of the object. Therefore, the usability of a computer program can be zero for a group that has no inclination of how to use a computer, even if the program is state of the art.

Usability, most commonly analyzed as a systems engineering—ility for computer interfaces and programs, creates a definite relationship between the program's purpose and the customer's ability to achieve a desired goal with the program. Usability analysis can be used to assess six different objectives or goals, some of which may be more important in some systems than others. The six measured objectives include the following characteristics about the product [16]:

1. Effective to use (effectiveness)
2. Efficient to use (efficiency)
3. Safe to use (safety)
4. Of good utility (utility)
5. Easy to learn (learnability)
6. Easy to remember how to use (memorability).

The goals related to analyzing the usability of a product are normally operationalized as questions to help provide an exact method of assessing the numerous aspects of the interactive product and the customer experience. The more detailed the questions, the more likely the designer is to find unforeseen problems within the design. Having a clear definition and understanding of the different usability objectives helps the designer develop the questions for the analysis. Within the current project, each product was assessed using a questionnaire asking users to rate each product iteration along each of these dimensions, where each dimension was rated using a semantic differential scale where a value of 1 was essentially assigned a description of completely unusable and a value of 7 was assigned a description of usable.

3.3 Designed Parts Overview

This research identified six separate brackets, tools, or processes having the potential to be made more efficient through the user-centered design approach. In the approach that was applied, individuals were asked to identify problems they faced due to insufficient product designs. Users were then involved in creating potential concepts, a product design was developed, the designed object was formed through an AM process, the users were asked to use the product and complete a usability questionnaire. Input on the design was gathered, and the process was repeated to address the user suggestion. This paper provides a high level overview of just a few of the designed tools used within the research.

EOD Bracket. Prior to this research, EOD operators duct taped their numerous sensors to the arm of their remote controlled robot during operational scenarios. While efficient and easy to do, the task was time consuming, imprecise, and required additional clean up time to remove the tape residue from the robot arm. This basic requirement was the foundation for the bracket that was designed, printed, and is now currently in use by the Airman at the 88th EOD unit at Wright Patterson AFB. Although the bracket went through ten design iterations, Figure 2 below shows the six main iterations that took place over the course of the design. The changes between the iterations was due to printer capabilities and product testing failures. The printer speed is based mostly on the height in the z-coordinate direction, so the change from iteration 1–2 required printing thinner parts and then assembling them post-print. Iteration 2 and 3 assembly design failed due to brittle material and unreliable printer tolerances making the assembly portion difficult. The final designs changed based on improving material usage and strengthening the attachment area. Total design and printing time took less than two months total. Usability scores were collected following successful testing and part handoff.

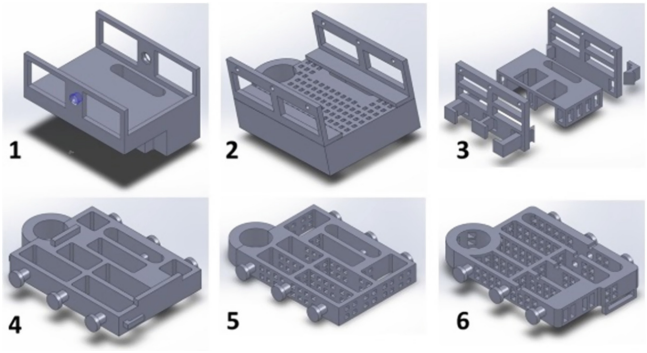

Fig. 2 EOD bracket design progression (Six Main Iterations)

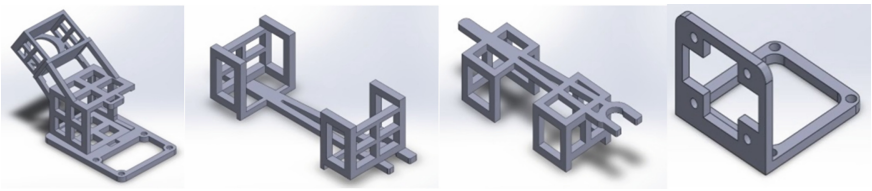

Fig. 3 Unmanned ground vehicle brackets

Iteration 6 is now in use by the EOD unit and being sent to other flights around the country for testing.

Autonomous Robot Brackets. Another researcher at AFIT was designing an unmanned ground vehicle (UGV) to conduct autonomous utility pipe inspections for the CE career field. The current method for attaching various sensors and the large UGV batteries made the robot too heavy and skewed the results of the test. The requirement to attach these sensors using lightweight, yet sturdy brackets, defined the foundational designs for the four designed and printed brackets (Fig. 3), which are still in use by the researchers at AFIT. AM's ability to rapidly produce more efficient, lightweight brackets based on material usage had a significant positive impact on the outcome of this UGV research. The requirement for the brackets came down last second, yet all the brackets were designed and printed within 24 h of the UGV test run. Few changes were made following the initial iterations of the brackets and the usability scores were in between 6 and 7, which proved its success.

3.4 Usability Results

The usability survey, given to those members for whom a part was designed and printed, identified that each part is undoubtedly usable in the terms specified by the seven components of usability. While each part may be usable for the need for which it was designed, the question of 3D printing's ability to provide a usable product for developing unique solutions for problems within the CE career field still stands. Each bracket's usability components were rolled up to calculate an aggregate usability score as shown in Table 1.

Based on the survey from all 13 users of the designed and printed brackets, the 90 % CI suggests that any bracket designed and printed using AM technology would most likely fall somewhere between a 4.78 and 7.0 on the usability scale. This score interval, along with the fact that every printed part is currently being used within the intended operation, provides evidence of the usability of AM technology as a capable tool for solving problems within DoD operations.

Table 1 Overall usability results (n = 13)

Objective	# of Questions	Evaluator scores			
		High	Low	Mean	Standard deviation
Quality	3	7	5	6.56	0.79
Efficiency	3	7	0	6.62	1.39
Effectiveness	4	7	3	6.81	0.69
Utility	3	7	0	5.23	2.18
Learnability	3	7	3	5.83	1.16
Safety	1	7	7	7.00	0.00
Memorability	2	7	5	6.92	0.39
Aggregate	19			6.48	1.33
90 % CI range		7.00	4.78		

4 Conclusion

4.1 Conclusions of Research

The overarching objective of the research was to answer two questions: (1) can AM add significant value to the DoD, specifically the USAF CE career field, and (2) has the current technology reached a point of being able to fulfill the mission requirements. Based on the objective and results of the research, the following conclusions were drawn from the literature review, user-centered design process, and overall usability survey results:

1. AM technology has reached a point where the manufacturing technology can be introduced near the point of use. As a result, designs can be iterated near the point of use, permitting rapid feedback and enabling rapid, user-centered design to enable more efficient and effective operations.
2. Successfully introducing AM into an operational unit is predicated on the education of all members about the capability of the technology, as well as incentivizing the identification and design of potential applications. To fully identify the possibilities of AM within a unit, the members of the unit must be educated on how the technology works and its potential capability. Additionally, the members must be shown specific examples related to their field of work where AM improved a process, created a unique part, or created a solution based on a past need. No educational tool is more effective than allowing users to see something with which they can relate and visualize. The more members understand the potential of AM, the more possible applications will surface.
3. The level of customization this technology provides also creates potential challenges. In the traditional manufacturing paradigm, engineering effort was spent with the assumption that thoughtful, near optimal designs were developed,

leading to products, which were well tested. Users were then often trained to apply the design effectively. However, as AM has the potential to relocate the design near the end user and several products might be designed by several end user's near their points of use, the potential exist to create a large numbers of products, all of which are intended to meet similar or the same needs. Therefore, to support effective training and minimize the proliferation of competing designs, it will be necessary to eventually centralize the design, distributing one of the products as the preferred product. Unfortunately, the necessary processes to harmonize competing designs to enable the development of common processes and procedures across organizations are yet to be developed.

4.2 Significance of Research

As AM is a new technology and its growth is considered significant, this research provides a foundation and baseline for follow-on research within the DoD and engineering industry. Although this was a study for USAF applications, the resulting conclusions are not specific to USAF operations and can be used in decision making by other military branches and civilian organizations. Similarly, the conclusions of this research can help leaders and decision makers understand the need to invest in AM and other technologies of the future. It is imperative to continue funding research into possible applications for AM, as well as working with industry leaders using the technology in order to continue growing the applications and education. Only through further exploration will the conclusions provide a sufficient basis for a test case in operational civil engineering AM applications. Within the literature review conducted for this study, the overall value of traditional manufacturing was identified and compared to the unique value found within AM. Companies and militaries around the world should begin leveraging the potential benefits of AM as a method for making a leaner, more flexible, and more capable fighting force.

The overall significance of this research proves that "need drives innovation." There is a need for better-designed parts and improved processes within all industry operations. Decision makers at the higher levels must understand that the true potential for AM will not be determined without educating their members on the capabilities of the technology. The true applications will only be identified and continue to grow once the customer becomes familiar with the technology and understands the process and benefits it is capable of providing. This study provides a basic process for the user-centered design of parts within any environment, as well being a significant step in determining the potential possibilities for AM.

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A Study on Activation of On-Site Management in Railway Enterprise—Focusing on Occupation Responsible for User's Safety

Minami Wakata, Kumiko Takahashi and Yusaku Okada

Abstract In this study, by targeting three railroad companies, we evaluated that on-site management work just as assumed to motivate site workers, and extracted problems in the management. First, we analyzed statement by some field supervisors to grasp a situation of the management and the essential points to activate it. Secondly, we modeled an influence of on-site management on site workers' motivation. And, we analyzed management effect on site-workers' motivation by using Hierarchical Liner Models and classified issues on the management of each work site. Thirdly, we suggested safety manager of the Japanese railway enterprises guidelines we made to indicate solutions for the issues. Finally, we verified the effective on activation of on-site management in railway enterprises applying the guidelines to the management. Therefore, the study concludes to suggest the possibility of that the analysis and the guidelines we made contributed to activate on-site management.

Keywords On-site management · Railroad enterprise · Motivation · Site-worker · Safety activities · Social value · Multilevel analysis

1 Introduction

1.1 Background

Recently for Japanese railway enterprises as public transportation, one of methods to engage in business is producing social value which the customer and the inhabitants in the community can possess a sense of safety. Once, safety activities used only to be targeted to reduce the number of accidents and error, but now the aim was changed to provide services which make the customer feel comfortable and assured. Then, some Japanese railway enterprises are promoting on-site management of

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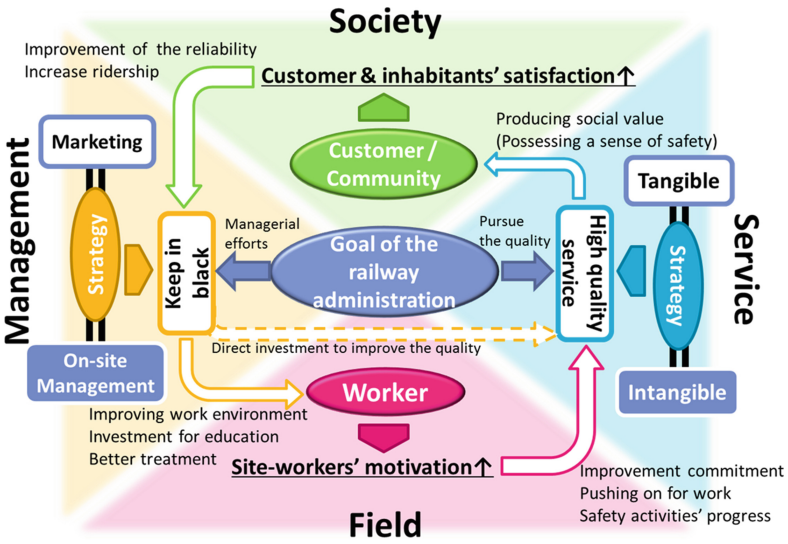

Fig. 1 Map of Japanese railway enterprises' long term strategy

safety activities to map out strategy led by field supervisor initiative. This strategy is purposed to enhance site-workers' motivation spontaneously to meet the needs of the general customer and inhabitants by considering from theirs point of view.

The strategy about goal of Japanese railway administration is below (Fig. 1).

1.2 Purpose

In this study, we assessed the on-site management as one of the safety activities' strategy. Its purpose was the assessment what it functions as the upper-level management's estimation, and what it relates improvement of on site-workers' motivation.

The process of the assessment is below (Fig. 2).

2 Grasping Problems 1—Analysis About Group Meetings

2.1 Survey Outline

The purpose of this analysis is that we assess and analyze the on-site management's progress by analyzing consciousness of the field supervisors.

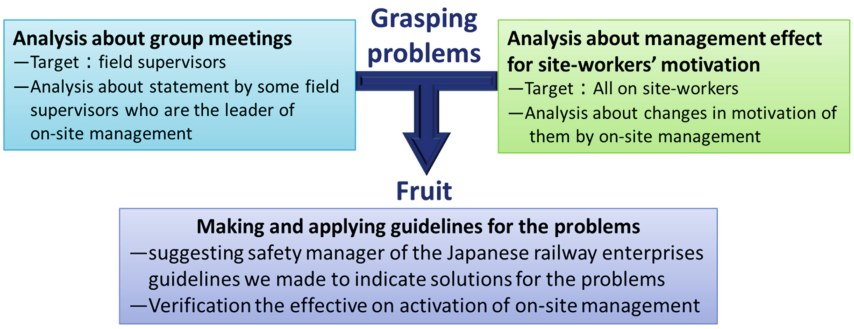

Fig. 2 The process of this study

The data of this analysis were the records of proceedings in the meeting at X shrine. Its participants are the field supervisors, safety section manager and safety department manager. It has being held once a month in 90 min at each department or section. Further, it has being no theme. Therefore, the field supervisors state the dissatisfaction or trouble of the routine operation, and their managers advise for their opinions.

2.2 *Analysis Method*

The performance index based on the study [1], and especially we focused on "clarity" and "diversity". Regarding "the clarity", we suggested that we assessed their consciousness at on-site management by analyzing the clarity about group's goal and member's role. Regarding "the diversity", we suggested that we analyzed what the activities' goal function at the field in the present situation.

We assessed the management's progress by the samples as the field supervisors' state. The number of sample was 245 in X shrine each section.

The determination criteria of "the clarity" are below (Table 1).

Next, we analyzed the viewpoint of their state. This classification is below (Table 2).

2.3 *Results and Discussion*

The results of the assessment about "clarity" are below (Fig. 3).

Regarding 2012, "Very abstract" and "Abstract" accounted for 70 % or more of all. According to the minutes' data, there is scarcely the discussion about the proper activities.

Table 1 The determination criteria of "the clarity"

Level	Determination criteria
Concrete	When they concretely explained the activities or the occupations at their field, and indicated their problems
A little abstract	When they explained only the nominal activities or occupations at their field, and indicated their problems
Abstract	When they didn't explain the activities at their field, and indicated their problems
Very abstract	When they didn't explain the activities at their field, and didn't indicate their problems. OR When they referred to only the abstract keywords; such as the accident or the safety

Table 2 The classification of the field supervisors' state

Grouping	Details
Service	When they referred to the activities or the work from the viewpoint of the customer
Communication	When they referred to the coaching or transmission between the workers
Routine operation	When they referred to the routine work besides about the communication
Measures	When they referred to the measures that they act in order to decrease an error or an accident
Accident	When they only referred to the accident including the occupational accidents

Fig. 3 The assessment about "clarity" at the meetings of X shrine

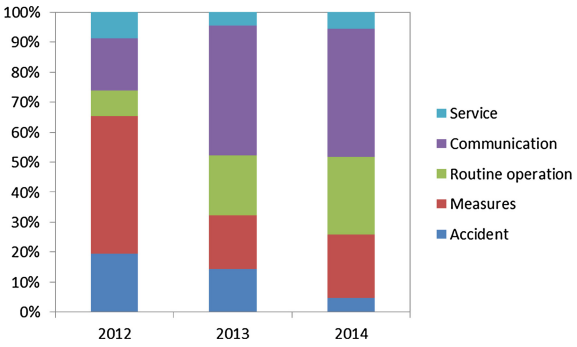

Fig. 4 The analysis about "diversity" at the meetings of X shrine

In contrast, regarding 2014, "Very abstract" and "Abstract" accounted for decreasing outstandingly and "Concrete" accounted for 40 % or more of all. It shows that their supervision reaches every part of all over the field.

In sum, the problem of on-site management is that there are some field supervisors whom state was abstract.

Next, the results of the assessment about "diversity" are below (Fig. 4).

Regarding 2012, "Measures" accounted for about 50 % of all. Further, "Accident" was equal to 20 %of all and its rate was highest than 2013 and 2014. That is to say, they tended to focus on what there is no accident and error.

In contrast, regarding 2014, "Accident" accounted for below 5 % of all. That is because most of them recognized that the goal of their work is not the situation as no accident or error.

3 Grasping Problems 2—Analysis About Management Effect on Site-Workers' Motivation

3.1 Analysis Framework

First, we organized the site-workers' motivation by the study [2] and the interview for the safety department manager and upper-level manager (Table 3).

Table 3 Details of on site-workers' motivation

Site-workers' motivation	Details
Support consciousness	What they share information and own notification with other colleagues in order to help each other
Diligence consciousness	What they understand that all operation is base of safety, and what they don't have excessive pride and work with a strong sense of responsibility
Ingenuity consciousness	What they make efforts to improve the work quality while thinking the value of their own job that adapts to change of the customers and local community on a daily basis

Table 4 Details of the concept of on-site management

Concept of on-site management	Details
Group norm	The contents of the tradition, atmosphere and role at the work
Mutual dependence	The contents of how the measures and occupations depend on many workers
Information sharing	The contents of share information being related to the organization's management in the field
Goal	The contents of the suitable setting at the group level about the vision of on-site management, and the communization of the vision in the field

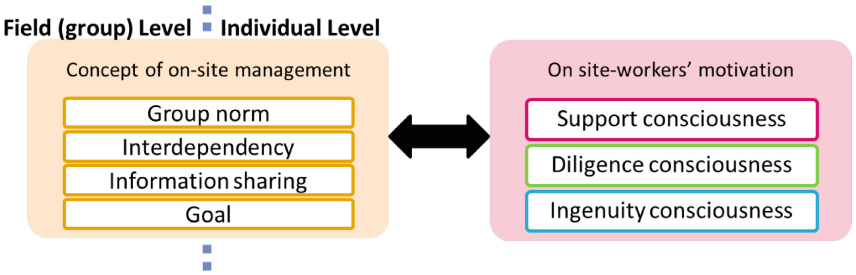

Fig. 5 Hypothetical model about the relationship between on-site management and on site-workers' motivation

Next, we organized the concept of on-site management based on the study [3] (Table 4).

Finally, the hypothetical model in this study is below (Fig. 5).

3.2 Analysis Method

Multilevel Analysis. The model in this study included group level and individual level. Therefore, we used the multilevel analysis in order to analyze different level variable. This time, we used Hierarchical Liner Modeling (HLM). HLM is adapted to the nested data which low level (individual level) data were classified by high level (group level).

The equations as the analysis model are below.

- Level 1 (Individual Level)

$$y_{ij} = \beta_{0j} + \beta_{1j} \times x_{ij} + r_{ij} \tag{1}$$

- Level 2 (Field Level)

$$\beta_{0j} = \gamma_{00} + \gamma_{01} \times Z_j + u_{0j} \tag{2}$$

$$\beta_{1j} = \gamma_{10} + \gamma_{11} \times Z_j + u_{1j} \tag{3}$$

y_{ij}	the motivation's score of the individual level variable
x_{ij}	the management's score of the individual level variable zonally ensemble averaged
Z_j	the ensemble average of the group level variable zonally total averaged
r_{ij}	population within the error
u_{0j}, u_{1j}	intergroup error
γ_{00}	the total average of y_{ij}
γ_{01}, γ_{11}	the coefficient of Z_j
γ_{10}	the total average of the x_{ij}'s coefficient

Simple Effect Analysis. After the multilevel analysis, we carried out HLM using dimidiated group level variable. This time, we used Simple effect Analysis that estimates each regression coefficient about score of high or low standard deviation from average score.

3.3 Results

The result of the multilevel analysis in X shrine is below (Table 5).

Regarding Null model, ICC is 0.676, namely it showed that the variance by the difference of the field was equal to 6.76 %. τ_{00} as the variance of null model's population within the error was significance, so there are satisfyingly variance by the factor differing in population within. In other words, if this variance is not significance, dependent variable is not affected by group level variable.

Next, if the variance is significance that is effect of interaction between the management's score of individual and group level, regression coefficient changes by the management's score of group level. We analyzed effect of interaction about group norm by the result of Simple effect Analysis in order to disclose this detail (Fig. 6).

It showed that "group norm" heightened "diligence consciousness" in the field of high group norm but "group norm" lowered "diligence consciousness" in the field of low group norm.

Table 5 The result of diligence consciousness in X shrine

	Null	1-1	1-2	1-3	1-4
Independent variable	Diligence	Diligence	Diligence	Diligence	Diligence
Intercept	3.420	3.393	3.404	3.409	3.401
Personal level (1)					
Group norm		−0.013			
Interdependency			−0.017		
Information sharing				−0.015	
Goal					−0.018
Field level (2)					
Group norm		−0.376			
Interdependency			−0.202		
Information sharing				−0.170	
Goal					−0.232
Group norm (1)x(2)		0.227			
Interdependency (1)x(2)			0.259		
Information sharing (1)x(2)				0.185	
Goal (1)x(2)					
γ_{00}	0.020	0.007	0.018	0.018	0.016
γ_{11}		0.001	0.006	0.003	0.003
σ_{00}	0.28105	0.279	0.278	0.279	0.27885

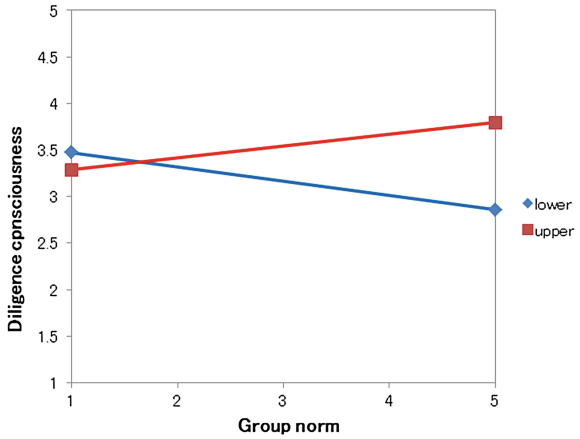

Fig. 6 Group norm and interdependency

3.4 Discussions

The X shrine's result showed that there are many concept of the management that affected the workers' motivation in individual level but there are few concept of the management in group level. In other words, concept of the on-site management does not fixed each field but stays individual level.

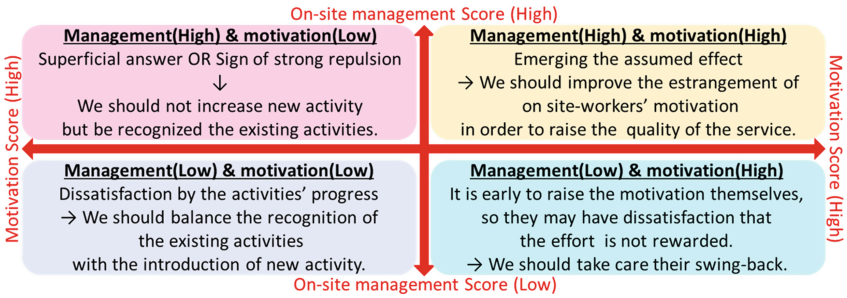

Fig. 7 The relationship between on-site management and site-workers' motivation

First, we considered about the field that received negative effects. This field is that management's fixation doesn't proceed. Moreover, site-workers is separated two strata. First stratum is the person who judges that the fixation proceeds but whom consciousness is low. Second stratum is the person who judges that the fixation doesn't proceed but whom consciousness is high.

Next, we considered about the field that received positive effects. This field is that management's fixation proceeds. Moreover, one site-workers' stratum is the person who judges that the fixation proceeds but whom consciousness is high. The other stratum is the person who judges that the fixation doesn't proceed but whom consciousness is low.

We organized the important point for each stratum (Fig. 7).

4 Making and Applying Guidelines for the Problems

We extracted the problems by considering presently existing activities, so we proposed the guideline to solve the problems. A part of the guideline is below (Table 6).

Table 6 A part of the guideline that we proposed

Issues	Suggestion	
Instruction of the subordinate	Strengthening the communication: you should talk more, and you should specially ask your companion about understanding	Group norm
On site-workers can't resist.	Uttering the dissatisfaction: you should make much account of the atmosphere that they are easy to say their discontent and grumbling	Interdepen dency
Improvement of the motivation for safety	Communization the advice: you should let all the members cooperate, so that you can raise each skill earlier. It will help the improvement of each level to communalize	Information sharing
Gap of values in the field	Communization the aim: you should ask all the members what is the aim of the safety activities	
Gap of the safety sense in the field	Viewpoint of the customer: safety is that the customer decides. You should always think that you get trust from the society	Goal

They advanced the existing activities along our proposal. As a result, the cooperation between department strengthened and the hierarchical relationship between site-workers changed. Moreover, the upper-level manager started to adopt the various communication plans in the company. It showed that site-workers became worked on the activities independently by the proceeding on-site management.

5 Conclusions

First, we made the map of Japanese railway enterprises' long term strategy in order to produce social value. Further, we clarified the placement of on-site management in the strategy map.

Next, we targeted X shrine, our purpose was the assessment what on-site management functions just as the estimation and relates the improvement of site-workers. Therefore, we analyzed about group meeting and management effect for site-workers' motivation. According to the results of the former analysis, we grasped the consciousness of the field supervisors and extracted the problem about the consciousness of their operations. in the latter analysis, first, we created the hypothetical model as "the progress of on-site management relates the improvement of site-workers". And, we took the survey for all workers of X shrine, and analyzed on-site management effect for site-workers' motivation. As a result, we organized the problems of each field.

Finally, we extracted the problems by considering presently existing activities, and we proposed the guideline to solve the problems. Moreover, we verified the effects about revitalization of the management at X shrine that adopts the guideline. According to the interview for the safety department manager, the cooperation between department strengthened and the hierarchical relationship between site-workers changed.

As has been noted, it may help the activation of on-site management that the railroad enterprise adopts the assessment and the guideline that we proposed in this study.

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Part X
Behavioral Ergonomics

The Effect of Speaking Aloud on Prospective Memory Performance in an Interrupted Situation

Ayanori Sato

Abstract An ability of remembering an intention in an appropriate time is referred to Prospective Memory (PM). PM error occasionally causes fatal errors in various real industries. Therefore, the developing method of preventing PM error is very important. This study was conducted to investigate whether speaking aloud the intention is effective in preventing PM error or not. Speaking aloud is used to prevent forget important plan as RTC in railway industry. Given this fact, to investigate the effect of speaking aloud in preventing PM error is quite matter. In this experiment, the delay-execute paradigm was used, in which some interrupting tasks were involved. Some participates used speaking aloud technique and the other did not. As a result, speaking aloud decreased prospective performance surprisingly. One reason of it could be that participants committed to speaking aloud itself rather than put the PM task in their mind.

Keywords Prospective memory · Speaking aloud · Interruption · Human error

1 Introduction

One cause of incident and accident in work place setting is human error. Kinds of human error are various and forgetting to do some intentions might cause fatal accidents [1, 2]. Failing to remember the intention is one of the most common forms of human fallibility [3]. The analysis of the database of self-reported error by airline pilots revealed that 74 of the 75 errors involving memory failures were prospective ones in nature [4].

Failing to remember intentions could be considered a prospective memory error. Prospective memory (PM) is defined as remembering to carry out intended actions at an appropriate time point in the future [5]. On the other hand, retrospective memory is defined as remembering events and knowledge that were experienced in

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the past. It is needed that the intended actions should be remembered at the appropriate time point, in order to carry out the intentions successfully. Remembering the intention after the elapse of an appropriate period of time can be considered a type of PM error. It is crucial that PM cue should be noticed and recognized by a person to remember the intentions at appropriate time point. For example, when you have an intention to send a message to your friend, PM cue is encountering your friend. In this case, PM cue is defined by the event and this type of PM is called event-based PM [6]. In addition to the event based PM, another type of PM is the time based PM, whose cue is defined by time (e.g., attending a meeting at 10:00 AM). PM cue by itself does not tell the existence of the intention to the people who have the intention. They need to remember that intention by themselves at the time of encountering (or noticing) PM Cue. This type of remembering is called "self-initiated retrieval" [7]. If they can notice PM cue and remember the intention successfully, they would stop doing any activities that are been doing before emerging PM cue, in order to complete the intention.

However, there are some cases where the person cannot start doing the intention at the time of emerging PM cue. For example, if your friend is having a conversation with another friend when you have noticed the friend, you cannot tell the message to your friend until that conversation will be finished. In this case, you have to maintain the intention in your mind for a while. If you can rehearsal the intention in your mind until the conversation is finished, you can tell the message to your fried. However, if your cellular phone rings, it is difficult for you to maintain your intention in your mind because you must have a conversation through the phone. Some previous researches demonstrated that the interrupting task such as a conversation through the phone in the above case decreases PM performance [8–10].

In order to investigate the effect of the interrupting task, an experimental paradigm called the delayed-execute paradigm has been developed on the base of the ordinary experimental paradigm to investigate PM. In this ordinary paradigm, the participants have to do a sort of cognitive task (e.g., lexical decision task, pleasant rating task, and so on). While they do this ongoing task, they press a key on the computer keyboard when they encounter a PM cue [11–15]. Whether or not they can response to PM cue is recognized as PM performance. In the delayed-execute paradigm, the participants have to perform eight ongoing tasks and ongoing tasks change every 12 trails. The PM cue is the changing the word color of the ongoing tasks from black to red, and The PM task is to press the "/" key when ongoing task changes. In other words, the participants must not make a PM response at the time of emerging PM cue, and they have to wait for the task changing to make a PM response. In the interrupting task condition, the participants have to perform cognitive task different from the ongoing tasks using a part of time from the emerging PM cue to the ongoing task change. In the no-interrupting task condition, the participants have to continue to do the ongoing task until it changes. The results of comparing PM performance between these two conditions showed that the participants in the interrupting task condition failed to make PM responses more than those in the no-interrupting condition [9].

This research investigates a technique of preventing PM error in the interrupting situation. Investigating the technique by the scientific method is a crucial matter, because PM errors by the interrupting task could cause the fatal accident and incident in work place settings. This study focused on the speaking aloud as the technique of preventing PM error. There is a technique using speaking aloud for preventing PM error actually in some industry. One example of it is the Risk Triggered Commentary driving (RTC) which is used as technique of preventing human error in the British Railway [16, 17]. RTC is a rehearsal technique by which the train drivers speak aloud what they are thinking. By speaking aloud periodically their intention, the intention continues to be put in their mind and it becomes easy to remember their intention at the appropriate time point.

It can be reasonably inferred that the speaking aloud has positive effects on preventing PM error in view of the previous psychological studies. In order for the people to speak aloud their intention, they have to think "when" and "what" to do their intention. It is known as Implementation Intention effect that thinking "when" and "what" to do the intentions improves the PM performance [18]. By thinking them, the context information related to the situation where the intention is performed would be created. The context information in forming the intention is associated with the intention (PM content) in Long-term memory (LTM). By encountering the information related to the intention, the context information is activated in LTM [19]. This activation will spread to the intention through the association. Therefore, to produce the context information in forming the intention is important in remembering the intention. When the similarity between the context information created in forming the intention and the context in performing the intention is high, it becomes easy to remember the intention at the appropriate time point.

As mentioned previously, it was confirmed in the previous study that thinking "when" and "what" improves PM performance. However, to the author's knowledge, this effect has not been yet confirmed in the situation involving interruption task. Furthermore, the effect of speaking aloud has not been confirmed in the same situation. Therefore, the purpose of this study was to investigate whether speaking aloud could improve PM performance in the situation involving the interruption task.

This study adopted the delayed-execute paradigm. The participants performed the eight ongoing tasks. Each ongoing task consisted of 12 trials. PM cue was changing the word color from black to red in the monitor. The participants who saw the PM Cue had to push the "/" key when the ongoing task was changed (PM task). The interruption task was to generate their first semantic associate to the word displayed in another laptop computer. The duration of the interruption task was 30 s. After it, the participants had to resume the ongoing task. In speaking condition, participants had to speak aloud "when" and "what" to do PM response, whenever the back color of the PC monitor changed from gray to green. In the no-speaking condition, the participants were prohibited to speak aloud anything related to PM tasks and there was no change of the PC monitor color.

2 Method

2.1 Participants

Undergraduate students were participated in exchange for fee. The experimenter randomly assigned participants to one of the two between-subjects condition (speaking condition, no-speaking condition) based on their arrival at the laboratory and tested them individually in session s that lasted approximately 45 min. The 36 participants were distributed as follows (male; 20, female; 16): we tested 18 in the speaking condition, and the other 18 in the no-speaking condition. The average of age was 21.9, and the standard deviation was 1.29.

2.2 Materials and Procedure

This study used a modified version of the experimental design used by [8, 9]. I developed eight ongoing activities for our experiment: (1) choosing the synonym of a word from among three alternatives; (2) choosing the antonym from among three alternatives; (3) rating the similarity of pairs of words on a 100-point Likert scale; (4) judging which of three lines was longest; (5) rating the pleasantness of words on a 100-point scale; (6) choose the letter (among five choices) that is included in a given word; (7) solving simple addition problems; (8) solving simple subtraction problems. The computer software ordered these eight tasks randomly for a given block of trials, and then reordered them randomly three additional times so that participants experienced each of the eight ongoing activities in four separate blocks. This provided 32 discrete phases of the experiment, with each phase of the ongoing activity lasting 1 min. Within each ongoing activity, participants experienced 12 discrete trials lasting 5 s each (see Fig. 1).

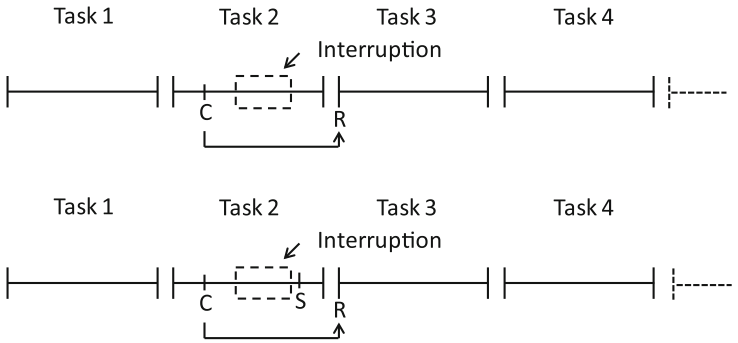

Fig. 1 The top panel shows a block of eight ongoing tasks for the no-speaking condition. The cue (C) signals participants to formulate the prospective response (R) to be executed when the computerized ongoing task changes. The bottom panel shows for the speaking condition. Participants in this condition had to speak aloud "when" and "what" of their prospective intention (S)

One salient prospective memory cue appeared in each of the four blocks of the eight unique ongoing activities, which provided a total of eight cues for measuring prospective memory. Numbering the ongoing activities sequentially from 1 to 32, the cues occurred in activities 6, 15, 23, and 31. Prospective memory cue appeared on Trial 3 of the ongoing task.

When participants were interrupted while performing an ongoing task, the software cleared the computer screen and displayed the message "turn back to an experimenter" in Japanese, which prompted participants to turn to the experimenter and start generating their first semantic associate to words displayed by a laptop computer held by the experimenter. The computer paced this task for the experimenter with short beeps at a 3-s space sot that participants generated 10 different associates for the 30-s interruption. When the interruption occurred, it replaced six ongoing task trials, which would have also lasted 30 s. Participants then returned to the ongoing activity they were performing before the interruption and completed three more trials.

The participants in speaking condition were required to speak aloud "Push the '/' key, when the ongoing task is changed", whenever the color of screen changed from gray to green. In speaking condition, its screen color change always occurred after the interrupting task was completed in the condition where the PM Cue was showed in that ongoing tasks. The duration of green screen was 5 s. it was enough time for participants to notice the color change after the interrupting task. The number of speaking aloud was 4 times in this experiment. On the other hand, in no-speaking condition, the color change did not occur, so that they did not speaking aloud.

Prior to commencing the sequence of ongoing tasks, participants read instructions for all tasks from the computer monitor. Experimenters reiterated the instructions gave participants a diagram of the task sequence, and further explained the task until participants understood their task clearly, especially for when they encountered a red cue word. Experimenter explained carefully to participants that they delay their prospective response (the '/' key) until the ongoing task changed. We gave further clarification that the semantic-associate interruption did not count as a task change.

Each after explaining of task (the ongoing task, the interruption task, the PM task, and the speaking aloud task), participants practiced those tasks. In first practice session, participants in the both conditions practiced the ongoing tasks and the interruption task. In next practice session, they in both conditions practiced the ongoing task, the interruption task, and the PM task. In third practice session, they in speaking condition practiced the ongoing task, the interruption task, the PM task, and speaking aloud task. On the other hand, they in no-speaking condition practiced the same as the second practice. Therefore, all participants practiced three times before the experimental session. When the experimenters found that the participants failed to make PM response in practice session, they cautioned the participants no to forget to make PM response.

3 Results

Unless otherwise specified with a p value, the probability of a Type I error does not exceed the conventional 5 %.

One participant in speaking condition misunderstood when to make PM response. Therefore, this participant was removed from the below analysis. The number of analyzed participants was 35.

3.1 Prospective Memory Performance

It was counted as correct PM response, that participants push the '/' key in 5 since the ongoing task changed in condition where PM cue was showed in the previous ongoing task.

Figure 2 shows the descriptive statistics of the prospective memory performance. T test was conducted a planned comparison between the speaking condition and the no-speaking condition and found marginally worse prospective memory in speaking condition (t (33) = 1.82, p = 0.078, d = 0.61).

3.2 False PM Response

In spite of the fact that PM cue was not showed in previous ongoing task, participant's pushing the '/' key was counted as false response. False responses were a few overall.

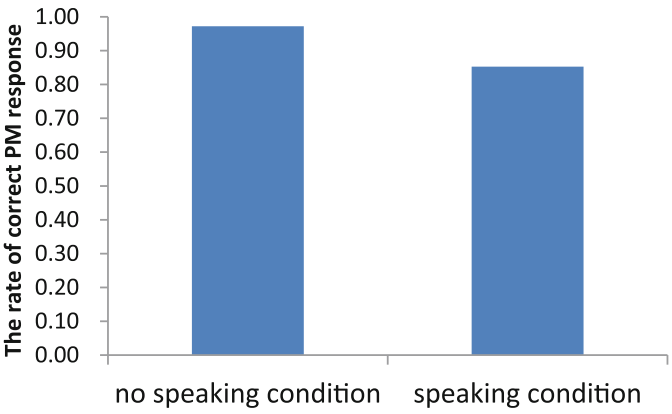

Fig. 2 The average rate of correct PM response

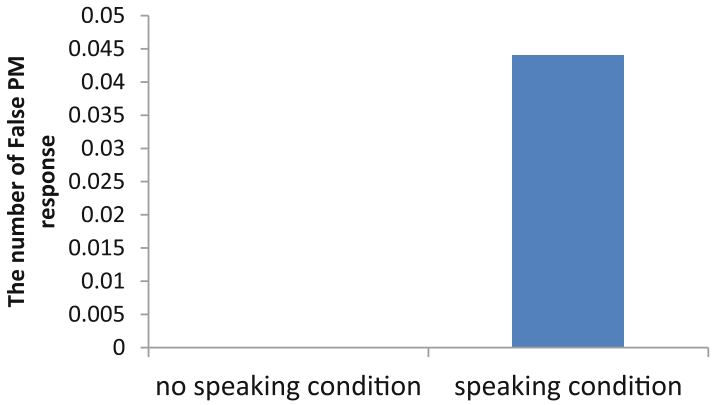

Fig. 3 The average number of false PM response

Figure 3 shows the descriptive statistics of the false PM response. T test was conducted a planned comparison between the speaking condition and the no-speaking condition and found no significant difference (t (33) = 1.82, p = 0.17, d = 0.48).

3.3 PM Point

The number which was subtracted the number of false response from the number of correct PM response was defined as PM point.

Figure 4 shows the descriptive statistics of the PM point. T test was conducted a planned comparison between the speaking condition and the no-speaking condition and found marginally worse prospective memory in speaking condition (t (33) = 2.00, p = 0.054, d = 0.67).

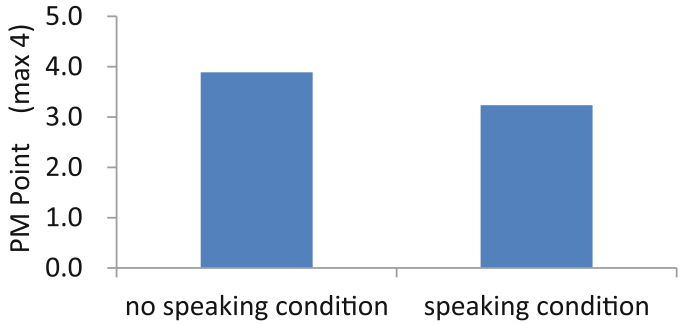

Fig. 4 The average of PM point, which was defined as the number that is subtracted the number of false response from the number of correct PM response

4 Discussion

The purpose of this study was to investigate whether speaking aloud can prevent the PM error in the condition where the interrupting task was occurred in ongoing task. As the results of this experiment, surprisingly, speaking aloud made the PM performance worse than when participants did not speak aloud.

This result was opposite to the expected result. It is thought that the implementation intention improves PM performance by specifying when and what to do their intention. Speaking aloud in this study was same as the implementation intention in that participants specified the situation of PM response by speaking aloud. From this view, it was expected that speaking aloud improves PM performance. However, speaking aloud decreased PM performance in this study.

This result in which speaking aloud decreased PM performance could be attributed to participant's monitoring to PM Cue. Participants in speaking aloud condition had to speaking aloud about "when" and "what" to response PM task when they saw the green screen after the interrupting task. This speaking task might be recognized as another PM task by participants. Therefore, participant's cognitive resource could be allocated to monitoring the color of screen in speaking aloud condition, which monitoring might have consumed cognitive resource. A previous study reported that the additional event based PM task decreased the performance of time based PM task [19]. According to some theories, detecting an event-based PM cue places a load on working memory which reduces the amount of resources for performing other tasks [20–22]. From this view, it could possible that monitoring to the color of screen decreased PM performance in speaking aloud condition in this study.

In this experiment, the rate of correct PM response in no-speaking condition was very high (over 95 %, see Fig. 2). In a previous study which was similar to this study, the correspondence rate was around 70 % [10]. It could be presumed that the number of practice time made a difference in the results of PM task between these two studies. In the previous study, the participants did not practice before experimental trials. In contrast to it, the participants in this study had to practice three times in order to prevent participants'' misunderstand how to do task (ongoing task, the interruption task, and PM task). First practice was for ongoing task and the interruption task without PM task and next two practices were for ongoing tasks with PM task. This repetition of practice might have made the importance of PM task higher for participants than one in the previous study, because experimenter asked the participants to do PM task if they forget to do PM response in practice trials. Previous studies claimed that increasing the importance of PM task made the performance of it better [23, 24]. Given this claim, it could be concluded that higher performance in PM task in this study was attribute to making importance of PM task higher by the multiple practices.

The result of decreasing PM performance in speaking aloud condition might mean that RTC could have negative effect for preventing prospective memory error. Especially, when train drivers commit to monitoring the timing of speaking aloud

what they think while operating train, it becomes to be easy to fail to remember their intention. Therefore, this results cleared that if RTC is to be implemented, drivers should not be monitored the timing of speaking aloud continuously. As previous study demonstrated [17], it could be presumed that speaking aloud should be executed when drivers think of their intention voluntary about the operating train.

Finally, it is important to note that there was a limitation, because of the difference between the procedure of repetition in this experiment and the one of repetition of RTC in realistic situations. Therefore, it is difficult to say that the results in this experiment indicate all the characteristic of real RTC. An example of the difference was a characteristic of ongoing tasks. In this experiment, the ongoing tasks were simple ones which involve the linguistic and numerical process. On the other hand, the ongoing tasks in train operating situation are to check signals, and to control train speed, which include higher cognitive processes. Another example of the difference was the timing of speaking aloud. In this experiment, the participants had to speak aloud "when" and "what" to do PM response when they see the monitor color changing from gray to green. Therefore, they had to monitor the color of screen. On the other hand, in train operating situation, train driver can decide the timing to speak aloud what they think. Therefore they had not to monitor necessarily for the timing.

Although there are some efforts to prevent human error by speaking aloud, there are few investigations to confirm the effect of speaking aloud in preventing error. Confirmation of the effect of speaking aloud and clarification of its mechanism is quit matter in developing the effective way of speaking aloud for preventing human error. This study investigated whether or not speaking aloud improve PM performance and then it did not confirm the effect of speaking aloud. Because the situation in this experiment was far from the realistic situation, further research is needed in more realistic situation.

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Proactive Behavioral Orientation of a Subject as a Process of Investing in Career Capital in the World of "Boundaryless Careers"

Agnieszka Cybal-Michalska

Abstract The contemporary social configuration opens for individuals the range of numerous possibilities of career construction. The contemporary study in the subject of career orders to take into account the process of investing in the career capital that aims at making a subject oriented towards proactivity. Being active in the contemporary reality means constantly adapting to the changing context of an individual career construction and the new way of thinking about career means being *a manager of the knowledge about yourself* and the construction of your career *portfolio.* A subject's career proactivity as a cognitive practice that is embodied in a continuous manner will be "a building material" to form the following features: looking for a change, seeing possibilities, creating situations, showing initiative and taking action. Looking at this issue from this perspective, the study of career is actually both, the study of individual changes and the changes in the society.

Keywords Proactivity · Career capital · Career development · Career portfolio · Boundaryless career

1 Introduction

Over the past four decades there has been a great proliferation and multiplicity of coexisting theoretical assumptions concerning the subject of career. What is more, the neoliberal discourse of economics has negatively affected the quality of the debate conducted on this topic. In that sense, the following considerations may constitute an invitation to reflection not only on the problematization of the career domain, but also on the quality of the discourse conducted in a very peculiar language. In fact, the distinguishing feature in thinking about career is not only the diversity of meanings in which this term is used, but also the language of economics, which increasingly determines the quality of the conducted debate. The highlighted

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approach is echoed in the statements of many theorists and researchers of the phenomenon of career cited in the article. The placement of considerations on the possible, but increasingly dominating way of approaching career could also lead to a reflection on the validity of the views on the excessively economic character of the semantic meanings attached to career. And although considerations concerning career could also be criticized for an overly simplistic approach to the treatment of human nature, it must be asserted that career development and the process of renewing career capital through proactivity is an undoubtedly important issue demanding recognition from the perspective of the subject and "in the course of human life" [1].

In the "discontinuous space-time and the heterogeneous system of cultural meanings" [2] career development and the building of a subject's professional identity becomes a cognitive practice, based on individual experimentation. The contemporary social configuration in which the quest for identity has become a flexible reference point, opens up a range of possibilities for an individual to shape their own career in the course of their life. K. Obuchowski contrasted the structure of a culture of objects with the formation of a culture of subjects, and concluded that "for the first time in the history of mankind, there is a real chance for the personal satisfaction and the freedom of initiative of the direct creators of ideas and things to become a condition for the proper functioning of their workshops, and not just the content of utopian, pro-humanist slogans" [3]. Indeed, as emphasized by A. Giddens, choice is a fundamental component of everyday activities of individuals. Intellectual emancipation and the ability of reflexive behavior in the world of permanent change and diversity of social environments (in which individuals are involved, either directly or indirectly), enable individuals to express personal subjectivity by creating individual lifestyles, "choosing" one's own identity [4], or investing in career capital.

The perception of an individual as a causative agent is an important theoretical construct. This issue was outlined by Herr, who stated that it is the individual who is capable of career creation. Careers do not exist, unlike professions or jobs [5]. As noted by K. Obuchowski, this peculiar shift "of the individual's orientation from external conditions of existence to internal conditions" [6] prompts us to consider career in connection with an individual seen as an individual entity, who owns an individual career [7]. At this point we should refer to a fragment of Collin and Watts' discussion, in which the authors assert the necessity of reevaluating our thinking about career. They state that, "we should focus more on career as an individual's subjective construction, rather than on career as an objective construction" [8]. Accordingly, the subject develops their career on the basis of their perception and attitude towards it. This means, as W. Patton and M. McMahon emphasize, that a career is "a pattern of influences, that coexist in an individual's life" [9]. This view represents the subject's individualistic tendency (ambition, sense of agency, motivation for action), which finds validation in economic theories that support investing in the potential of human resources within an organization [10]. This view provides a background for thinking about career as a "property" of an individual, which includes their individual career choices, individual stages of its development, and the career planning and management strategies.

2 Proactivity in Career as Taking Actions Aimed at Bringing About Change

The contemporary discussion on career is to a large extent combined with an emphasis on the proactive behaviors of the subject. The context for the development, planning, directing and management of the career, as well as the subject's decisions concerning career, is provided by the fusion of the knowledge of the subject's inherent abilities and the diagnosis of the labor market and the possibilities existing in the world of work. This tendency is manifested in the treatment of career as the "property" of the individual, but also in the perception of career as inseparable opportunities for the development of the individual, the development of the organization and a change in the social environment. Reflections on the process of socialization to the labor market focus on the aspect of the spontaneous "adaptation through seeking information and (…) adaptation through the development of feelings and facilitation of adaptation to the <unknown>", which is initiated by the subject [11]. For Greco these basic elements of the subject's activity are the foundation of career planning and management, because, as the author puts it, "you can create possibilities for the future by taking control of your career. Your initial commitment means taking complete control over your activities" [12]. Adequate and realistic self-assessment and perception of social facts provide the basis for innovative proactivity not only in the individual, but also in the social dimension, as "career, work and the market are social categories" [13].

Proactive behaviors, as deliberate actions of a subject, have been the subject of interest of Z. King, R.A. Noe and C. Orpen. Studies allowed for distinguishing two groups of proactivity components, which can be described as: cognitive components and behavioral components [14]. The main distinguishing feature of proactivity is the fact, that the subject takes initiative to change the environment to an extent exceeding the ability of the environment to shape his behaviors. As emphasized by T.S. Bateman and J.M. Crant, actions undertaken with agency and manifested in the social reality can derive from proactivity as a permanent personality trait, but they can also be the effect of "proactivity as an attitude of involvement resulting from life conditions, circumstances and other needs created by the environment" [15]. As emphasized by J.M. Crant, the construct of proactivity defined in such a way covers both individual and contextual variables. The views of T. Bateman and J. M. Crant had a significant impact on the perception of proactivity as a personality disposition and proactivity as an attitude of involvement resulting from conditions, needs, and contextual circumstances. According to the authors, proactive persons are distinguished by seven mutually interrelated characteristics: searching for the possibility of change, setting effective and change-oriented objectives, anticipation of problems and taking remedial measures, searching for ways to achieve goals, entering the path of action with the awareness of risk and responsibility, perseverance in the pursuit of goals and achievement of goals, making achievements and implementing changes which affect the environment [16].

The distinctive feature of people "searching for the possibility of change" is the exploration of the environment in order to bring about change or achieve something. Proactive individuals enter on the path of action, and if necessary—also go beyond the constraints of the situation, in order to obtain the possible benefits resulting from its transformation. "Defining effective and change-oriented objectives" is another characteristic determining the subject's proactivity. The motivating factors include: maximization of achievements, utilization of the responsibility, search for changes that will transform the environment. As a result, achievements proactively motivate the subject and its social environment to take new paths of activity. This way proactivity changes human perception and is the "building blocks" for crossing the boundaries identified from the perspective of the subject and the environment. "Anticipation of problems and taking remedial measures" is implemented through the analysis of the subject's own achievements, seeking changes outside the area of own actions, using feedback information, active participation in meetings and tasks within events bringing about changes. Interest in "establishing new traditions" is another psychological characteristic of proactive people. "Creative individualism" is the permanent focus on searching for ways to achieve the defined objectives. It involves entering the path of action and not settling on the idea, with the awareness of the undertaken risk and responsibility. Proactive individuals are characterized by "perseverance in the pursuit of goals", which means that if the situation requires it, they are willing to change their action strategies. It is the unyielding desire to achieve the objective, rather than stubborn attachment to the methods of achieving them, that characterizes the perseverance of a proactive individual. In addition, achieving and implementing changes and making commitments "affects the social environment" [17]. The essence of proactivity is therefore self-efficacy, also defined as the individual's assessment of their potential. As emphasized i.a. by M.E. Gist and T.R. Mitchell, it is a fundamental variable of the subject's motivation, who has a tendency to be more effective in the performance of tasks, copes more efficiently with changes, sets more complex objectives or applies effective task strategies, when referring to their inherent causative potential. Generalized self-efficacy is a competence relating to the potential of an individual geared towards the proactive performance of tasks and contributes to an increased sense of a subject's agency [18].

3 The Development of Career Capital as a Result of Integration of the Process of Proactive Career Planning and Career Management

The immanent feature of career capital renewal is therefore constant development. Career development is a life-long process of a comprehensive nature. It is the result of integration of two processes: the individual's career planning and the processes of career directing and management. In this sense, it is understood as the subject's

achievement of the objectives of their career. The distinguishing feature of proactive planning, directing and management of a career is the "awareness of being a subject who performs actions in a desired direction" [19] and influences the surrounding reality, thereby initiating changes. There is a kind of qualitative "convergence" between the activities of career planning and career management, which in turn determines the conditions for career development and influences the level of work satisfaction. Treating the highlighted components as correlates, we can point to a conceptual model of career development [20]. The concretization of this position can also be found in the views of J. Adomaitiene and I. Zubrickiene, who emphasize the individualized nature of the results of the planned career, as they are associated with the individual's satisfaction with their own career, self-realization, and quality of life, which are concepts understood and considered in (…) an individual way" [21].

The concept of career development was first introduced to the literature of the subject by E. Ginzberg, S.W. Ginsburg, S. Axelrad and J.L. Herma. Their reflections were based on the assertion, that the choice of an occupation is a developmental process which lasts many years and ends in early adulthood. In the following years (Ginzberg) further specified his position, assuming that it is a process of making career decisions (choices of profession) throughout one's life. This view is espoused by the theoreticians of the concept of career development. D. Brown and L. Brooks described career development as a process of preparing for choice, the process of selection and the constant choosing among the many occupations available in society. For most people this is a life-long process [22].

In the literature of the subject we can encounter attempts to equate the terms "professional development" and "career development". According to A. Bańka, a career is an "individual's property", which means that professional development can be equated with the understanding of career development. In accordance with the life-long learning orientation, the highlighted understanding of career does not limit its updating, both in terms of the temporal and the spatial horizon [23]. For D. Super "the process of professional development involves the shaping and realization of the professional self-image (…) as a result of the mutual interactions of inherited abilities, physical construction, the opportunity to observe and play different social roles and the assessment of the extent to which the roles played are met with the approval of the guardians and peers" [24].

The modern type of careers in the times of "careers without boundaries" has its consequences for the psychosocial and behavioral attitude of the individuals, whose life goal is professional activity (a basic attribute of mental health), rather than professional passivity (a basic indicator of social exclusion) [25]. As N.E. Amundson put it, "the common thread is that people make sense of the world of work through subjective interpretation of their own career experience" [26]. In a situation where no career scenario adopted a priori guarantees success, investment in career that is identified as the "property" of the subject ("in one's own case") becomes a necessity. As stressed by A. Bańka, the dynamics of contemporary careers, known as boundaryless careers, force the proactive planning, directing and management of careers, not only among young people or people in early adulthood

(and therefore "novices (..) trying to transition from the education market to the labor market") but also among people in other age groups [27]. This is the inseparability of work and life which was pointed out by D. Wolfe and D.A. Kolb.

Although this view was formulated in the 1980s, there is no reason to consider—given the direction and pace of changes—the definition of career development presented by the authors as not fit for the times in which "career makes a career". They have asserted, that "career development involves one's whole life, not just occupation. As such, it concerns the whole person (…) in the ever-changing contexts of his/her life. The environmental pressures and constraints, the bonds that tie him/her to significant others, responsibilities to children and aging parents, the total structure of one's circumstances are also factors that must be understood and reckoned with. In these terms, career development and personal development converge. Self and circumstances—evolving, changing, unfolding in mutual interaction—constitute the focus and the drama of career development [28]. The highlighted definition of a dynamic nature (individual-environment, continuity and change) sheds additional light on the discussed issue. It allows us to conclude, that the construction of a career focuses on the life-long development of the individual, and is a process of crystallization of an individual's identity in relation not only to the world of work but to "the world in the man and the man in the world".

The qualitatively differentiated—within the existing theories—process of career development is usually examined through the presentation of both the changes as well as the elements of continuity. The changes occurring in the duration of a professional life cycle are associated with the acquisition of career maturity. As a construct derived from the psychology of human development and career development, career maturity ascribes significant importance to the effective implementation of the assigned life tasks associated with the crystallization of the professional identity [29]. In this sense, according to D. Super, the condition for transition to adulthood is the achievement of career maturity, defined as a "psycho-social construct determining the degree of an individual's professional development on the continuum of life phases starting from the development phase all the way to the decline phase" [30]. A measure of "career maturity" is the determination of the individual's readiness to make career decisions [31]. It should be noted however, that—as emphasized by M.L. Savickas—even though the subject's vocational self-concepts become increasingly stable from late adolescence forward, providing some continuity in choice and adjustment, "self-concepts and vocational preferences do change with time and experience, as the situations in which people live and work change" [32]. In view of this fact, the concept of "career maturity" which indicates the degree to which a subject fulfills the professional development tasks at every stage of life has been replaced by M.L. Savickas with the concept of "adaptability" [33]. Therefore, in a broader sense the scope of the term "career maturity", in addition to the crystallization of the professional identity and the transition to adult social roles, also includes the constant willingness to explore, and the permanent involvement in exploration. The individual is therefore only able to achieve adequate and realistic self-assessment and competencies necessary for the realization of their career by exploring the

environment and exploring the possibilities inherent in career. The role of seeking and possessing information in making binding decisions in life is indisputable [34].

In accordance with the general tendency for the intensification of the career development processes, career planning is seen as the first step on the path to its realization. Individual plans and goals are "adapted" to expectations. In the general sense, career planning is treated as an initiative undertaken by the subject. An equally important issue in this respect is to emphasize the fact, that "the individual utilizes personal control over their own career and makes informed choices concerning their profession, organization, tasks (…) and self-development" [35]. It is a life-long highly complex process which consists, i.a., of the following aspects: the choice of occupation, the search for a job, promotion, striving for changes in the quality of the realized career [36].

The highlighted aspects can be found in the career development and exploration theory formulated by D. Super, who M.L. Savickas referred to as "the planning researcher". What is more, the author starts out from the assertion that planning, a planning attitude (which can be developed) and a temporal orientation for the future, are the main factors determining the readiness for career choice. The conclusions reached by D. Super point to a holistic approach to the issue of planning. It refers to the skills, values and interests of the individual expressed in various social roles (importantly: not only in the professional role), and the individual's task is to anticipate which of them will be available to them in their environment, to prepare for them and to model them [37]. As D.V. Tiedeman and R. O'Hara emphasized in their original career construction theory, the activities distinguishing the phase of anticipation are exploration, crystallization and clarification. In the stage of exploration the individual further defines themselves through numerous interactions with others and capturing the "difference" in relation to others, and then in the crystallization stage they develop an "image" of themselves and a vision of their person on the basis the accumulated knowledge. The selection of a career path is the realization of the stage of clarification and a signal of transition to the implementation phase (stages: induction, reforming, integration), realized in the practice of their profession in the work environment [38].

D.T. Hall defined career planning as "a purposeful process of becoming aware of oneself, one's abilities, constraints, choices and their consequences, and also of identifying objectives associated with career (direction, duration and sequence of steps) and the methods of achieving them" [39]. Moreover, the state of the competencies possessed at a given moment is a certain basis for the construction of the future. The accumulation of competencies is an ongoing process, always perceived from the perspective of the future career [40]. These thoughts were further developed by the perspective of the renowned career theorist J. Krumboltz, which emphasized the life-long practice of career planning, understood as continuous learning, improvement and acquisition of new skills and qualifications [41]. It is predicated on the thesis of the need for a life of permanent change in a world undergoing constant fluctuations. The pace and direction of the changes in the labor market generate the necessity of managing the changes, which attest to the flexibility of a career and are an expression of the ability to adequately respond to the

various circumstances and events, while maintaining a balance in the sphere of professional life. Drawing attention not only to the anticipation of events but also to taking actions, clearly directs the reflection to the causative agent in career planning. The direction of the career planning process understood in this way was illustrated by Z.B. Leibowitz, who claimed, that it is a process "in relation to which individuals determine their skills, interests, values. (…) Individuals are responsible for initiating their career plans, identifying their goals, values and interests, and for searching for their career options, in order to plan their career" [42].

We should note, however, that reflections on career directing and management promote the tendency to ascribe importance to the initiation of actions (and not settling for aspirations). It is an indisputable view, that career management understood as a continuous process of organizing of the professional life is an important determinant and condition of career development (in other words: the next step) after its previous planning. The goals and stages of career development planned by the individual require their implementation. This is done through skills, specific competencies and relevant practices for career management [43]. Watts asserted that we live in an era of "career management", and added that the "do-it-yourself" formula is becoming the obligatory slogan. The inability to predict careers renders them "false" [44]. The key to career is agency. This view is reflected in the considerations of R. Bolles, in which the author recommends, that "one should take control over searching for a job or changing a career, if they want to succeed" [45]. The individuals are doomed to active participation and cooperation in the development of their career. According to D.T. Hall (a similar position is presented by J.G. Greenhaus) career management is "a constant process of preparation, development, implementation and monitoring of career plans and strategies, undertaken by the individual independently or in cooperation with the career development system of the given organization" [46]. Career management in the times of "boundaryless careers" becomes an activity which requires the subject's orientation to the future (futuristic temporal orientation) and active participation and cooperation in the reality subject to permanent change.

The dynamics of modern careers built of "career mini-cycles" (which is illustrated by the transition from one employment cycle measured by the long duration of the employment contract—tenure, lasting from 5 to 7 years), requires a proactive career management style, manifested in the subject's creation and recreation of the mental capital and construction of a social support networks. As emphasized by R. Claes and S.A. Ruiz-Quintanilla, the causative factor of effective career management, based on proactive behavior in a career, is the broadly defined initiative, which refers to: (1) career planning (initiative manifesting itself in innovative behaviors, and therefore in the introduction of changes in the course of the career); (2) skill development (initiative directed at the improvement of the capabilities inherent in the subject, in order to improve the competencies for solving and performing tasks), (3) consultative behavior (initiative manifesting itself in the search for sources of information, advice or assistance from others), (4) behaviors in the network of social interactions (initiative leading to the construction of a network of interpersonal connections). The semantics of discourse on the highlighted

domains of proactive behavior leads us to determine, that they are separable only at the level of general theoretical constructs. At the level of proactive behaviors they clearly overlap with each other [47].

Career management clearly relates to the perspective of the sense of professional identity. In their summary of the research on the validity and reliability of the Vocational Identity Scale, J.L. Holland, L.A. Johnston and N.E. Asama concluded, that persons with a strong sense of professional identity are individuals who are professionally mature, possess many constructive views and opinions on making career decisions, have interpersonal competencies, are characterized by conscientiousness, optimism and responsibility, care for mental hygiene and are able to proactively deal with obstacles or environmental difficulties without being discouraged [48]. The pattern indicated in B. Adekola's research shows the general links between career planning and career management, the sense of job satisfaction and career commitment. The reflections on the direction of the mutual dependencies seem to be more important, however. The conclusion of the research is as follows: "career planning and career management are the condition for career development, while job satisfaction and career commitment are the result of its development" [49]. The emphasis on the importance of designing a career development path is an important implication. The conclusions of the research indicate a stronger relationship between career planning and its development, rather than between career management and its development. Based on this reasoning we are able to draw the conclusion that career planning is relatively more important than career management in the context of its development [50].

4 Closing Remarks

The practice of career planning and management involves the ability of processing information. In their focus on the decision-making process, contemporary researchers such as G.W. Peterson, J.P. Sampson, R.C. Reardon, and J.G. Lenz [51] support the approach known as Cognitive Information Processing (CIP), which points to three career choice domains. The basis of the pyramid scheme is the Knowledge Domain, formulated and constituted by self knowledge and occupational knowledge. Self knowledge is the subject's own perception (self-assessment is not always realistic and adequate), while occupational knowledge is based on facts and can be verified. Above the foundation of the pyramid is the Decision-Making Skills Domain, which consists of five information processing skills known as the CASVE cycle: communication, analysis, synthesis, valuing, executing. At the top of the pyramid is the Executive Processing Domain, which focuses on meta-cognition, thinking about our thinking, which promotes the subject's internal exploration, delving deeper into oneself. The evaluating and monitoring part of the process is an individual's dialog with itself concerning its relationship with the world of work. In the pyramid of information processing domains, the subject's cognitive activity proceeds from the practice of collecting

and possessing knowledge about oneself and about one's abilities, through the awareness of how the subject makes decisions, to thinking about the practice of the subject's decision-making [52].

The multiplicity, fragmentation, volatility and complexity of the forms of organization of social life determine the changes in the perception of career development and overcoming the tension between the experiences of the past and the possibilities of the future. Creating one's own person as an attractive "market product" should be accompanied by proactive behavior aimed at "creating" (and not "finding") a job and developing one's career, seen from a "perspective of agency" [53]. This perspective is similar to the view espoused by R. Bolles, stating that "you will improve your efficiency and your sense of yourself as a person by 300 % if you learn to think (…) of yourself as an active entity, helping to shape your own present environment and your own future, rather than a passive entity, waiting for the environment to shape yourself" [54]. The individual participates in the processes of "investment and renewal" of the capital career as a conscious creator of their own biography.

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Does Instructional Video Advertising Influence Behavioral Intention? Comparative Study Between Hong Kong and Malaysia

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Abstract This study aims to examine the influence of video type (commercial video vs. instructional video) and three cultural/individual difference factors (location: Hong Kong vs. Malaysia; education background: engineering/science vs. non-engineering/science; experience of using touchless technology: yes vs. no) on an individual's behavioral intention to use the touchless system. This study was conducted with 60 participants (30 males and 30 females) from Hong Kong and 62 participants from Malaysia (31 males and 31 females) to investigate whether the video type and cultural/individual difference factors has an impact on individuals' behavioral intention. The findings of this study reveal interesting comparative results between Hong Kong and Malaysia as well as provide useful insights for marketing practitioners.

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Keywords Video advertising · Instructional video · Cultural difference · Touchless system · Hong Kong · Malaysia

1 Introduction

In this digital world, online video clips can be produced and broadcasted at lower cost than traditional TV commercials, which is relatively short with abstract content. The video-based marketing has been the latest trends of e-commerce [1], and there is a growing number of online stores create and integrate videos on their sites [1]. With the flexibility of length and content of the online video, instructional video advertising is a creative medium for advertising the product [2]. Although instructional video advertising appears in different websites and these videos are viewed by people from various countries, there are little studies on investigating the impact of instructional video advertising on consumers' perception and behavioral intention.

The purpose of this study is to identify the influence of video type (commercial video vs. instructional video) and three cultural/individual difference factors (location: Hong Kong (HK) vs. Malaysia (MA); education background: engineering/science vs. non-engineering/science; experience of using touchless technology: yes vs. no) on the behavioral intention to use the touchless system. In order to control confounding effect in which participants have prior knowledge about the product demonstrated in the videos, this study adopted Leap Motion touchless technology for commercial video, and an in-house developed touchless technology for instructional video.

2 Method

2.1 Participants

Sixty Hong Kong participants (30 males and 30 females) and 62 Malaysia participants (31 males and 31 females) were invited to join the study. Participation was voluntary and informed consent was obtained. The participants' education background was classified into two categories: engineering/science (eng/sci) and non-engineering/science (non-eng/sci). Participants' experience of using touchless technology was captured through a self-reported survey questionnaire (Have you used a touch-less system?). Table 1 shows the profile of the participants.

Table 1 The distribution of gender, education background and experience of 122 participants

		Hong Kong (n = 60)	Malaysia (n = 62)
Number of participants	Male:Female	30:30	31:31
Education Background	Eng/Sci:Non-Eng/Sci	46:14	22:40
Experience	Yes:No	14:46	14:48

2.2 Materials and Procedures

Two videos (A: commercial video vs. B: instructional video) were created for investigation in this study. The commercial video (1 min and 50 s, Leap Motion [3]) shows the interaction of the touchless system in various applications such as entertainment and home control system. The Instructional video (2 min and 51 s, in-house developed touchless technology) demonstrates the step-by-step interaction of the touchless technology in the entertainment and home control system.

A 27-item questionnaire (see: Appendix) were adapted from the previous studies [4–8] to measure usability (Q1–Q7), complexity (Q8–Q11), enjoyment (Q12–Q14), perceived ease of use (Q15–20), perceived usefulness (Q21–Q24) and behavior Intention (Q25–Q27).

2.3 Procedures

Within-subject design was used in this study. Each participant was required to view both Video A and B, and to complete the 27-item survey questionnaire after viewing each video. The order of Video A and B are counterbalanced.

3 Results

The responses of 27-item questionnaire on video A and B [N = 244 (60 HK subjects + 62 MA subjects)*2 videos] was compared using a paired t-test. Since the 27-item questionnaire was adapted from previous studies, factor analysis was conducted to determine the factors based on the subjective responses. Next, Analysis of Variance (ANOVA) was conducted to investigate the effects of video type, location, education background and experience on these factors.

3.1 Paired T-Test

Figure 1a, b show the responses of 27 questions on two video conditions from both HK and MA respectively. Both Fig. 1a, b demonstrate the similar pattern. Compared with video B, participants perceived video A has significantly higher usability and enjoyment, less complexity, easier of use, more useful and higher intention to use the touchless technology at home.

However, for both HK and MA responses, two items (*Q11*: *It takes too long to learn how to use the touch-less system to make it worth the effort; Q19*: *It will be easy for users to become skillful at using the touch-less system*) have no significant

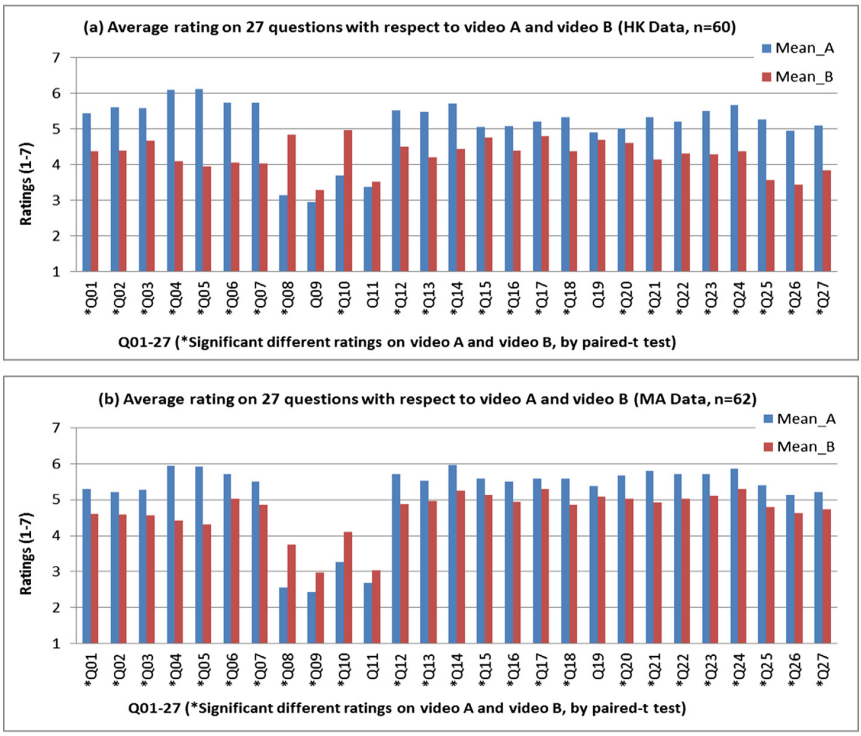

Fig. 1 The histogram of average rating on 27 questions with respect to video A and video B, **a** HK Data, n = 60; **b** MA Data, n = 62

different between video A and B. Additionally, for HK responses only, Q9 (*The touch-less system is so complex, it is difficult to understand what is going on*) has no significant different between two video versions.

The findings show that the amount of difference between two videos appears to be larger for the HK responses. Therefore, the interaction effect of the video type and location was further verified in the ANOVA.

3.2 *Factor Analysis*

The result of the factor analysis (see: Table 2) shows that some items from different studies [4–8] could be combined and contributed to one single factor. For example, Factor 1 could be interpreted as "System Performance & Enjoyment", which contains items from Usability (Q4–Q7) and one item (Q8) from Complexity. Moreover, Factor 3 could be interpreted as "Behavior Intention", which consists of the original 3 items from Behavior intention and one item (Q23) from Perceived

Table 2 Factor analysis of 27-item questionnaire (values in bold are factor loadings that are the greatest among 6 factors)

	Item	Factor 1 "System Performance & Enjoyment"	Factor 2 "Perceived Ease of Use"	Factor 3 "Behavior Intention"	Factor 4 "Usability"	Factor 5 "Perceived Usefulness"	Factor 6 "Complexity"
Usability	Q1	0.195	0.227	0.139	**0.851**	0.121	−0.077
	Q2	0.183	0.205	0.166	**0.867**	0.098	−0.100
	Q3	0.167	0.190	0.035	**0.831**	0.084	−0.118
	Q4	**0.679**	0.161	−0.109	0.393	0.343	−0.147
	Q5	**0.640**	0.102	−0.040	0.381	0.476	−0.091
	Q6	**0.621**	0.221	0.215	0.435	0.167	−0.040
	Q7	**0.635**	0.209	0.217	0.388	0.178	−0.048
Complexity	Q8	**−0.579**	−0.055	−0.130	−0.142	−0.427	0.284
	Q9	−0.108	−0.304	−0.161	−0.131	−0.022	**0.753**
	Q10	−0.429	0.039	−0.265	−0.033	−0.235	**0.620**
	Q11	−0.047	−0.314	−0.136	−0.129	−0.100	**0.730**
Enjoyment	Q12	**0.615**	0.137	0.308	−0.010	−0.097	−0.065
	Q13	**0.720**	0.139	0.322	0.153	0.011	−0.090
	Q14	**0.667**	0.276	0.372	0.055	0.124	−0.128
Perceived Ease of Use	Q15	0.095	**0.701**	0.066	0.257	0.099	−0.285
	Q16	0.229	**0.649**	0.217	0.186	0.362	−0.183
	Q17	0.214	**0.782**	0.168	0.105	0.172	−0.055
	Q18	0.321	**0.439**	0.352	0.038	0.348	−0.178
	Q19	0.092	**0.780**	0.129	0.220	0.058	−0.079
	Q20	0.177	**0.810**	0.175	0.145	0.114	−0.191
Perceived Usefulness	Q21	0.151	0.296	0.300	0.166	**0.734**	−0.053
	Q22	0.082	0.194	0.352	0.160	**0.771**	−0.148
	Q23	0.349	0.220	**0.585**	0.062	0.445	−0.054
	Q24	0.427	0.263	0.440	0.005	**0.451**	−0.085
Behavior Intention	Q25	0.280	0.165	**0.817**	0.156	0.183	−0.127
	Q26	0.192	0.188	**0.809**	0.121	0.280	−0.188
	Q27	0.216	0.189	**0.822**	0.135	0.132	−0.224
Variance Explained		4.380 (16.22 %)	3.891 (14.41 %)	3.621 (13.41 %)	3.184 (11.79 %)	2.679 (9.92 %)	1.984 (7.35 %)

Usefulness. The interpretation of the other four factors (Factor 2, 4, 5 and 6) remains the same as the original labels. These six factors were used for the further data analysis.

3.3 Anova

Prior to performing the ANOVA, the value of each factor was represented by the average value of the corresponding items (e.g. the value of Factor 4: Usability is the

Table 3 P−value of main effects and interaction effects (values in bold are the p-value < 0.05)

	Factor 1 "System Performance & Enjoyment"	Factor 2 "Perceived Ease of Use"	Factor 3 "Behavior Intention"	Factor 4 "Usability"	Factor 5 "Perceived Usefulness"	Factor 6 "Complexity"
Location (L)	0.289	**0.002**	**0.002**	0.712	**0.008**	**0.01**
Version (V)	**0**	**0**	**0**	**0.001**	**0**	**0.003**
Major (M)	0.491	**0.028**	0.341	0.547	0.33	0.131
Experience (E)	0.058	**0.011**	0.491	0.158	0.157	0.392
L * V	0.057	0.865	0.057	0.248	0.484	0.713
L * M	0.918	0.267	**0.016**	0.142	0.273	0.408
L * E	0.934	0.882	0.812	0.978	0.776	0.577
V * M	0.451	0.658	0.369	0.685	0.198	0.43
V * E	0.963	0.513	0.275	0.115	0.349	0.872
M * E	0.127	**0.002**	**0.07**	0.076	**0.001**	**0.003**
Lack-of-Fit	0.246	0.664	0.921	0.942	0.853	0.642

average of the responses in Q1, Q2 and Q3). Then, the ANOVA investigates four main effects, location (HK, MA), video version (A = commercial video, B = instructional video), Major (engineering/science = 1, non-engineering/science = 0) and experience on touchless technology (yes, no) and the corresponding two-way interaction effects (see: Table 3). Video version has significant effects on all six factors. Compared with video version B (instructional video), version A (commercial video) is more favorable in six factors (see: Fig. 2). This indicates version A has higher rating on System Performance & Enjoyment (Factor 1), Perceived Ease of use (Factor 2), Behavior Intention (Factor 3), Usability (Factor 4), Perceived Usefulness (Factor 5) and lower rating on Complexity (Factor 6).

Participant's location has significant effects on four factors (Table 3, Fig. 3). HK participant has significantly lower rating on Perceived ease of use (Factor 2), Behavior intention (Factor 3), and Perceived Usefulness (Factor 5) and higher rating on Complexity (Factor 6). Figure 2b shows that participant's Education Background (Major) and Experience of using touchless system have significant main effect on perceived ease of use (Factor 2).

The interaction effect between Major and Experience is significant on four factors (Fig. 3). The participant, who has non-engineering/science background without experience on using touchless system, gave highest rating on Perceived Ease of Use (Factor 2, Behavior Intention (Factor 3), and Perceived Usefulness (Factor 5); and lowest rating on Complexity (Factor 6). Meanwhile, the participant, who is non-engineering/science background with experience on using touchless

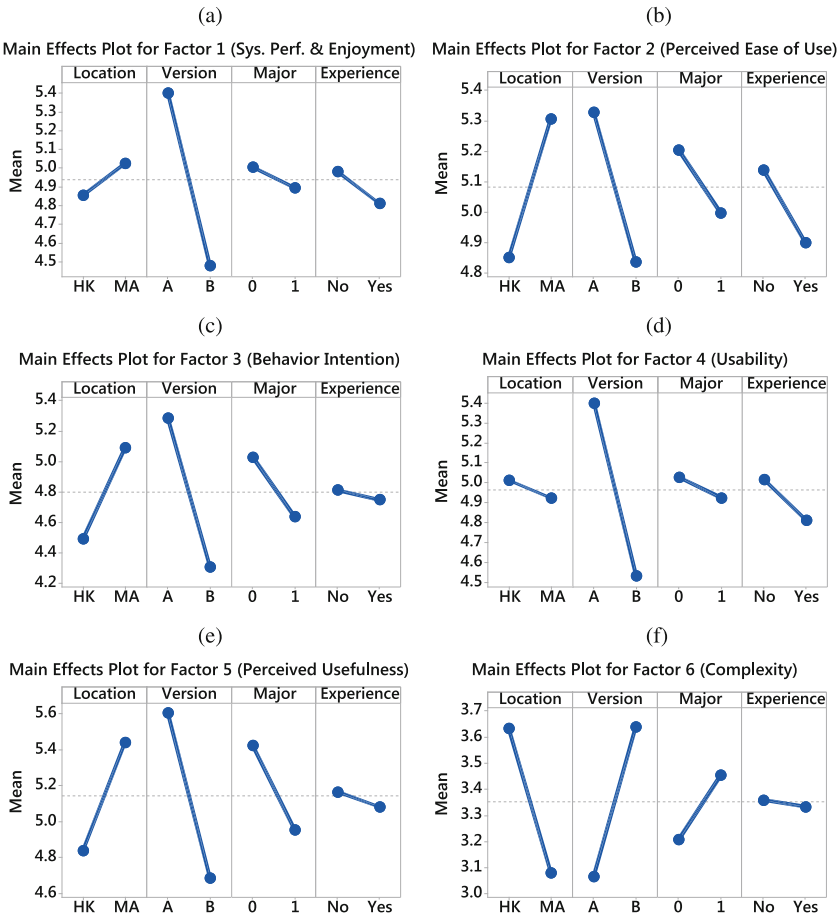

Fig. 2 The main effects plots of six factors (* Significant main effects, p-value < 0.05)

system, gave lowest rating on Perceived Ease of Use (Factor 2), Behavior Intention (Factor 3), and Perceived Usefulness (Factor 5); and highest rating on Complexity (Factor 6).

The interaction between major and location has significant effect on Behavior Intention (Factor 3). For the HK participant with non-engineering/science background, the rating on the Behavior Intention is lowest. For the MA participant with non-engineering/science background, the rating on the Behavior Intention is highest.

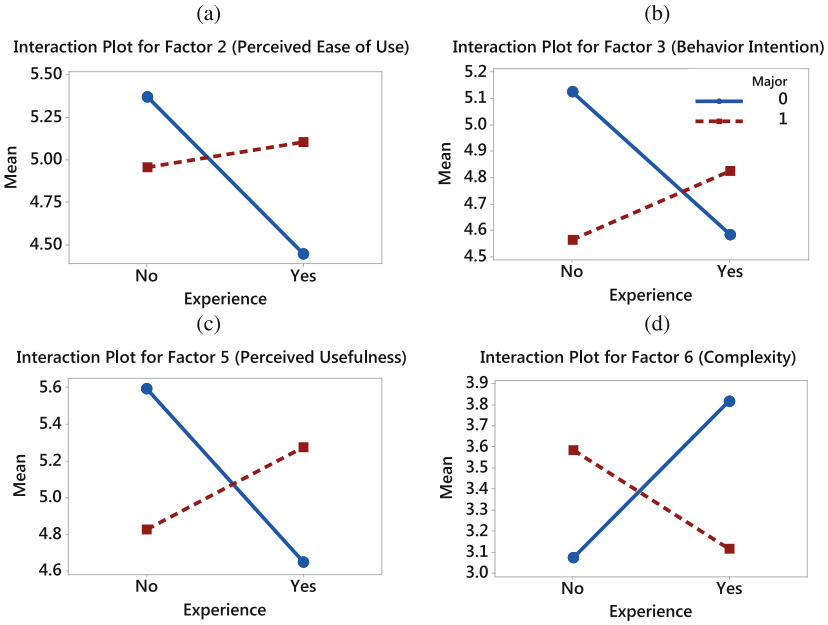

Fig. 3 The plots of significant interaction effects (p-value < 0.05) between Experience and Major on **a** Factor 2-Perceived Ease of Use, **b** Factor 3-Behavior Intention, **c** Factor 5-Perceived Usefulness, **d** Factor 6-Complexity

4 Discussion

The result of ANOVA showed that video version has significant effects on all six factors (see: Table 3). The significant difference between two video versions is due to different purpose of the commercial video (video A) and instructional video (video B). Commercial video aims to promote the product and boost the sale. Therefore its content has to be attractive and the product has to appear usable, easy and simple to operate. However, the purpose of the instructional video is to demonstrate how to operate the system. Compared with the commercial video, instructional video would consist of more detailed operation steps and procedures, which would lead participants to perceive less usable and more complex to operate.

The significant difference between two locations may due to the cultural difference and the technology usage habit. The effect of cultural differences on the responses to a Likert scale has been widely studied [9–11]. Figure 1a, b indicated that MA participants are more generous on giving ratings. This phenomenon was also explained in Johnson et al.'s study [10], which investigated the relation between culture and response styles. In addition, HK people may have high exposure on the latest technology [12], so they may have higher expectation on the usability of the technological product. Moreover, the usefulness and benefit of using the touchless

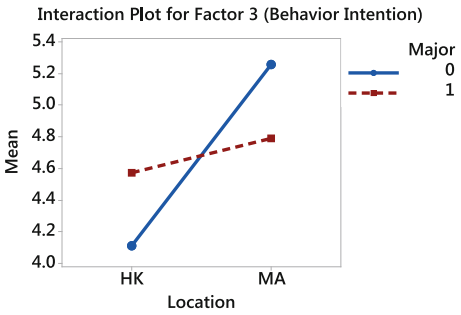

Fig. 4 The plot of significant interaction effect (p-value < 0.05) between Location and Major on Behavior Intention

system at home could be increased with the living space. Due to the living standard is different between HK and MA [13]. Generally, compared with MA, HK people has relative less living space, so it may lead to lower perceived usefulness (Factor 5) and less intention to install touchless system at home (Factor 3). In HK, the intention of installing touchless system at home will be further lowered if someone has non-engineering/science education background. However, in MA, this intention will be significant higher if someone have non-Engineering/Science education background (Fig. 4).

5 Conclusions

Compared with the commercial video, the instructional video appears to be less attractive to viewers. This is because the instructional video provides viewer with closer to the direct experience of the product [14], and it helps to reduce the gap between how the products are expected to function and how the products can really function [2]. The significant difference between HK and MA may due to the difference of living style [13] and the technology usage habit. This study also contributes to practice. Given that the online shoppers are the global consumers from different countries, companies and marketing practitioners should consider the cultural difference and focus on the regional needs and preferences when producing the online video advertising.

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Appendix: 27-Item Survey Questionnaire

Usability
In the video you just saw, what you think about the user's action with respect to:

Q1: Accurate pointing [1: Very Difficult, 7: Very Easy]
Q2: Target selection [1: Very Difficult, 7: Very Easy]
Q3: Gesture-based interaction [1: Very Difficult, 7: Very Easy]
Q4: Responsiveness during touch-less operation [1: Very Slow, 7: Very Fast]
Q5: Speed of touch-less operation [1: Very Slow, 7: Very Fast]
Q6: Your opinion of touch-less system [1: Very Dis-satisfied, 7: Very Satisfied]
Q7: Perceived performance of touch-less system [1: Very Dis-satisfied, 7: Very Satisfied]

Complexity
Answer the following based on the video you just saw. [1: Strongly Disagree, 7: Strongly Agree]

Q8: The touch-less system takes too much time to use.
Q9: The touch-less system is so complex, it is difficult to understand what is going on.
Q10: Using the touch-less system involves too much time doing hand movement and palm-close gestures.
Q11: It takes too long to learn how to use the touch-less system to make it worth the effort.

Enjoyment
Answer the following based on the video you just saw. [1: Strongly Disagree, 7: Strongly Agree]

Q12: Users will find using the touch-less system to be enjoyable.
Q13: The actual process of using the touch-less system will be pleasant.
Q14: Users will have fun using the touch-less system.

Perceived Ease of Use
Answer the following based on the video you just saw. [1: Strongly Disagree, 7: Strongly Agree]

Q15: Learning to operate the touch-less system will be easy for the users.
Q16: Users will find it easy to get the touch-less system to do what they want it to do.
Q17: Users' interaction with the touch-less system will be clear and understandable.
Q18: User will find the touch-less system to be flexible to interact with.
Q19: It will be easy for users to become skillful at using the touch-less system.
Q20: User will find the touch-less system easy to use.

Perceived Usefulness
Answer the following based on the video you just saw. [1: Strongly Disagree, 7: Strongly Agree]

Q21: Using the touch-less system would enable users to access home edutainment more quickly.
Q22: Using the touch-less system would enable users to access home control system more quickly.
Q23: Using the touch-less system would improve users' life.
Q24: Users would find the touch-less system useful in their life.

Behavior Intention
If the touch-less system becomes available: [1: Strongly Disagree, 7: Strongly Agree]

Q25: I intend to use a touch-less system at home.
Q26: It is likely that the touch-less system will be the medium I use at home.
Q27: I predict I would use a touch-less system at home.

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Analyzing Driving Behavior Change as Influenced by Visual Feedback in Following Distance

Heishiro Toyoda, Tina B. Sayer and Joshua E. Domeyer

Abstract Rear-end crashes are the most common crash in US. One factor influencing this type of crash is following distance. Since achieving and maintaining an appropriate following distance is a function of vehicle speed and distance, a mental model is difficult to establish. In general, it is thought that visual feedback is effective to support driver awareness. In the present research, changing driver behavior was investigated by giving in-vehicle visual feedback. The results indicated that drivers try to improve their behavior in a trip as a result of the visual feedback. The detail of improved behaviors included indirect impact of feedback such as frequency of receiving feedback as well as direct impact such as recovery time. Moreover, the effectiveness was not consistent with all drivers. This also suggests that research should focus on population subgroups instead of the entire group when evaluating the effectiveness of driver assistance systems.

Keywords Driving behavior · In-vehicle feedback · Visual feedback · Following distance

1 Introduction

In the US, one of the most common crash types is rear-end collisions which accounted for approximately 40 % of all crashes in 2013 [1]. Rear-end crashes are caused by a combination factors, including glances away from the forward roadway, abrupt changes in lead vehicle velocity, and/or inappropriate following distances.

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Data from field operational tests showed that about 20–30 % of steady state driving time was spent at a following distance (FD) under 1.0 s, for both adults [2] and teens [3]. In previous research, Fancher et al. [4] reported 0.8 s was the most likely value of FD. In contrast to observed behavior, the recommended following distance in drivers' education documents range from 2 to 4 s (e.g., Virginia Department of Motor Vehicle [5], State of Michigan [6]). An appropriate FD depends on both vehicle speed and distance (i.e., time-to-collision or TTC). A driver can easily perceive the distance to a lead vehicle; however, estimating the risk associated with a particular FD is difficult [7]. Hoffman [8] and Victor et al. [9] found that drivers will most often respond to changes in the angular size of the lead vehicle (i.e., looming). Due to this, FD time is inherently difficult for humans to make an appropriate mental model. In particular, novice drivers may lack the skills necessary to have a complete mental model of appropriate risk assessment. The present research is focused on the drivers' risk assessment of their following distance behavior.

1.1 Proposed System

In order to help novice drivers form an accurate mental model of an appropriate FD, the Following Distance Training (FDT) system was developed. In the first iteration, only visual, in-vehicle feedback on following distance was provided. The FDT feedback consisted of a set of color, size (stepwise proximity) coded images (Fig. 1); the red, large image shows the shortest FD, while the green, small image is the longest FD. The feedback images are based on the research of Dingus and colleagues [10]. A driver with the FDT system can see visual feedback on a dash-board mounted display and regulate their FD accordingly. This is similar to Eco Driving indicators, which encourage smooth driving to improve fuel economy [11]. Giving real-time feedback may encourage the driver to make immediate improvements in their behavior.

1.2 Hypotheses

In general, it is thought that visual feedback is effective to support driver awareness. However, how visual feedback affects and regulates driving behavior is unclear. An on-road experiment was conducted to investigate the influence of the FDT system on driver behaviors such as recovery time, FD deviation, approach, and frequency of activation.

Fig. 1 FDT system visual feedback

If the driver's behavior is assumed to be caused by the effect of visual information only, the reaction would be binary (i.e., once recognizing the visual feedback, the driver would try to react in order to reach his/her desired FDT status). In this context, the driver behavior would change in terms of the time exposed to the visual feedback (i.e., how quickly driver recovers his/her status from worse to better). In this study, due to the visual feedback having only three colors and sizes, only recovery time was considered as a direct behavioral variable and others (deviation, approach) as indirect behavioral variables. Figure 2 shows a concept of the relationship between time and FD. Recovery time as a direct variable is simply the exposure time of receiving feedback. Then, if the driver's time to response to the visual feedback decreases (assuming that the slope to minimum FD is consistent) the maximum deviation of FD would change due to visual feedback. Thus, one of the indirect behaviors influenced by the FDT would be deviation. If visual feedback can affect a driver's behavior, the slope to the peak deviation, or approach, would be increased. Lastly, an iteration of visual feedback in the same trip would cause a driver to increase self-regulation, trying to prevent negative feedback. Thus, the frequency of getting feedback would change. This is also an indirect factor affecting driver behavior.

In the present study, it was hypothesized that both direct and indirect behavioral factors would be influenced by visual feedback.

- H1: Visual feedback will improve following distance to a lead vehicle.
- H2: Visual feedback which only includes color-coded information and not actual following distance will improve indirect behavioral factors (deviation, approach and frequency).

Moreover, in this research, individual differences in effectiveness were investigated. The primary goal of this study was to recruit and investigate the effectiveness of the system on riskier drivers; thus, more effectiveness was expected for drivers who had higher ratings of riskiness based on a standard scale.

- H3: Visual feedback will be more effective for drivers who rate higher on a scale of risky driving behavior in self-reported questionnaire or baseline behavior.

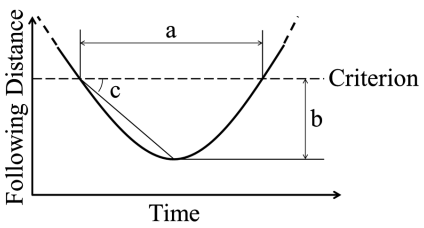

Fig. 2 Behavioral factors—**a** Recovery time, **b** deviation, **c** approach. The criteria are FD = 0.8 s or 1.8 s (*dotted line*)

2 Method

2.1 Participants

Ten participants (8 males, age range 21–29) were recruited internally from Toyota Motor Engineering and Manufacturing North America in Ann Arbor, MI. Younger participants were preferred due to their relatively worse risk assessment in the driving population. Before a participant was invited to be in the study, the Checkpoints Risky Driving Scale (C-RDS) was administered [12]. The C-RDS is a scale comprised of 19 driving behaviors where the respondent is asked how frequently they have engaged in each of the behaviors in the past month. In research by Simons-Morton et al. [12] the C-RDS was predictive of a composite measure of kinematic risky driving. Only participants with average scores greater than 1.3 on the C-RDS were selected in order to ensure that the drivers had slightly higher risk than the normal driving population. Informed consent was obtained from the participants before the C-RDS was administered. A participant number was assigned to all collected data to ensure anonymity.

2.2 Apparatus

The test vehicle was a 2015 model year Lexus NX 200t with a front radar distance sensor. A 5-in. display for visual feedback of FD was mounted on the dashboard. Vehicle kinematic data was collected through the native data network (i.e., CAN bus) at 10 Hz. FD time was computed with FD and current vehicle speed. Based on FD time, Green (FD > 1.8 s), Yellow, or Red (FD < 0.8 s) images were presented on the display only when velocity was greater than 64 km/h (40 mph).

2.3 Measurements

FD data corresponding to each criterion value was extracted. A criterion of less than 1.8 s was used for identifying the yellow category and a criterion of less than 0.8 s was used for identifying the red category.

Recovery time was defined as the time for a driver to recover from the start of the yellow or red visual feedback until the feedback ends (i.e., the driver corrects their behavior based on the feedback and receives green feedback after yellow feedback or yellow feedback after red feedback). Shorter recovery time means improved behavior. Deviation was defined as difference between the criterion value and the minimum FD during the recovery time; a smaller deviation is better. Approach was defined as the deviation divided by the time when the minimum FD

is reached. Again, a smaller approach is better. Frequency was the number of times that yellow/red feedback was given in a trip. Smaller frequency is better and implies the driver is avoiding feedback. These definitions of factors are based on Fig. 2.

2.4 Procedure and Tasks

All participants drove a predetermined, 80 km route on 2 separate occasions, which included a pre-treatment baseline without feedback and a treatment drive with feedback. All drives were conducted when medium traffic density was anticipated. In order to identify the exact effectiveness of visual feedback, only the first exposure of feedback was compared to the baseline.

The Southeastern Michigan route, which took about 50 min to complete, included surface roads (speed limit of 72 or 88 km/h), freeways (speed limit of 112 km/h), and three interchanges. The route was programmed by the experimenter into the on-board navigation system prior to the drive. The driver was instructed to drive as they normally would and not to use cruise control or lane keep assist during their drive. Before the treatment drive, a short explanation of the FDT was given to the driver; however, they were not explicitly instructed to follow the visual feedback. After both drives, participants were requested to answer a post-drive questionnaire asking about traffic condition as well as a subjective assessment of their behavior during the drive.

3 Results

Data analysis was done with this procedure:

- Time series data was extracted for FD under 3 s in order to evaluate overall effectiveness.
- Time series data was extracted for FD under 1.8 s (Yellow) or 0.8 s (Red) and divided into each ‘event’ when drivers received feedback. Frequency is the number of events in a trip.
- Calculated the values of the dependent variables: recover time, deviation, and approach at each ‘event’.
- Calculated descriptive statistics (e.g., mean and standard deviation) for the dependent variables for each session.
- Paired-data t-tests between baseline and treatment were conducted for each dependent variable. Additionally, Hedge’s effect size [13] was calculated for each comparison.

3.1 Behavioral Factors

First, using data from each participant (N = 10), overall effects of the FDT were analyzed. Figure 3 shows that the mean difference between baseline and treatment for following distance (FD < 3 s) was significant, $p = 0.059$, $g = -0.968$. The standard deviation was also significantly improved, $p = 0.016$, $g = 1.33$. This trend of effectiveness was consistent with the other criteria (FD < 1.8 s and FD < 0.8 s) results (Table 1).

Next, t-tests for each dependent variable were executed (Table 2). Due to low sample size, statistical significance was observed only for a few variables. However, effect size g showed many variables were effective. The mean and standard deviation of recovery time for the red feedback (Fig. 4) were significantly reduced when compared to baseline, $p = 0.015$, $g = 1.35$ and $p = 0.013$, $g = 1.38$, respectively. Recover time for yellow feedback was also decreased only in the mean when compared to baseline, $p = 0.298$, $g = 0.494$. Deviation (Fig. 5) was significantly decreased only in the mean for yellow and red feedback when compared to baseline, $p = 0.060$, $g = -0.960$ and $p = 0.033$, $g = -1.12$, respectively. Approach (Fig. 6) did not change. Lastly, frequency (Fig. 7) was significantly decreased only for Red feedback.

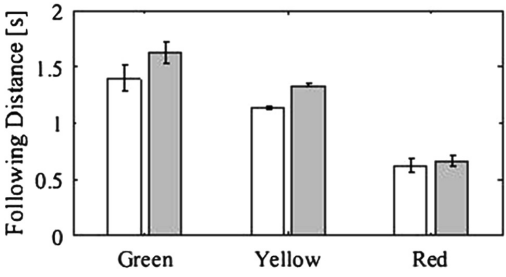

Fig. 3 Overall effects of visual feedback—(*White* Baseline, *Gray* Treatment, *Bar* shows SE)

Table 1 Overall effects of visual feedback for following distance

	Green (FD < 3 s)		Yellow (FD < 1.8 s)		Red (FD < 0.8 s)	
	Baseline	Treatment	Baseline	Treatment	Baseline	Treatment
FD mean [s]	1.53	1.84	1.13	1.33	0.617	0.663
t ($df = 9$)	$t = 2.16$		$t = 2.44$		$t = 2.08$	
p value	$p = 0.059$		$p = 0.037$		$p = 0.068$	
Effect size	$g = -0.968$		$g = -1.09$		$g = -0.928$	
SD [s]	0.638	0.551	0.117	0.104	0.352	0.294
t ($df = 9$)	$t = 2.971$		$t = 2.83$		$t = 0.970$	
p value	$p = 0.016$		$p = 0.020$		$p = 0.358$	
Effect size	$g = 1.33$		$g = 1.27$		$g = 0.434$	

Table 2 Statistical results of behavioral variables change—baseline (B) versus treatment (T)

Session		Recovery time [s]		Deviation [s]		Approach [−]		Frequency [−]	
		B	T	B	T	B	T	B	T
Yellow (FD < 1.8 s)	Mean	42.2	30.9	0.928	0.718	0.218	0.304	21.3	22.3
	t (df = 9)	t = 1.11		t = 2.15		t = 1.65		t = 0.600	
	p value	p = 0.298		p = 0.060		p = 0.133		p = 0.563	
	Effect Size	g = 0.494		g = 0.960		g = −0.738		g = −0.268	
	SD	42.7	34.2	0.408	0.401	0.324	0.370		
	t (df = 9)	t = 0.643		t = 0.256		t = 0.912			
	p value	p = 0.536		p = 0.804		p = 0.386			
	Effect size	g = 0.288		g = 0.114		g = −0.408			
Red (FD < 0.8 s)	Mean	15.6	4.98	0.263	0.183	0.118	0.131	13.9	9.6
	t (df = 9)	t = 3.01		t = 2.52		t = 0.407		t = 1.20	
	p value	p = 0.015		p = 0.033		p = 0.694		p = 0.260	
	Effect Size	g = 1.35		g = 1.12		g = −0.182		g = 0.538	
	SD	16.4	3.33	0.137	0.125	0.102	0.097		
	t (df = 9)	t = 3.09		t = 0.705		t = 0.218			
	p value	p = 0.013		p = 0.499		p = 0.832			
	Effect size	g = 1.38		g = 0.315		g = 0.097			

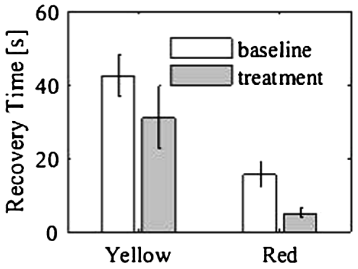

Fig. 4 Recovery time

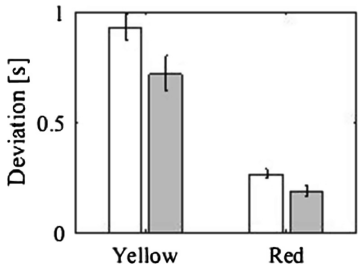

Fig. 5 Deviation

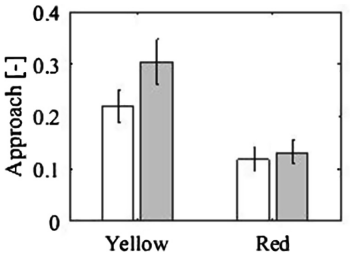

Fig. 6 Approach

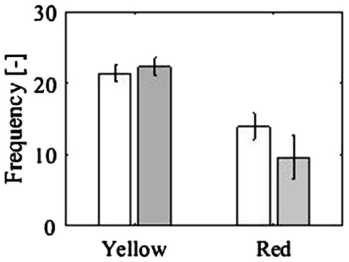

Fig. 7 Frequency

3.2 Individual Differences

The individual differences of FDT effectiveness was investigated to understand whether some groups respond better to the training than other groups (H3). Figure 8 shows the relationship between each participant's effect size of following distance and baseline following distance. This indicates larger effects for drivers who have shorter following distances during the baseline drive, $r = -0.752$, $p = 0.180$ for yellow feedback, $r = -0.667$, $p = 0.287$. In each behavioral variable, recovery time and deviation compared to approach had better correlations for FD effect size, $r = 0.551$, $r = 0.678$, and $r = -0.106$, respectively for yellow feedback and $r = 0.534$, $r = 0.368$, and $r = -0.446$, respectively for red feedback. Table 3 shows

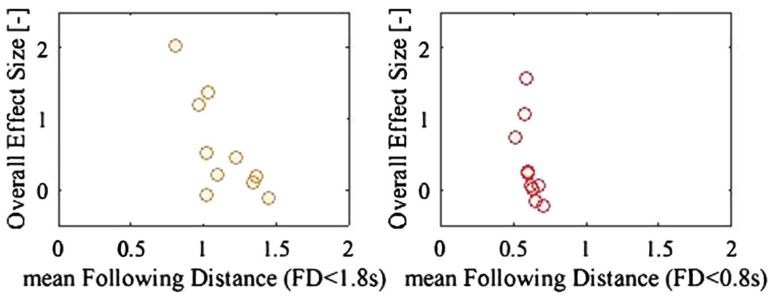

Fig. 8 Individual differences in effectiveness—mean following distance was from baseline data. *Left* Yellow feedback, *Right* Red feedback

Table 3 Pearson's correlation coefficient (r) between individual overall effect size and individual behavioral variable

	Yellow (FD < 1.8 s)		Red (FD < 0.8 s)	
	Baseline	Treatment	Baseline	Treatment
FD effect size versus following distance	−0.752	0.537*	−0.667	0.679*
FD effect size versus recovery time	0.551*	−0.469	0.534*	−0.076
FD effect size versus deviation	0.678*	−0.702	0.368	−0.665
FD effect size versus approach	−0.106	−0.352	−0.446	−0.745

*$p < 0.05$

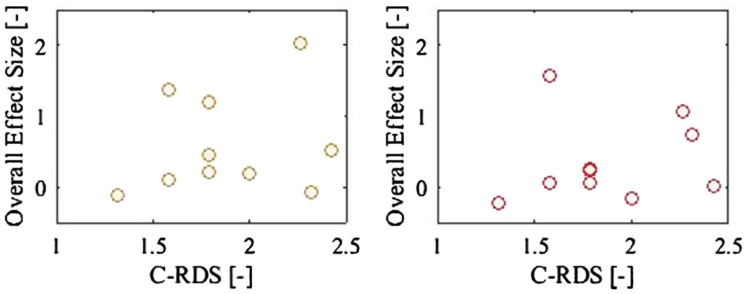

Fig. 9 Self-reported score and effectiveness—*Left* Yellow feedback, *Right* Red feedback. Plots of 10 participants for each. C-RDS score is one data for each participant

the correlations between effect size and the independent variables for the overall changes in following distance.

Finally, Fig. 9 shows that that there was no significant relationship between self-reported risky driving behavior score (C-RDS) and effectiveness.

4 Discussion

In order to clarify the effectiveness of visual feedback for driving behavior, recovery time, deviation, approach, and frequency as driving behaviors were defined. Prior to analyzing the driving behavior, overall effectiveness of visual feedback was found for each color code—green, yellow, red (Fig. 3, Table 1). These results suggest that visual feedback provides an immediate improvement of driving behavior in a trip which is consistent with previous research [10]. Thus, we found evidence supporting the first hypothesis.

In addition to the overall analysis, the other independent variables were analyzed to understand the results in more detail. One direct (i.e., recovery time) and three indirect (i.e., deviation, approach, and frequency) behavioral variables were

analyzed for this step. Due to the visual feedback having only three colors and sizes, only one variable, recovery time, was considered as a direct behavioral variable. Deviation was thought of as an indirect factor due to no specific following distance being provided in visual feedback, but it may influence recovery time as consequence. The other two factors, Approach and Frequency, were also indirect factors since it was predicted that the visual feedback causes safer behavior to reduce opportunity of event or to moderate riskier behavior. The effect size values in Table 2 show that, for red feedback, the means of recovery time and deviation were significantly improved at the treatment drive comparing to the baseline drive while the mean of approach was not significant. This suggests that visual feedback mainly encourages the driver to response quickly and this causes reduction of amount of deviation from criteria. This trend was consistent for yellow feedback as well as for red feedback, but a weaker effect was observed for yellow feedback. Also, frequency was significantly improved for red feedback but not for yellow feedback. This implies that driver would try to avoid receiving worse feedback in the total number of exposure although no effect in approach implies that driver doesn't try to keep him/herself from exceeding criteria of receiving feedback. The differences between yellow feedback and red feedback indicate that the driver thinks that the criterion for red feedback is more appropriate than the yellow or that the yellow feedback is not representing the actual risk. These results support the second hypothesis although all variables were not significant.

In order to identify individual differences in effectiveness, the effect sizes of the FD were compared with the behavioral factors. The results (Fig. 8, Table 3) showed some correlation between effect size and original behavior (i.e., baseline). This suggests that the effectiveness of visual feedback is not consistent with all drivers. This matches with the third hypothesis which stated that riskier drivers receive more benefits from the system. The trends in the yellow and red feedback were not different from each other. This implies that the individual differences in effectiveness would be observed regardless of the driver's judgement of the meaning of the feedback (i.e., yellow or red). These findings may be similar to behavior adaptation theory. Rudin-Brown et al. found in her research [14] personality factors such as 'locus of control' and inclination toward sensation-seeking, were associated with a driver's propensity to trust system. This implies that whether or not driver tries to follow the visual feedback may also be affected by them. In this research, C-RDS as an individual factor was corrected but no explicit relationship with effectiveness of visual feedback was observed due to low sample size. Further research of relationship between actual behavior and self-reported personality is needed. The findings of individual difference also suggest that automotive researchers should focus solely on the entire population when they evaluate effectiveness of driver assistance systems. Even if a system is effective only for a special population it is still important.

5 Conclusion

The present study tested simple color-coded visual feedback for training appropriate following distance. This investigation indicates that: (1) real-time visual feedback of following distance is effective in improving following distance behavior (2) visual feedback immediately affects indirect driving behavior due to receiving feedback multiple times during a trip (3) effectiveness of visual feedback is dependent on individual differences in driving skill. Visual feedback will be more effective to driver who has risky driving behavior.

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Electromyography (EMG) as a Tool for Computerized Psychomotor Test Validation

Wenjuan Zhang, Manida Swangnetr, Peter Bloomfield and David Kaber

Abstract Standardized psychomotor tests are commonly used to evaluate human motor and cognitive skills. Computerization of these tests can promote ease of administration and data collection. However, computerized versions of tests are typically validated via performance measures. In this study, a virtual reality (VR) based simulation of the Block Design (BD) test (a standardized psychomotor task as part of the adult IQ test) with a haptically-enabled control was developed and compared with a physical version of the test. Electromyography (EMG) measures of forearm and thumb muscle activation levels were used to assess the validity of the simulation from a muscle use perspective. Results revealed comparable muscle activation levels between the VR-based task and the conventional BD test. Validation of such of a simulation of psychomotor testing promotes application of computerized psychomotor tests in experimental and clinical studies.

Keywords Virtual reality · Psychomotor tests · Electromyography · Hand motion

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1 Introduction

Psychomotor tests, or human performance tests involving cognitive and motor processing, are commonly used to diagnose cognitive and/or motor impairments, serve as mechanisms for skill training, and predict psychomotor abilities [1]. The Block Design (BD) test, developed in the 1920s [2], is a classical psychomotor test that has been used frequently by researchers for almost 100 years. In this test, participants are required to arrange colored blocks in order to construct an identified pattern. The test requires the use of spatial ability in positioning an orienting blocks in order to ensure that the combination of colored block faces accurately reproduces the target pattern. The BD task is frequently presented as a subtest on the Wechsler Adult Intelligence Scale (WAIS) for measuring visual-spatial abilities [3].

Recent research has observed benefits of using VR technology to automate psychomotor tests by integrating three-dimensional display technology and haptically-enabled control interfaces [4–6], including collection of additional human performance data that would be difficult to capture through direct observation of participant native task performance [7, 8]. Related to this, in a previous research project, we developed a haptic-based VR simulation of the BD test based on the WAIS BD protocol [7]. The VR-BD program provided recording of block and control cursor trajectory data at a frequency of 10 Hz. The pattern of user behavior in reconstruction of any block design can be played-back through the VR system and analyzed in terms of performance variables, kinematic responses, etc. In addition to superior data collection features, the use of haptic controls can facilitate motor performance by patients with impairments in situations when real object manipulation would be difficult, if not impossible (see Fig. 2 for example of haptic control use with the VR-BD task interface). We also conducted several follow-up studies using this VR-BD program and demonstrated the simulation to be comparable to the physical form of the BD task in terms of the BD test score, task completion time, and a strategy index score [9]. However, no prior investigations have involved biometric analysis of computer-based simulation of such psychomotor tests.

Electromyography (EMG) is a well-accepted tool for analysis of motor task performance. Recent studies have also used EMG to provide patients with sensory feedback and promote motor learning. As a reliable measure of muscle activity, EMG techniques allow for accurate analysis and clear understanding of motor control patterns. Such measures may be complimentary in nature to any subjective and performance-based evaluation of motor performance. While subjective evaluations and performance measures can be influenced by a subject's personal life experiences or psychological states, muscle activity simply provides information on how a subject reacts to a physical task stimulus. For this reason, the present study used EMG to further investigate if use of the VR-BD test should be populated in clinical practice and experimental research.

The objective of the current study was to use EMG responses as a form of biometric validation of the VR-BD test as being comparable to its established

physical form. It was expected that the VR-BD test and the physical task would pose comparable challenge to participants and comparable muscle activation levels in various phases of movement (rotation and honing motions).

2 Method

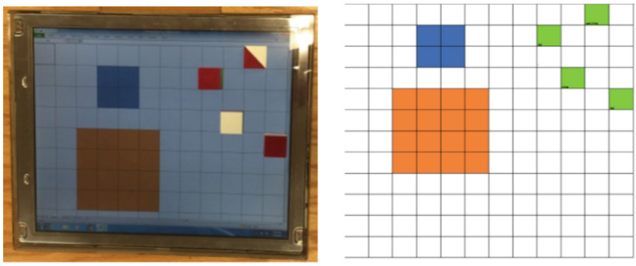
2.1 Participants

Twenty-four right-handed participants were recruited from the North Carolina State University and local community populations for the EMG study. Participant age ranged from 19 to 46 years (mean = 26.4; standard deviation = 6.5). All participants were required to have 20/20 or corrected vision (if corrected, they were asked to wear their glasses or lens while performing the tasks) and to have neither current nor chronic wrist disorders (e.g., carpal tunnel syndrome). All criteria were confirmed in a screening step prior to scheduling an experiment session. All participants signed an informed consent form prior to experiment testing and were compensated by cash at a rate of $15/h.

2.2 Task

Participants were assigned to perform one of the two versions of the BD test, including the VR-BD test or the native BD test. Administration of the tests followed the Wechsler Abbreviated Scale of Intelligence (WASI) [10] protocol. Designs 4–9 of the WASI booklet were used as stimuli and required participants to use four colored blocks to reconstruct design patterns. Each participant repeated the same set of six designs (in random order) with three repetitions. A short break (5 min.) was provided in between each set. Participants were instructed to complete each trial as quickly and accurately as possible.

In order to complete the BD test, participants must perform simultaneous translational and rotational movements (i.e., moving a block to a specific position while rotating it to reveal a desired top surface). Consequently, we inferred that arm muscle activation levels would be influenced by the degree of challenge experienced by participants in the different types of movement as part of the test. On this basis, some modifications were made to the BD task protocol described above. In both the native and VR test conditions, a specific workspace was identified in which participants were required to perform rotation of blocks for ultimate placement in an assembly grid. (See Figs. 1 and 3 for block rotation areas, shown in “orange” and “taupe”, respectively). Participants were instructed to not perform block rotation in any other task space. When participants moved a block out of the rotation space, they were permitted to only perform transitional movements without changing the



(a) Native BD workstation (b) Location indicators in Excel

Fig. 1 Custom workstation for native BD test

orientation of the block. This constraint was added to the original WASI protocol in order to separate the rotation of blocks from the positioning or honing phase (i.e., transitional movement). This approach was necessary in order to facilitate accurate EMG analysis of specific muscle use during task performance. Definition of the rotation space ensured that muscle responses while reorienting blocks could be analyzed and compared separately from responses collected during block displacement. Related to this approach, prior research has also demonstrated that separating combined movements into pure translational movement and pure rotational movement does not significantly increase time-to-task completion [11].

2.3 Apparatus

Native BD Task. A custom workstation with a flat-screen monitor was mounted in a wood tabletop and was used as a basis for performing the native BD task (see Fig. 1). An Excel file (see Fig. 1) was presented on the display with highlighted cells indicating starting block positions, a destination grid, and block rotation area for participants. The green cells in Fig. 1 show where the blocks were initially located. The orange area served as the rotation area. The blue grid represented the target area where participants were asked to position blocks according to the designated design pattern. All block positions presented on the display were consistent with those in the VR version of the task. In order to precisely observe participant performance, a Logitech® HD Webcam C525 was mounted on the ceiling of the lab on a rack directly above the monitor in the table. Prior to each trial, participants were asked to sit erect and a goniometer was used to help them flex their neck by 20°, which is a comfortable posture for performing the BD task. (In the VR-BD task simulation, the position of a virtual worktable was adjusted to achieve the same viewing angle.) While performing the task, the muscle activation of participants was recorded (see Sect. 2.4 below for details on the EMG methodology).

VR-BD Task. The VR interface was presented on a high performance PC integrated with a stereoscopic display using a NVIDIA® 3D Vision™ Kit,

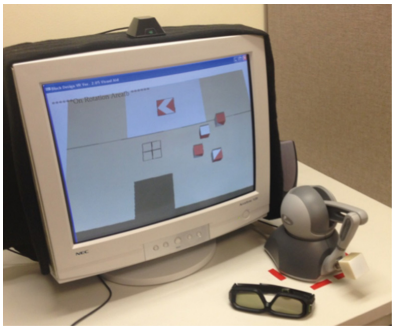


Fig. 2 Virtual reality workstation for BD test

including 3D goggles and an emitter (see Fig. 2). Stereoscopic rendering of the task simulation was supported by an OpenGL quad-buffered stereo, high-performance video card (NVIDIA® Quadro™). A SensAble Technologies PHANTOM Omni® Haptic Device was used as the haptic control interface and was integrated with the PC. The Omni includes a boom-mounted control that supports 6-degree-of-freedom (DOF) movement and 3-DOF force feedback. The conventional stylus control of the Omni was replaced with a custom "block-shaped" hand control that we designed and prototyped based on the dimensions of real BD task blocks. The block control was made of a high strength plastic and included electronics; a push-bottom with a wiring-harness integrated with the existing Omni sensor electronics. The haptic interface automatically recorded participant movement behavior (rotations and translations) at a frequency of 10 Hz.

The VR-BD simulation presented a virtual tabletop divided into two parts, including a display area and a work area (see Fig. 3). The display area presented the stimulus design patterns to be replicated by a participant. The work area was used for arranging the virtual blocks. The work area and blocks were presented at approximately 70 % of actual size in order to allow the design pattern and work-space to be viewed on a 21-inch stereo monitor. The view angle of the work area was set to 70° from horizontal for a condition comparable to participant view angle

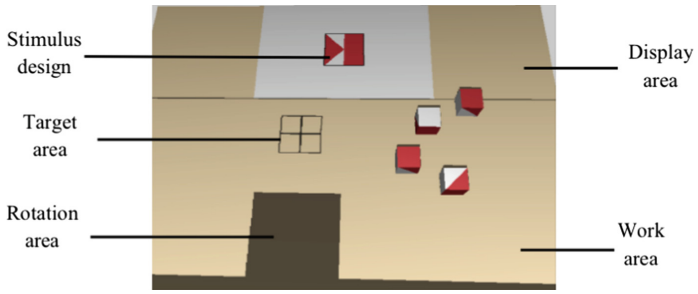


Fig. 3 VR-based BD test simulation

of the flat-screen monitor in the native task condition with 20° of neck flexion. Similar to the native version of the task, all BDs were constructed with the aid of a target grid, which appeared as a 2 × 2 collection of squares in the work area. A "taupe" shaded area was presented at the bottom of the display to identify for participants the block rotation area in the virtual task.

Each participant assigned to perform the VR-BD test was required to also complete a dice-manipulation training task before the formal experiment. This program was designed to familiarize participants with use of the haptic control, including the block-shaped interface, for manipulating virtual blocks. Participants were trained in the task for proficiency with the VR system. In every trial of the dice-training task, a single virtual die was presented near the center of a display on a virtual work surface. A two-dimensional stimulus (image of a die face) was presented at the top of the display area. The participants were instructed to move the virtual die as quickly and accurately as possible to a target square near the right bottom of the work surface, with the top surface of the die matching the stimulus. This training program was developed in a prior study [12] and proved efficient in familiarizing participants with the haptic device through a series of 40 trials. Pilot testing of the training program as part of this research revealed no significant fatigue effect due to the device training; therefore, only participants under the VR condition were required to complete this part of the experiment protocol for experimental efficiency.

2.4 EMG Measurement

Four muscles were identified for measurement in this study, including the flexor pollicis brevis (CH1), pronator teres (CH2), flexor carpi ulnaris (CH3) and extensor carpi radialis (Ch4). The flexor and extensor muscles were selected for analysis as they are used in gripping blocks and for positioning at target squares, as part of the task. The pronator muscle was also selected as it is used in block rotation. Muscle activation data was recorded using a BIOPAC® MP 150 system. Disposable Ag/AgCl electrodes (with circular contacts of 11 mm diameter and square cloth backing) were used. For each participant, eight electrodes were mounted across four muscle positions, with two electrodes placed at 2 cm apart for each muscle. One electrode was mounted at the elbow as a ground. All electrodes were then connected to the system amplifier using leads with standard snap connections. Four amplifier modules were cascaded together, providing four channels of muscle output. The signal gain was set to 2000x. The amplifier system was connected to a laptop computer using a 2 m Ethernet crossover cable (CBLETH2). Raw data was recorded with the "AcqKnoweldge 4.2" software. The EMG data was collected with a sampling rate of 1000 Hz. All responses were preprocessed with a fourth-order Butterworth filter (high-pass filter set as 20 Hz and low-pass filter set as 450 Hz) and notch filtered at 60 Hz (to remove power line interference).

The screened data was then rectified and averaged across 50 ms intervals for smoothing purposes. Mean values of EMG amplitudes for each trial were calculated to represent overall muscle activation under the different experimental test conditions.

2.5 Experimental Design and Variables

This study followed a between-subjects experiment design in which each participant was randomly assigned to either the native or VR test condition. The two BD test conditions served as setting of the experiment independent variable. Under the native condition, participants performed conventional BD pattern reproduction using physical blocks. For those persons assigned to the VR condition, design reproductions were performed using the simulated test program with the custom block-shaped haptic control interface. The activation levels of the four muscles collected under the two experimental conditions served as dependent variables. It was expected that the hand and forearm muscle EMG responses would be comparable under the native and VR task conditions, as reflected in EMG signal amplitudes.

3 Results

Diagnostics on the EMG responses revealed normality violations for parametric analysis. Appropriate transformations were attempted but they were not successful. Therefore, the EMG responses were ranked and submitted to parametric procedures to perform non-parametric analysis.

Descriptive statistics of muscle activation are summarized in Table 1 with grouping by test condition (native vs. VR) and phase of movement (rotation vs. honing). On average, muscle activation was greater during the rotation phase, as compared to honing, under either test condition. With the exception of the flexor

Table 1 Descriptive statistics summary for EMG responses (% of MVC)

	CH*	Honing		Rotation	
		Native	VR	Native	VR
Mean (SD)	1	4.97 (6.24)	2.23 (1.53)	11.06 (9.78)	7.25 (3.82)
	2	0.83 (0.53)	0.90 (0.59)	1.92 (1.51)	2.57 (1.19)
	3	0.71 (0.55)	0.90 (0.71)	1.79 (0.93)	2.81 (1.82)
	4	1.62 (0.89)	1.64 (1.05)	4.04 (1.62)	4.58 (1.94)

*CH1—Flexor pollicis brevis, CH2—Pronator teres, CH3—Flexor carpi ulnaris, CH4—Extensor carpi radialis

pollicis brevis, all muscles showed similar levels of response between the native and VR test conditions.

To further analyze the EMG responses, a MANOVA test was conducted with the objective of identifying any significant effects of test condition and phase of movement. Although each participant performed three trials of the BD task under the native or VR test condition, the MANOVA revealed no significant trial effect (see Table 2). These results indicated no significant occurrence of participant fatigue during the experiment trials. Despite the absence of a trial effect, significant differences were detected between the rotation and honing phases of movement for the EMG responses (see Table 2). Based on this result, response data for the two phases of movement were separated for further analysis.

For each phase of movement, a MANOVA was applied to the EMG responses in order to detect any significant effect of test condition. As shown in Table 3, no significant differences were detected between the two conditions. That is, the two versions of test yielded similar EMG responses within the rotation and honing movements.

In order to identify any potential differences in activation levels among muscles within each phase of movement, a two-way ANOVA was applied with muscle type and test condition group as predictor variables. The ANOVA results are summarized in Table 4. In the statistical model, the test condition was treated as a between-subject factor while the muscle type was a within-subject factor. Significant differences were revealed among the four muscles under both phases of movement. Consistent with the previous MANOVA results, there was no main effect of test condition on the EMG responses in the honing phase or in the rotation phase. There was, however, a significant effect of interaction between the test condition and muscle type.

As an extension of the ANOVA results, post hoc analyses were conducted on the EMG responses for each muscle type within the specific phases of movement by using the Tukey-Kramer test method. Figure 4 presents bar charts of the EMG responses across muscles. Those response values appearing with the same grouping letter (e.g., "A", "B") are not significantly different, one from the other. For the pronator teres (CH2), flexor carpi ulnaris (CH3) and extensor carpi radialis (CH4), native and VR test condition responses appeared comparable. For the flexor pollicis brevis (CH1), EMG responses were significantly higher under the native condition as compared to the VR condition ($p = 0.0003$ under honing phase; $p = 0.0045$ under rotation phase). In addition, the pollicis brevis (CH1) showed significantly higher activation levels than any of the other three muscles within either phase of movement ($p < 0.0001$).

Table 2 MANOVA results on trial and phase effects

	Wilks' Lambda	F value	P value
Trial effect	0.9772	F(8, 226) = 0.33	0.9550
Phase effect	0.2520	F(4, 113) = 83.84	<0.0001

Table 3 MANOVA results on test condition effect

Honing Phase	Wilks' Lambda	F value	P value
	0.8302	F(4, 19) = 0.97	0.4461
Rotation Phase	Wilks' Lambda	F value	P value
	0.7862	F(4, 19) = 1.29	0.3085

Table 4 Two-way ANOVA results on test condition (C) and muscle (M) effects within phase of movement

		ANOVA Statistics
Honing phase	Condition (C)	$F(1, 22) = 2.43$, $p = 0.1330$, $1\text{-}\beta = 0.3203$
	Muscle (M)	$F(3, 258) = 24.02$, $p < 0.0001$, $1\text{-}\beta = 0.9461$
	C M	$F(3, 258) = 7.08$, $p = 0.0001$
Rotation phase	C	$F(1, 22) = 0.39$, $p = 0.5365$, $1\text{-}\beta = 0.0923$
	M	$F(3, 258) = 52.85$, $p < 0.0001$, $1\text{-}\beta = 0.9998$
	C M	$F(3, 258) = 6.53$, $p = 0.0003$

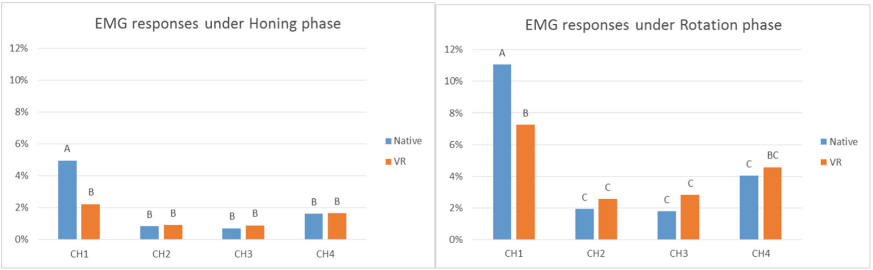


Fig. 4 Results of post hoc analyses on EMG responses

4 Discussion

It was expected that EMG responses would be comparable in completion of the BD task under native and VR conditions. This hypothesis was supported by the results. No significant differences were found in EMG responses for both the honing and rotation phases, indicating a comparable magnitude of muscle activation in task performance when using the VR workstation versus native task setup. (Related to this finding, posterior power of test values ranged from 0.09 to 0.32.) This suggested that participants used their forearm muscles in a similar way when interacting with the physical blocks in the native BD task and the virtual blocks in the VR-BD task. This result is important from a rehabilitation perspective as correspondence of muscle activation levels across the VR and native BD tasks would be

more critical to motor skill development than any performance based measure, such as BD test score or task completion time.

Whitman et al. [13] used a lumbar motion monitor to capture maximum lateral velocity, maximum sagittal velocity, maximum twist velocity, maximum lateral acceleration, maximum sagittal acceleration and maximum twist acceleration during lifting tasks in a virtual environment (VE) and real environment (RE). However, they concluded that performance in virtual and real environments was not comparative. The fidelity of their virtual environment was identified as a cause for the discrepancy. In the present study, the visual display of the VR-BD was of a high fidelity and the novel haptic control interface modeled the shape and size of blocks handled in the real task. These features likely contributed to the comparativeness of behavior in the VR and native versions of the BD task. In addition, Whitman et al. measured and evaluated different types of physiological responses than those recorded in the present study. It is possible that the degree of sensitivity to test conditions may vary among different measurements. It would be valuable to use other forms of measurement, such as fine motion tracking, in order to extend the present study.

During a simulated simple assembly task, Pontonnier et al. [14] collected EMG responses on five muscles, including the erector spinae (back extensor), deltoideus medialis (shoulder abductor), biceps brachii (forearm supinator and elbow flexor), triceps long head (elbow extensor and shoulder stabilizer), and flexor carpi ulnaris (wrist flexor and adductor). They found significant differences in average muscle activities (AMAs) for different types of task interaction, including use of a VE versus a RE. However, there was significant correlation of AMAs measured in the RE versus VE, indicating that despite the reported discrepancies between the VE and RE, the trends of the AMAs were the same across the various task manipulations. This conclusion is consistent with the findings of the present research, which provided physiological evidence supporting use of the VR-BD task in a manner similar to the native BD task.

Comparisons among muscle responses revealed the flexor pollicis brevis to produce significantly higher activation levels as compared to the other three muscles under both test conditions. This result was due to the important role the thumb played during grasping, holding and rotating blocks (or in use of the block-shaped interface at the haptic device).

Beyond this finding, there was an interesting trend in muscle activation between the test conditions. On average, the forearm muscles (pronator teres, flexor carpi ulnaris and extensor carpi radilis) all showed higher responses under the VR condition. However, opposite to this, the thumb muscle (flexor pollicis brevis) showed relatively higher activation under the native test condition. Such difference in the pattern of performance suggested that the flexor pollicis brevis might be used more often in performing the native BD task, which was likely a result of physical task behaviors. Participants could easily control blocks with the thumb and slight movements of other fingers, especially during the rotation phase. While doing this, it was possible for participants to hold their elbows still. However, in order to manipulate a virtual block with the haptic control device, participants usually had to

drag the block-shaped control in order to position the virtual block at the target grid area. In addition, while rotating virtual blocks with the haptic control, the required magnitude of movement of the forearm was larger than in the native BD task. Therefore, both the thumb and forearm were used to move the virtual block to the target area with the desired orientation. In addition, the haptic device had a rotational limitation preventing participants from rotating a virtual block in only one direction in order to achieve all possible faces for placement. This behavior was, however, possible with a physical block in hand. With such a constraint, participants had to twist their forearms while rotating the block-shaped control device in order to complete the VR-based task. Considering the fact that the set of muscles observed in this study revealed no substantial differences in activation between the VR and native conditions, it is possible that in the VR test condition, the three forearm muscles served as compensation to the loss of freedom at the thumb in use of the haptic device. This situation likely alleviated otherwise heavy reliance on the flexor pollicis brevis, observed in the native BD test performance. This finding provides us with some information on how to further improve the VR-BD task as a simulation of native task performance.

5 Conclusion

The objective of this research was to assess the validity of a VR-based simulation of a standardized psychomotor test from a biometric perspective. In contrast to prior investigations focusing on performance based (product-oriented measurement) validations, this study focused on muscle responses (process-oriented measurement) as a complementary approach to simulation evaluation. A between-subjects experiment was conducted in which performance under two test conditions (VR vs. native) was compared on the basis of the muscle activation (EMG) responses of four muscles used in task performance. Results of the experiment suggested that levels of forearm muscle activation were comparable across the two test conditions (the native BD task vs. the VR-BD task).

On the basis of these findings, we infer that it is possible to develop computerized-versions of standardized psychomotor tests to facilitate objective and systematic evaluation of motor control as well as to provide a platform for training and learning of fine motor skills from a process perspective. Another conclusion is that custom design of haptic control interfaces can lead to levels of muscle responses in VR-based simulation of psychomotor tasks comparable to native task performance. Therefore, the computer-based simulation evaluated in the present study may allow users to achieve similar levels of skill rehabilitation as native tasks.

Another application of the simulation in the present study could be motor skill development in abled persons for complex assembly tasks in industrial environments. Ma (2014) recently found the VR-BD simulation to have utility for worker training in manual assembly requiring fine handwork with small objects (e.g., iPhone assembly). Furthermore, it is possible to classify individual motor ability

level with data from such computerized psychomotor performance tests. This information can be used as a basis for prescribing motor control training regimens for specific levels of performance in assembly tasks [15].

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Part XI
Ergonomics Strategy

How We Can Create an Ergonomic Culture in a Company: An Application in Turkey

Gizem Akalp and Ahmet Fahri Ozok

Abstract Nowadays, many organizations make a great effort to reduce workplace risk, prevent injuries and promote safety and awareness. As it is known, the emphasis is both muscular and mental work in Workstations, as well as the Occupational Health and Safety and foremost the work science that can be contributed is very important for the efficiency of ergonomics. When it comes to reducing ergonomic injuries-soft-tissue injuries, musculoskeletal disease and others that are extremely prevalent and costly for many companies-developing the correct culture is especially important. The aim of this study is to present an ergonomic culture implementation in a chemistry company in a city in Turkey. We implemented some ergonomic improvements in the company and we gave cultural seminars on ergonomics all blue color workers are participated in this theoretical and practical approach. Among the obtained results; Teaching of ergonomic principles to all employees are tested. Applications in pilot workstations are also checked to be satisfactory. By the way some ergonomic instruments are developed.

Keywords Occupational health and safety · Ergonomic participants · Muscular work · Ergonomic culture · Work load level

1 Introduction

Rapid developments in technology brought by globalization have increased the use of technology-intensive industry. This gives acceleration to the human-machinery relationship in the business life. The increase in mechanization and automatization

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raises the work speed as well. On the other hand, labor-intensive production still continues, and a lot of physical problems are experienced. Though there is a "so-called" decrease in the burden loaded on human body thanks to rapid technological advancements and increasing mechanization, musculoskeletal disorders in industrially-developed and developing countries are still one of the most important diseases as a result of occupational expectations [1]. This is accompanied by financial losses. These losses affect not only individuals but also organizations and societies as a whole. Therefore, it is important to perform the risk analyses of job requirements and detect the factors which lead to physical overloading before such disorders develop.

The recent industrial boom has created a need for science of ergonomics, which coordinates relations between human beings, machines, and working environment. It has become clear that there is a need for ergonomic practices to increase productivity.

Planned and systematic studies regarding occupational health and safety protect the future of the employees and businesses. Therefore, businesses should initially adopt and maintain the principle of "health and safety come first" in order to have a more effective and efficient working life both for employees and businesses. This is only possible through creating a culture of ergonomics.

Kaplan (1995) described the interplay between culture and work, describing culture as the mediator between the user and the system or technology. Referring to culture in the sociological sense, it is the aggregation of values, experiences, beliefs, and attitudes. Culture is communicated through constructs developed by the social group [2]. Constructs are ideas that have a shared meaning and are products of the cultures that define them. In that regard, culture is a prominent factor within the social ecology affecting the meaning and representations assigned to such constructs as words, symbols, and colors used in safety communications [3].

Ergonomics is concerned with the 'fit' between people and their technological tools and environments. It takes account of the user's capabilities and limitations in seeking to ensure that tasks, equipment, information and the environment suit each user.

With the subject matter of ergonomics increasingly broadly conceived, a need is suggested for the systematization and codification of cultural influences on the wide-ranging elements of the field. Pertinent types of systematic analysis, basic and applied research, and training are viewed as necessary, both to generate new knowledge, and to develop culturally appropriate user applications that are important for varied work environments world-wide [4]. Ergonomics is so important to the business: when every employee is a linchpin, their health and well-being equates directly to the health and well-being of the company [5, 6].

The purpose of this study is to introduce an ergonomic perspective to the corporate culture through Ergonomics Training and Practices, thereby raising employees' satisfaction and productivity. In addition, it was made compulsory to abide by ergonomic principles in all the works to be performed within the company from then on. Moreover, a core ergonomics group was formed within the company to place a careful ergonomic validity criterion for all the works to be done.

2 Purpose and Method

This ergonomic study was conducted in a business which was in high danger group and had 32 employees. With this study, an attempt was made to adapt ergonomics principles, which had not been thoroughly adopted up to that time, into the corporate culture in an 8 month period. The business is located in one of the largest industrial cities of Turkey. It has foreign shareholders. It was founded in 1883 with its headquarters in Pittsburgh, USA. The company is the global supplier of dye, optic products, special materials, chemicals, glass, and fiberglass. It has more than 140 production plants, and its affiliates are active in more than 60 countries. Participatory ergonomics method was employed in this study to introduce the consciousness of ergonomics and raise an awareness regarding this issue. Hence, it became possible to implement a program participated and approved by both blue-collar and white-collar employees. Moreover, various ergonomic problems encountered in all aspects of life were scientifically discussed during the training. In this way, an attempt was made to raise ergonomics awareness among the employees.

2.1 Procedure

The steps below were followed to introduce ergonomics into the business: 1. Training, 2. Selection of pilot workstation, 3. Data collection and evaluation, 4. Developing solution options, 5. Application of selected solution, 6. Maintaining sustainability by generalizing the results.

The first phase involved creating 2 training models with different contents taking into account employee profile and functions. These are “White-Collar Training” and “Blue-Collar Training”. All the ergonomics training provided within the company was fulfilled with a participation rate of 80 %. The training given at the beginning of the application was repeated three times for blue-collar staff to create a real awareness among them.

The second phase involved the implementation of participatory ergonomics principles and the application of the theoretical knowledge, which was taught through training, by the staff and manager of the relevant workstation. Meanwhile, the views of the employees working in that workstation were taken in person. Data was collected in order to optimize the workstations in accordance with occupational health & safety and quality & productivity principles. During the works, the appropriateness of all the dynamic and static criteria of the relevant workstation to the body measurements of the employees was examined in terms of body position, leaning, the difficulty of carrying load and equipment, strains in the movements of organs such as head, hands, arms, and legs, and the existence of adequate volume. Maximum attention was paid to the examination of the forces to be applied in the

course of working either standing or sitting and while carrying the loads (with hands). Quick Exposure Check method was used in the workstations.

Selection of pilot workstations: Selection was made at the end of the field trips in which production managers and occupational health and safety manager also participated. Prior to the selection, photographs were taken and videos were recorded to observe natural flow of works done in the workstations, which resulted in sounder detections. The photographs and videos were evaluated with the operators performing the works. The errors in the records were discarded. Three stations were chosen following these selections. (A) Phosphate production station, (B) Grinder group, (C) Solvent-based production station.

2.2 Ergonomic Analysis

(**A**) **Phosphate Workstation**. The production of phosphate, which is conducted once or twice a week, is carried out by using a mixture of 450 kg on the average. However, there are times when 2 tons of mixtures are used. The temperature of the product may rise up to 60–65 oC. There is a need to keep the temperature under control constantly. After raw material is supplied, exothermic reaction starts, and the temperature rises. There is a cooler around the tank. Cooling water circles the tank. There is an indicator, and the valve activates when the temperature exceeds 40oC. During the chat with the operator, the operator stated that his job is a stressful one. The stress stems from keeping temperature under control and the constant need to check the indicators, which creates a high pressure on him.

Environment. The analyses carried out in the environment indicated that it was an appropriate environment in terms of physical effects such as noise, temperature, and thermal comfort. In other words, it was determined that there is no unnecessary risk in the environment. The operator uses the appropriate personal protective equipment during the work. The operator has an apron and a filtered powder machine.

Muscular Activity. During the work, there are dynamic and static muscular activities performed via heavy or light muscular groups. There are also movements of constant leaning, rising, and twisting. Since there is no lift system, the operator lifts the powder sacks by leaning on the palette. He carries the 25 kg sacks by performing inappropriate movements during this work.

Environmental Conditions. Though the temperature of the environment is appropriate for heavy muscular activity in winter, the employees complain about the hotness and excess humidity in the environment in summer. No inappropriateness to influence the performance was observed in terms of vibration, illumination, noise, etc.

According to the results of the "Quick Exposure Check" conducted in this workstation, the employees are in very high risk group in terms of musculoskeletal disorders (42/41–56) and are in high risk group in terms of shoulder and arm disorders (36/31–40). They are in medium risk group in terms of wrists and hands

(26/21–30) and are in low risk group in terms of performing work constantly (1/4), vibration (1/4), and difficulty in continuing a work (1/4). They are also in high risk group in terms of stress level (5/9).

Generally speaking, serious problems may be experienced in the musculoskeletal system given the inadequacy of movements. There is a need to make certain changes in this workstation. The operator experiences strains while leaning and lifting the sacks discharged into the tank from the ground. Therefore, the sacks should be elevated to the operator's waist level via a scissor lift. Since this task is carried out once or twice a week, this equipment may not have been deemed necessary initially. However, serious musculoskeletal system disorders (MSDs) will emerge if this act is performed frequently.

After all these examinations, the necessary actions started to be taken in this production station, which is noteworthy for the ergonomic risks it has. The first steps were taken to establish a lift system. Following the negotiations within the company, some organizations which can supply such a system were contacted. The production offer was approved by the company and started to be used. Figure 1

(**B**) **Grinder Group**. This group performs grinding operations. There are 4 different grinding machines in this workstation. It was determined that the total cycle time of a grinder in this workstation is 1 h and 20 min. Powder-throwing was analyzed in detail as it particularly involves ergonomic strains. Quick Exposure Check was conducted.

According to the Quick Exposure Check results regarding the grinder group, the employees are faced with certain ergonomic risks. They are in high risk group in terms of musculoskeletal disorders (38/31–40) and shoulder and arm disorders (36/31–40). They are in medium risk group in terms of wrists and hands (22/21–30) and are in low risk group in terms of performing work constantly (1/4), vibration (1/4), difficulty in continuing a work (1/4), and stress (1/9).

Given the inadequacy of the movements of the employees working in this workstation, it is clear that serious problems may be experienced by them in their musculoskeletal systems. The use of a lift system leads to lower general Quick

Fig. 1 Phosphate production station

Fig. 2 Grinder group

Exposure Check values in grinder groups compared to phosphate production stations. However, that employees carry 25 kg sacks in 4 steps to empty them may lead to musculoskeletal disorders that stem from lifting weights. A vacuum-lift system or a carrying system that will be established on the gate with a conveyor scissor may prevent employees from lifting these weights (Fig. 2).

(**C**) **Solvent-Based Production Station**. The production of PMC, which is a new product, was launched in this station within the framework of works for creating product variety. In this production, firstly powder was thrown into the boiler, and then the products mixed in the mixer were filled in the buckets. Ergonomic evaluations were made in the works performed during the test of the production of the products.

According to the results of the 'Quick Exposure Check' conducted for powder-throwing in this workstation, it can be said that the operator is in high risk group in terms of musculoskeletal disorders (38/31–40). It can also be stated that he is exposed to a medium ergonomic risk in terms of shoulder and arm disorders (28/21–30) and to a low risk in terms of wrist and hand disorders (4/2–6), performing work constantly (1/4), vibration (1/4), difficulty in continuing a work (4/4), and stress (9/9).

The evaluations made during the powder-throwing act are as follows:

- Anthropometric measurements are not appropriate.
- To get the distant bags, he has to pull them while the upper body leaned. This is a movement that strains the musculoskeletal system to a considerable degree.
- The platform area was determined to be narrow. This area has to be doubled at least.
- Among the handrails around the portable platform, the one on the right side may prevent working.
- Workers usually work at 0.7–0.8 tempo level. Two people may work during the discharge of bags. Work should be properly organized so that workload is not very straining, even accidentally.

Fig. 3 Solvent-based production station

- There must definitely be information exchange with workers during the design of any assembly, apparatus, platform, etc. to enjoy ergonomic principles. Operators should be put to work, and the critical points of the design should be determined based on the obtained data in advance.

Another important point is to ensure that ergonomic principles are always taken into consideration in the courses of conduct within the business as a basic culture. A continuous effort must be made to achieve this (Fig. 3).

By taking into account the anthropometric measurements appropriate to 90 % of the employees with normal distribution, an attempt was made to ensure that the workstation would be adjustable based on static and dynamic measurements. After necessary arrangements were made, portable ladders started to be used in the company (Fig. 4).

Fig. 4 Solvent-station improvement

3 The Monitoring and Evaluation of Application Results

The results obtained should be reevaluated after the best solution option selected in the applied ergonomics project is put into practice. Necessary corrections should be made after the outputs acquired through a system which is just like an automatic control system are compared with target values. It should always be remembered that job simplification and the design of excellent workstations are a continuous journey. Hence, it is clear that an ergonomics commission that is made up of production operators and senior production and laboratory staff must ensure sustainability in ergonomic convenience through joint and participative work whenever a new apparatus is to be purchased or a new project is to be developed within the scope of ergonomic improvement and placement within a specific corporate culture.

4 Results and Discussion

During the practices performed for 8 months within the scope of an applied ergonomics project, firstly training was provided, then solution suggestions were developed through participative ergonomics methods, and after that the suggestions of all participants were taken into consideration, thereby carrying out the best solution possible. It can be said that a model of this sort has a lot of benefits. Core knowledge is consciously internalized by all participants and is reinforced through practices. Moreover, as the concept of ergonomics is intensely featured throughout the project, it is possible to take ergonomic criteria into consideration for every activity in the business in the long term. A successful implementation of a project of this sort is one of the important instruments of continuous improvement, which is one of the basic principles of total quality management.

At the end of this study, it is recommended to review ergonomic knowledge periodically and monitor practices carefully within the scope of ergonomic training, just like in training in other fields.

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Including Ergonomics Aspects into Mixed-Model Assembly Line Balancing Problem

Fabio Sgarbossa, Daria Battini, Alessandro Persona and Valentina Visentin

Abstract Not considering ergonomics in the assembly systems can bring to sub-optimal solutions and, in case of high levels of ergonomics risk in the tasks execution, several musculoskeletal disorders affecting the global performance of the assembly line. Several papers have been developed in the last years about how to integrate the ergonomics aspects into traditional Single Assembly Line Balancing Problems (SALBP). In this paper, we have extended our recent integrated ergonomics approach to the Mixed-model ALBP (MALBP), where many products are processed in the assembly system in the same period. First, a theoretical model has been developed in order to simplify the MALBP into SALBP, under time and ergonomic approaches. Then the behavior of the assembly system with the real products has been evaluated in terms of time smoothness and ergonomics levels. General discussions and future agenda will be introduced at the end of the paper.

Keywords Mixed-Model assembly line balancing problem · Ergonomics · Energy expenditure · Multi-Objective optimization · Pareto frontier

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1 Introduction and Literature Background

Assembly Line Balancing Problem (ALBP) consists in assigning assembly tasks to several stations optimizing goals, such as time, cost and profit, under particular constraints (cycle time and other restrictions) as well as precedence relations are met. In recent years, the study of manual ALBP has received particular attention from both academics and practitioners, and especially the integration of ergonomics while designing and managing the assembly systems.

Three different methodologies to put in practice Assembly Line Balancing problem are described in literature [7, 12]: single-model assembly line balancing problem (SALBP), batch-model assembly line balancing problem (BMALBP), mixed-model assembly line balancing problem (MALBP).

As described in [1], to solve these line-balancing problems it is necessary to take into account different kinds of constraints (such as assignment or cycle time constrain). The solution methods might be exact methods, simple heuristics, metaheuristics and the way to search for a compromise for two or more conflicting objectives is the multi criteria approach: lexicographic resolution, fuzzy goal programming and Pareto based ranking.

In the last years, referring to the design of the system, many studies have highlighted the relevance of taking into consideration the ergonomics aspect and many of them have based their approaches in traditional ergonomics evaluation methods, such as OWAS or OCRA. So in order to take into account the ergonomics aspect into these kinds of balancing problem, it is necessary to put in practice one of these multi criteria approaches. Please refer to [4] and [5] for comprehensive literature review.

In Battini et al. [2], the author explains how much the right choice of the design of the assembly system might influence the ergonomic conditions of operators, preventing musculoskeletal disorders. This strong relation between production routines in assembly and ergonomics condition (causing lower productivity of operators, absenteeism and higher defect rate) is also noted in [10], in which through a two-stage heuristic approach and the simulated annealing ergonomic risk is incorporated into assembly line balancing problem. A similar scope is followed in [6], whose proposal is to take ergonomics problems into account into a T-SALBP.

Despite the SALBP, in literature also the mixed model assembly lines are deeply analyzed, evaluating different balancing strategies such as making a join precedence diagram in order to turn the MALBP into SALBP [8] but the energy issue, related to ergonomic conditions, has never been faced.

The aim of this paper is to continue the research of the authors developed in Battini et al. [4, 5], in which the ergonomic level of each assembly task is evaluated thorough the formulation of Garg, Chaffin and Herrin [9] based on energy expenditure rate and a multi-objective ALB model (considering both time and energy) is implemented in order to evaluate what is the effect of moving from a time-optimal solution to the energy-optimal solution. The same approach of solving this bi-objective system (where two functions are analyzed and minimized,

typically time efficiency function and ergonomic level of the systems) with the Pareto Frontier [11] is put in practice in this paper, but the focus is not a single model but a mixed model assembly line, in which many products are processed in the assembly system in the same period.

A theoretical model has been developed and applied to a simple case study. First we have defined a joint precedence graph in order to transform the mixed-model ALBP in a SALBP [8, 13] and to obtain a virtual average model under time and energy approaches which could simulate the set of different products and the previous SALBP model has been applied to solve the problem. It isn't easy to evaluate the behavior and the efficiency of a mixed model assembly line so the utilization of a VAM can help make the balancing problem easier but, considering a multi-objective model optimizing time and energy, this approach can lead to optimal solutions in terms of time and energy different than considering the entire mix instead of the VAM. Then the behavior of the assembly system with the real products has been evaluated in terms of time efficiency and ergonomics level and several new objective functions have been introduced in order to improve the previous solving process. General considerations have been made about the impact of ergonomics on the final result and some guidelines for the practitioners have been introduced.

2 Time and Energy MALBP

2.1 Virtual Average Model Within Time and Ergonomics Approaches

In the MALBP, different models of the same product family are processed without any or with minor setup or rearrangement between the different work pieces. In this case the production process is similar between each product and it differs mainly due to customized features. This kind of line is possible due to high level of standardization of finished products, and it is particularly common in Assembly-To-Order systems and during seasonality peak period, in order to satisfy the market demand.

As summarized in Boysen et al. [8], if the demand of each product is often unknown, in order to balance such kind of line, it is easier to turn the mixed-model assembly line into a single-model case by joining the precedence graph of each model into a join precedence graph [13]. A join precedence diagram implies that a subset of tasks is common among the considered models but also, despite the different operation time of each task for different models, the tasks have to be performed in the same station. The balancing of a mixed-model assembly line not only implies a joint precedence graph but also the concept of Virtual Average Model (VAM) which consists in a dummy average model representing all the

products assembled in this assembly line. The time of each activity of VAM can be calculated as:

- the maximum time required for this activity considering all the products;
- the average time required for this activity considering all the products;
- the weighted average time required for this activity considering the mix of products;

In our research the third approach of evaluating VAM is carried out and is integrated with the multi-objective problem based on energy expenditure [3–5].

In the multi-objective approach, not only the solution that optimizes time is considered but also the one that optimizes energy. The analysis of the Pareto frontiers allows evaluating which is the trade-off from one solution to the other. In fact, they are the set of non-dominated solutions of a multi-objective system, where solutions optimize one of the objectives of the problem.

In order to apply this kind of approach, it is necessary to have the task time and the energy expenditure for each task of each model. Noted t_{jm} as the time of task j for model m, e_{jm} as the relative energy expenditure, and d_m as the percentage demand of model m in the considered mix, the formulations of t_j and e_j for a VAM are the following:

$$t_j = \sum_m t_{jm} \cdot d_m \tag{1}$$

$$e_j = \sum_m e_{jm} \cdot d_m \tag{2}$$

2.2 Time-SALBP and Energy-SALBP with VAM

The definition of t_j allowed us to balance the mixed model assembly line with the SALBP-2, which is the SALBP model which ensures the minimization of the cycle time with a predefined number of stations and cycle time in order to increase the productivity [12]. Based on the binary linear model [12] in the single-model assembly line, the binary variable called x_{jk} is used to indicate the assignment of task j to station k and B_k is the set of task assignable to the station k (within a set of workstations from 1 to K), to solve the SALBP-2 the subsequent constraints need to be considered:

- Occurrence constraint

$$\sum_{k \in [Ej, Lj]} x_{jk} \text{ for } j = 1, \ldots, n. \tag{3}$$

- Cycle time constraint

$$\sum_{j\in B_k} x_{jk} \leq c \text{ for k = 1,. . .,K.} \tag{4}$$

- Precedence constraint

$$\sum_{k\in[E_h,L_h]} k{\cdot}x_{hk} \leq \sum_{i\in\left[E_j,L_j\right]} i{\cdot}x_{ji} \text{ for k = 1,. . .,K.} \tag{5}$$

With the definition of E_j and L_j respectively the earliest and latest station in Patterson and Albracht solving model [12].

The different balancing solutions could be many and to evaluate each one we select the objective function of Time Smoothness Index (*SX-T*) to measure the equality of workload distribution among the stations and the Energy Smoothness Index (*SX-E*) to distribute physical load among workers at different stations [5]:

$$\min SX\text{ - }T = \min\sqrt{\sum_{k=1}^{K}\left(c_r\text{ - }\sum_{j\in B_k} x_{jk}{\cdot}t_j\right)^2} \tag{6}$$

$$\min SX\text{ - }E = \min\sqrt{\sum_{k=1}^{K}\left(e_r\text{ - }\sum_{j\in B_k} x_{jk}{\cdot}e_j\right)^2} \tag{7}$$

where $c_r = \max\left\{\sum_{j\in B_k} x_{jk}{\cdot}t_j | k = 1\ldots K\right\}$, which is the maximum station time among all stations and $e_r = \max\left\{\sum_{j\in B_k} x_{jk}{\cdot}e_j | k = 1\ldots K\right\}$, as the maximum energy expenditure among all stations.

As developed in our previous research, we defined the Pareto Frontier (the set of non-dominated solutions of a multi-objective system), in order to understand in this bi-objective approach the trade-off between time-based and energy-based optimal solution, using the following function:

$$\min\{SX\text{ - }T;SX\text{ - }E\} = \min\sqrt{\sum_{k=1}^{K}\left(c_r\text{ - }\sum_{j\in B_k} x_{jk}{\cdot}t_j\right)^2};\min\sqrt{\sum_{k=1}^{K}\left(E_r\text{ - }\sum_{j\in B_k} x_{jk}{\cdot}e_j\right)^2} \tag{8}$$

2.3 Time- and Energy-MALBP

In a mixed-model assembly line the Time-SALBP and Energy-SALBP referred to the concept of VAM might not be sufficient in order to evaluate properly the

changing in the Pareto Frontier. Taking into account the same balancing solutions, knowing the number of stations and the cycle time (MALBP-F), the idle time and the workloads may be different depending on the distribution of work [12]. To evaluate properly a balancing solution it is necessary to take into account objective functions for the analysis of smoothed station loads. In a mixed-model assembly line we can define T_{mk} and E_{mk} as the processing time and energy expenditure per unit of model m in station k. S_k is the set of task assigned to station k, T_{mk} and E_{mk} can be defined as follow:

$$T_{mk} = \sum_{j \in S_k} t_{jm} \tag{9}$$

$$E_{mk} = \sum_{j \in S_k} e_{jm} \tag{10}$$

Knowing the values of T_{mk} and E_{mk} allows us to define for the model m, c_{mr} and e_{mr} as, respectively, the maximum T_{mk} expressed by $c_{mr} = \max\{T_{mk} | m = 1 \ldots M\}$ and E_{mk}, by $e_{mr} = max\{E_{m_k} | m = 1 \ldots M\}$.

Defined these instances, the balancing solutions can be evaluated not only for the operation time but also for the operation energy.

The following functions put in evidence the maximal deviation of operation time/operation energy of a model from the maximum station time/energy, weighed on the demand of each model:

$$\Psi_t = \sum_{m=1}^{M} \sum_{k=1}^{K} |T_{mk} - c_{mr}| \cdot d_m \tag{11}$$

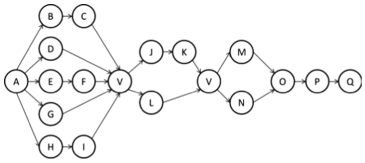
$$\Psi_e = \sum_{m=1}^{M} \sum_{k=1}^{K} |E_{mk} - e_{mr}| \cdot d_m \tag{12}$$

The multi-objective functions of this second approach are introduced to let us compare them to time-based and energy-based approach applied to a Virtual Average Product in order to put in evidence how the Pareto Frontier changes considering one approach or the other in a mixed-model assembly line.

3 Numerical Example and Analysis

In the numerical example, based on [5], we describe an assembly process consisting of 17 tasks denoted A, …, Q and the input data of t_j and e_j are considered in the Fig. 1.

The precedence diagram shown above is the joint precedence diagram of three different models: M1, M2, M3. The data included in the figure is the values of t_j and e_j for each of the three models but also the values of t_j and $e_j$of different kinds of VAM, obtained by considering a different demand of each model M1, M2, M3



							VAM SCENERIES							
							MIX A		MIX B		MIX C		MIX D	
	MODEL 1		MODEL 2		MODEL 3		33.3% - 33.3% - 33.3%		5.56% - 22.2% -72.2%		22.2% - 72.2% - 5.56%		72.2% - 5.56% - 22.2%	
R	0.559		0.729		0.678		0.662		0.684		0.696		0.598	
Task	t_j [s]	e_j [kcal]	t_j [s]	e_j [kcal]	t_j [s]	e_j [kcal]	t_j [s]	e_j [kcal]	t_j [s]	e_j [kcal]	t_j [s]	e_j [kcal]	t_j [s]	e_j [kcal]
A	19.20	0.76	24.00	0.95	28.80	1.14	24.00	0.95	27.20	1.07	23.20	0.92	21.60	0.85
B	46.00	2.69	55.20	3.23	36.80	2.15	46.00	2.69	41.40	2.42	52.13	3.05	44.47	2.60
C	15.60	1.08	13.00	0.90	10.40	0.72	13.00	0.90	11.27	0.78	13.43	0.93	14.30	0.99
D	7.00	0.18	5.60	0.14	8.40	0.21	7.00	0.18	7.70	0.19	6.07	0.15	7.23	0.18
E	20.00	0.95	25.00	1.19	30.00	1.43	25.00	1.19	28.33	1.35	24.17	1.15	22.50	1.07
F	15.00	0.88	12.00	0.70	18.00	1.06	15.00	0.88	16.50	0.97	13.00	0.76	15.50	0.91
G	4.00	0.12	5.00	0.15	6.00	0.18	5.00	0.15	5.67	0.17	4.83	0.15	4.50	0.14
H	45.60	1.47	30.40	0.98	38.00	1.23	38.00	1.23	36.73	1.19	34.20	1.11	43.07	1.39
I	11.00	0.96	8.80	0.77	13.20	1.16	11.00	0.96	12.10	1.06	9.53	0.84	11.37	1.00
J	64.00	3.65	96.00	5.47	80.00	4.56	80.00	4.56	82.67	4.71	88.00	5.02	69.33	3.95
K	68.00	4.06	85.00	5.07	102.00	6.09	85.00	5.07	96.33	5.75	82.17	4.90	76.50	4.56
L	30.00	1.20	25.00	1.00	20.00	0.80	25.00	1.00	21.67	0.87	25.83	1.03	27.50	1.10
M	60.00	1.08	72.00	1.30	48.00	0.87	60.00	1.08	54.00	0.97	68.00	1.23	58.00	1.05
N	65.00	1.17	52.00	0.94	78.00	1.41	65.00	1.17	71.50	1.29	56.33	1.02	67.17	1.21
O	36.00	0.74	45.00	0.92	54.00	1.10	45.00	0.92	51.00	1.04	43.50	0.89	40.50	0.83
P	20.00	0.40	25.00	0.50	30.00	0.60	25.00	0.50	28.33	0.57	24.17	0.48	22.50	0.45
Q	19.20	0.76	12.80	0.50	16.00	0.63	16.00	0.63	15.47	0.61	14.40	0.57	18.13	0.72

Fig. 1 Input data of numerical example

weighted on the mix. The correlation index R between t_j and e_j for each model and VAM is provided.

The aim of this analysis is to apply a multi-objective approach through the utilization of the Pareto Frontier in a MALBP, discovering if the traditional practice to evaluate a mixed model assembly line approximating all the considerations to the concept of VAM has a meaning or not and in which cases.

The numerical example has been carry on by computing different balancing solutions for each kind of VAM with the Patterson and Albracht algorithm [12], evaluating each possible assignment of task to each station in order to respect occurrence, cycle time and precedence constraint.

For each feasible balancing solution of each VAM (whose values of t_j and e_j depend on the particular mix considered), we have calculated *SX-T* (Time Smoothness Index) and *SX-E*(Energy Smothness Index), basing on the concept that a mixed model line can be transformed to a single model one producing a VAM. Then we calculated Ψ_t and Ψ_e through which we managed to consider the line efficiency in time and energy, taking into account the effect that a particular mix might have.

Through these functions it is then possible to define two different kinds of frontiers: the aim of obtaining the non-dominant solutions in time and energy is the same but one considers *SX-E* and *SX-T* and the other Ψ_e and Ψ_t.

These two kinds of approaches cannot have the same frontier as can be seen in the example below referring to a mix composed by 33.3 % of M1, 33.3 % of

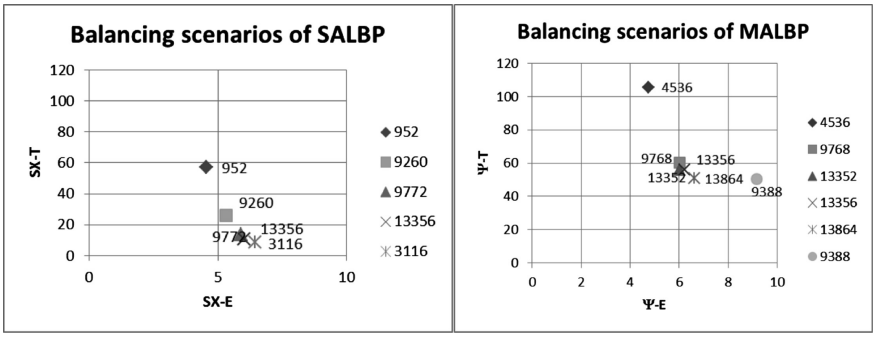


Fig. 2 SALBP and MALBP frontiers for mix A

M2 and 33.3 % of M3. In fact the numbers and kind of scenarios (each one implies a specific balancing solution staying in the frontier) are different (Fig. 2).

If the scenarios of Pareto Frontier are different between the two approaches, there is the need to evaluate if the difference is more evident in some kind of mixes than others. If the difference is substantial, the choice of SALBP approximation is not the right way to evaluate a mixed model line or if used, the choice of one of the SALBP solutions would not correspond properly to the MALBP solution.

In the Fig. 3 for each kind of mix, the effective frontier of MALBP is compared with the frontier of MALBP if the scenarios of SALBP frontier are considered and the scenarios of time-optimal solution and energy-optimal solution are highlighted.

The difference between the two frontiers is not the same in all kinds of mix but the frontier of SALBP is always on the right of the real frontier of the mix takes into account. As explained in Battini et al. [5] a frontier can move itself from left to right if the correlation index R (the relation between t_j and e_j) decreases and more it increases more the frontier moves to left and is reduced to a point. Consequently there is the need to understand how is the difference between the correlation index of VAM, R_{VAM} and the correlation index of each product, R_m, weighted on the demand of each model, R_v, which can be expressed as follow:

$$R_v = \sum_{m=1}^{M} d_m \cdot \left| \frac{R_{VAM} - R_m}{R_{VAM}} \right| \tag{13}$$

We face increasing values for R_v with this order of mix: mix B (0.032); mix A (0.0619); mix C (0.0718); mix D (0.0817). The deviation of the two frontiers increases in the same order as the increase of R_v so the two frontiers are more similar and we can approximate more correctly to VAM frontier if R_v is as small as possible. This happens when the value of R_m that has a stronger effect on R_v is the one of the model in the mix that has the highest demand.

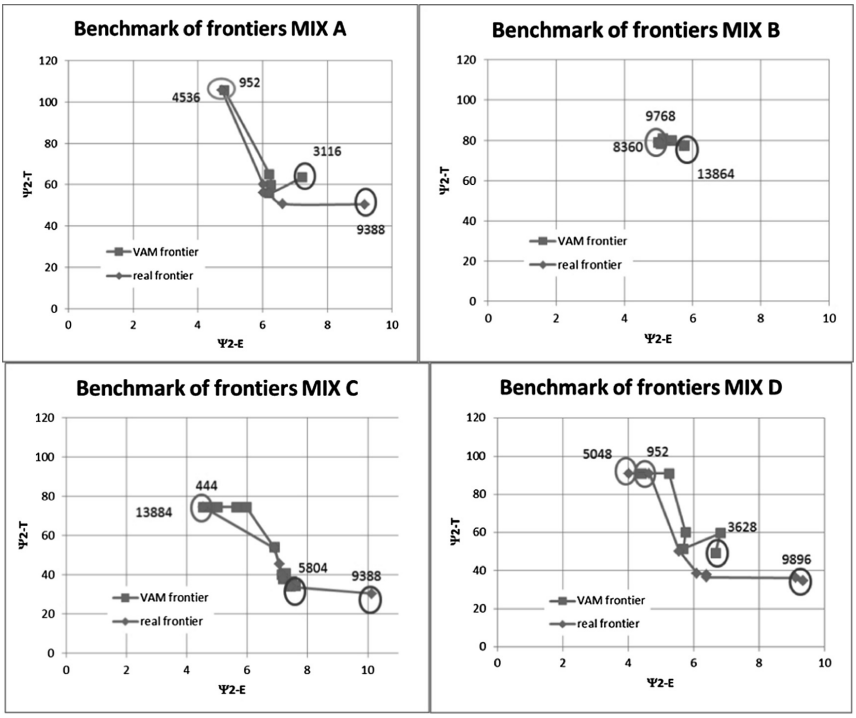


Fig. 3 SALBP and MALBP frontiers comparison for all mix

In order to evaluate properly the deviation between the two frontiers ΔT_{opt} and ΔE_{opt}, it is necessary to consider the two point of time-optimal and energy-optimal solution of the two frontiers and analyze the subsequent measures. We defined $\Psi_{T\text{-}VAM}$ and $\Psi_{E\text{-}VAM}$ the points of optimum of SALBP frontier for time and energy and Ψ_T^*, Ψ_E^* the points of optimum for time and energy of the other frontier in MALBP.

$$\Delta T_{opt} = \frac{\Psi_{T-VAM} - \Psi_T^*}{\Psi_T^*} \tag{14}$$

$$\Delta E_{opt} = \frac{\Psi_{E-VAM} - \Psi_E^*}{\Psi_E^*} \tag{15}$$

The results for the considered mix are the following: (Table 1)

As can be seen in the table above, the error in the points of energy-optimal solutions is lower because the feasible balancing solutions take into account only the time (cycle time), on the contrary there is a higher value of the error for the time-optimal solutions.

Table 1 Results for the different considered mix demand

Mix	ΔT_{opt}	ΔE_{opt} (%)
A	20.6 %	1.7
B	–	2.6
C	11.9 %	9.7
D	29.7 %	9.2

4 Conclusion and Future Research

In this study we have proposed a multi-objective approach in order to integrate the ergonomic aspects into a mixed-model assembly line. Comparing the frontier of the classical approach based on the creation of a Virtual Average Model to the frontier obtained by the definition of new functions Ψ_t and Ψ_e, we have found a certain difference between the two frontiers depending on the different values of R. This error is higher in the points of time-optimal solutions than in the points of energy-optimal solutions.

The next steps will be a parametrical analysis on the R_v index in order to evaluate for what kinds of R_v is appropriate the approximation to the VAM frontier.

Then further researches will be carried out about the mixed-model sequencing problem in order to have better ergonomic conditions without the decreasing of the line efficiency in time.

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Study on the Use of Expanding the Scope of Near-Miss Data in the Work Safety Activities—Based on the Pattern Analysis of the Characteristics of the Methods and Field Activities Related to Work Safety

Kota Takahashi and Yusaku Okada

Abstract Industrial safety activities are roughly divided into two types: activities to take measures for "direct factors" and for "latent factors". Activity which may be mentioned as measures against latent factors is the near-miss activity. How to use the data of near-miss is that they select the required data on the basis of intuition and experience and reflect it in the field activities. However, measures against direct factors have priority over latent factors, and the measures against latent factors often do not work. There are large differences in the quality of the extracted data and the proposal of the activities between the experienced manager/skilled person and the inexperienced employee. Therefore, the aim of this study is to make aware of the lack of view and to help inexperienced employee extend measures against direct factors to against latent factors by encouraging them to systematically understand the methods and activities.

Keywords Latent factor · Work safety · Near-miss · PCA

1 Background

If an accident occurs in a number of companies including the manufacturing industry, he effect is not only the person caused the accident, but also there is a possibility to give a great deal of loss to production activities and credit of the organization, the local environment. Therefore, it is essential to carry out Industrial safety activities for companies.

Industrial safety activities are roughly divided into two types: activities to take measures separately for "direct factors" and comprehensively for "latent factors".

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Until now, various efforts in the activities for the direct factors have been made sufficiently in the companies. On the other hand, activities may be mentioned as measures against latent factors are, for example, the development of the working environment and near-miss activities. However, measures against direct factors have priority over latent factors in reality, and there are many cases that the measures against latent factors do not work to the extent that secure administrators want. For example, how to use the data of near-miss is that they select the required data on the basis of intuition and experience and reflect it in the field activities. Then, at present, there is a large difference in the quality of the extracted data and the proposal of the activities that take advantage of it between the experienced manager/skilled person and the inexperienced employee. In other words, when someone uses data of the near-miss, the variation due to the ability of the user would come out big. If there are people who can implement the appropriate use of methods based on their intuition and experience, there is no problem. Nevertheless, the people and companies that it cannot do have not fully utilized the data.

Even the experienced people also could not do in the beginning. They are able to rely on their own intuition precisely because they gained and learned from various field experiences and failure experiences.

On the other hand, the opportunity when the employees gain the experiences is becoming less and less than in the past because of the rise of the level required socially for the safety and the progress of science and technology. So, we think if there is one of the criteria how to take advantage of the data, it can aid the people that were not able to do until now to choice the use of method.

As mentioned above, at present the near-miss activity that is one of the activities for "latent factor" would come out a large difference in the use of the way by the ability of people to take advantage of it. In addition, as the difference between the inexperienced people and the experienced people, there is the presence or absence of my own criteria to select the way for taking advantage of the data.

Therefore, the aim of this study is to make aware of the point of view that is the lack of their own and to assist them in extending the approach to the direct factor to the activities for latent factors by encouraging a systematic understanding of the activities for latent factors and direct factors to inexperienced people.

2 Past Research

First, we surveyed the methods and field activities related to work safety that were previously established. Ample studies have demonstrated development of a method for evaluating the safety culture of organizations and evaluation or comparison of one or a plurality of methods and activities. For example, Takano [1] and Matsuoka [2], evaluation methods of safety culture called ASCOT suggested by the IAEA, Takeuchi [3, 4] can be cited.

However, it was found from the survey that despite there are the large number of such studies, the study which has been systematically evaluated and organizing various methods and activities does not exist.

3 Method

In this section, we mention how the result of systematically organizing work safety activities, in this paper we shall call it "MAP", would be utilized in the actual company. The MAP contains a wide range of work safety activities that are actually used by the companies. There are technical methods of analysis about risk assessment, and there are also activities such as taking place at site on a daily basis. However, many of these activities are made to primary factors, but they are insufficient for secondary factors. Therefore, the application of the near-miss data which is information of latent factors to the activities on the MAP would enable anyone to cope with secondary factors equivalent to primary factors.

We must understand the characteristics of the potential factors in order to realize the above, so we focused that latent factors can be classified into following three.

(1) Factors that direct deal is needed
The factors do not always actualize. Because they have always subjected to the same measures against rough direct cause, they think that they have make measures and the factors become secondary factors. So, simply application of past measures to the near-miss is sufficient to make measures. Therefore, it is necessary to finely organize the methods and to systematically show a variety of case studies about analysis and measures.

(2) Factors that tendency comes into view by collecting statistical data
The factors seem to actualize and do not do, and they are not captured only by sense for many people. For example, workers sometimes feel a bit of awkwardness in their work, but they judge it nonsense to bother thinking the measures with neither money nor time. Naturally, we cannot apply the one by one measure against these feelings. However, these feelings are potential risks. Moreover, Accident would happen by a pile of leaving these risks. Therefore, it is necessary to reduce the risk that we collect statistical data and grasp tendency, take comprehensively measures rather than individually. For this purpose, the collecting ways and the statistical processing of the necessary data will be realized by application of the existing approaches.

(3) Factors involved in the human reliability
This factor does not apply to a discussion of whether or not to manifest, because the answer would be changed by different occasions. For example, both politeness and speed of work are not necessarily compatible. Moreover, whether we consider speed or politeness more important would change depending on the situation. In the environment that changes moment by moment, it is a key factor what workers value. Although what man is superior

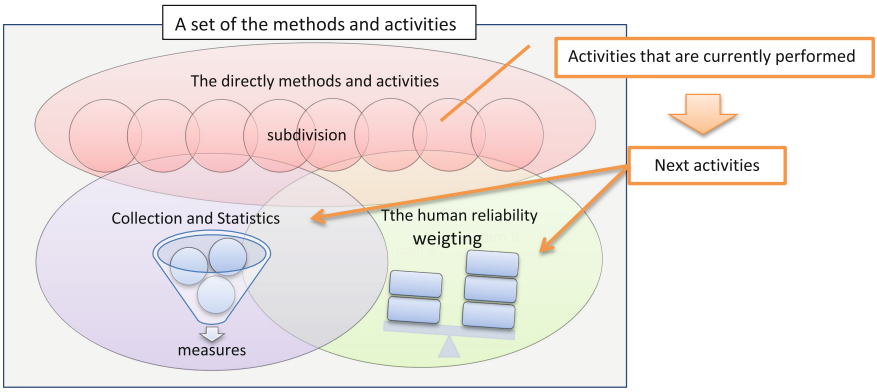

Fig. 1 The flow of utilization of the "MAP"

to the robot is its flexibility, it also often causes them puzzlement. We tend to rely on the experience when they make a decision in the face of unexpected scene. Naturally, the skilled person can judge correctly, but immature person has little experience for the judgement. Thus, it is necessary for immature subordinates to make up for the lack of experiences to weight the importance of the work or factors and to show it by skilled administrators. To show in this paper that what kind of method can be applied to the weighting becomes the help of the education.

The summary of the three described above is shown in Fig. 1. Of course, we speculate that classes of the latent factors would not be simply only three. However, the purpose of this study was that when we take action against near-miss, they can notice that there is an approach from a different point of view by the use of this map, and the classes is only an example of the use of methods.

4 Development of the MAP

Based on the foregoing, we done the following two to organize the methods and field activities related to work safety.

(1) Determination of the evaluation items in order to arrange (35 items)
Upon generally organizing them, we considered that its purpose is to increase the safety of the organization, and we created items in reference to past studies of evaluating the safety culture of the company from a variety of perspectives. In addition, the method of risk assessment are also targeted in this study, we considered that evaluation items of a different point of view from field activities are needed. Accordingly, we referred to past studies about a comparison of the risk assessment method, and we created a total of 35 evaluation items.

(2) Collection of typical methods and field activities (139 items)
We collected mainly the information that has been published in the safety report of each company with respect to field activities and the evaluation method that was including the risk assessment in reference to the past papers and technical books.

First, we show the 35 evaluation items and the process of determination. Takeuchi [4] showed review of the part of past studies on the evaluation and measurement of safety culture and arrangement of the approaches to evaluate, assess and measure the safety culture (safety climate) of organizations and its viewpoints. Moreover, 8 issues related them were showed.

In this paper, we use the one of 8 issues as reference that is item of the importance and attainment of the contents of safety climate.

Miyachi et al. [5] mentioned the method described below. They summarized the contents of the evaluation items, the total number of item is 1000, that had been used in the research on railway in the past to about 200 items, and ranked *content importance* of the evaluation item separately; operating system and maintenance system.

The ranking from A to E was made by personnel in charge of safety management and researchers who study human factors related to safety. At the time of evaluation, the weighting is carried out by "the level of dedication for activities" of each group. "The level of dedication for activities" shows the relative position of a particular workplace of scoring among the score distribution in the same conditions, such as the same area and the same job category.

In this paper, we referred to items that were evaluated as A or B, that is to say particularly important and created 27 evaluation items. Table 1 shows the 27 items.

In addition, in order to be able to assess the work safety activities in general from a broader point of view, we created new 4 items in reference to Hurukawa et al. [6] showed perspectives and disciplines to evaluate the safety culture. Table 2 shows the 4 items.

In addition to these, since the risk assessment method is the target of the evaluation, we verified also from the point of view. We referred to Matsuoka [2] suggested comparison items of risk assessment techniques and JIS31010, and we created new 4 items. Table 3 shows the 4 items.

In this way, we created a total of 35 items. Next, when we would make the evaluation of each work safety activities, we adjusted the evaluation criteria in order to evaluate each item in 5 steps. The 5 steps are based on the following 5 steps.

1. Strongly disagree
2. Disagree
3. Does not apply
4. Agree
5. Strongly agree

However, the 5 steps cannot be applied to some items, so we changed to become clearer. Then, we scored 139 pieces of methods and field activities by the 35 items

Table 1 Evaluation items about methods and activities (1)

1	The required degree of the external information and institutions
2	Efficacy of the encouragement to cooperate with each relevant departments
3	Complexity of the activities and methods
4	Efficacy of promoting to reconsider the activities and evaluations
5	Availability of support for the teaching methods of administrators
6	Efficacy of increasing the risk cognitive ability
7	Efficacy of leading to the accumulation of know-how was born in the site
8	Efficacy of the encouragement to a simple safety measures in the site
9	Simplicity of obtaining the site of feedback
10	Suggestion of the site of policy
11	Possibility of measuring the penetrance of the measures
12	Required degree of knowledge of the work site
13	Presentation of the work procedure
14	Possibility of eliciting opinions from subordinates
15	Efficacy of the encouragement to aggressiveness of the employees about the work
16	Efficacy of leading to the improvement of the motivation of the employees
17	Flexibility to match, such as in the department
18	How often to practice the methods or activities
19	Job title of the person who uses the methods mainly
20	Scale of the event should be applied the methods to
21	Efficacy of the encouragement to cooperate with the top and the bottom
22	Efficacy of promoting the physical and mental health
23	Possibility of originating as information for publicity
24	Simplicity of transmitting the intention of the measures
25	Possibility of measuring the rate of implementing of activities
26	Capability of being associated with other methods and workplace
27	Providing opportunity to pass on experience and skill from elderly to young

Table 2 Evaluation items about methods and activities (2)

28	Job title of the person who is the main target of the methods
29	Based on numerical value
30	Logicality of measures being followed by the methods
31	Prices of necessary expenses

Table 3 Evaluation items about methods and activities (3)

32	Number of persons required in carrying out the method
33	Time required for once carrying out the method
34	The required degree of taking advantage of past experience
35	The required degree of detailed information

of evaluation. Next, principal component analysis (PCA) was performed for the result. The purpose is the realization of a more simply structured MAP to reveal a new synthetic variable in the work safety activities from the 35 items of the evaluation score. We grouped the 139 methods and activities into 16 types to use from the first main component to the fourth according to the result of PCA.

The cumulative contribution ratio of them is about 45 %. Although it is not a sufficient numerical, the number of types should not become huge to take into account the use in the actual site. Therefore, a point of compromise was up to fourth principal component.

5 Discussion

In this study, we systematically organized the methods and activities of work safety and health that contains activities that are not applied to professional and academic frame and are actually carried out in the site. As a result, we developed a tool that helps even the shallow experienced people of leader positions in the field take advantage of information about latent factors, such as the near-miss, with a broader perspective. The advantage of this study is by no means proposed of new methods and measures. We suggested the tool helps them grasp the viewpoint lacking among the various existing methods and extend the activities to latent factors by cleverly operating them.

However, there are things to reflect on. First, the cumulative contribution ratio had become to a low value of about 45 %. Nevertheless, evaluation axis approaches become four, and we considered that some point analysis is insufficient to encourage really shallow experienced person to understand systematically.

Future outlook on research, if we further pursue each of the characteristics of the 16 types and evaluate based on the result, we would form a MAP that is more reliable and convenient.

6 Case Study

In this section, we introduce examples of the proposed utilization of the near-miss against work safety and health activities that were created based on the MAP and actually operating in a petroleum plant.

We selected one or more of the methods or activities from each 16 group and proposed the utilization. We introduce the one proposal of them.

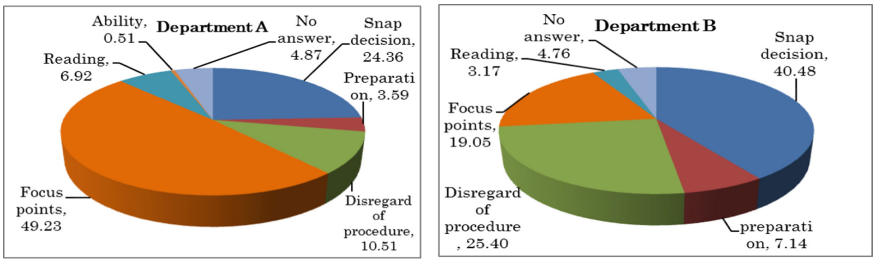

Fig. 2 Difference of tendency between departments A and B

6.1 Site Improvement Activities by the Safety Patrol Check List

Managers/supervisors make a patrol and observe the situation and atmosphere of each workplace by using the check list consisting of dozens of items. Although uniform evaluation can be for each item because of using a checklist, managers and supervisors read the changes of tendencies on the basis of individual values. Therefore, we suggested extracting data from near-miss data as reference to improvements which enable us to find a change in trend from the fact. The near-miss report often contains multiple choice questions. We made the percentage of answers to each department in the graph, so it is possible to grasp the difference between the tendencies by department. Actually, since there is the one of the items of the near-miss report at the target company that is called "Problems that led to the near-miss", we grasped the differences in the tendency of each department by making a graph of the percentage of selected factors in the report.

It shows differences of each department in the ratio of factors that has been reported as problems that led to the near-miss in the following Fig. 2.

Then, it has become possible to implement measures that are more suitable for that department by reading the difference.

7 Conclusion

In this study, we defined the target as people and companies that are not able to take full advantage of the information about latent factors such as near-miss data. Then, we organized systematically the methods and field activities related to work safety, and we created the tool that is a help to them to extend the target of the activities against direct factors to latent factors.

Future outlook on research, against the issue of the ability of the people that may occur by reduction of opportunity to experience in the future, we hope that this study will be a tool that can take advantage even a little.

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Comparing Psychosocial Factors Associated with Job Stress Among Administrative Staff and Cleaners

Rupesh Kumar, Theorell Töres and Tore Markeset

Abstract In this study the Swedish version of the Demand—Decision Latitude—Social support model was used. A total of 40 administrative staff and 40 cleaners participated. Demands and decision latitude scores were significantly higher in the administrative staff than in the cleaners. Social support scores were not significantly different between the administrative group and the group of cleaners. Psychological demands and skill discretion differed between the two working groups. The administrative staff's perception of higher work demand and better decision latitude may be based on their belief that they possess appropriate education, general knowledge and detailed information about their work. Both groups had similar social support scores; it may be that members of both groups felt that they work as a group or team where their proximity fostered this perception of group social support.

Keywords Psychological stress · Administrative staff · Cleaners · Demand-control-support model

1 Introduction

Stress can be defined as the mobilization of energy in situations where an increased level of energy is needed. It can provide both positive and negative benefits to individuals [1]. Gruen et al. [2] states that, 'the conviction that psychological stress is a causal factor in mental and physical illness underlies much current theory and

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research in the biological and behavioral sciences'. Job stress can be defined as the harmful physical and emotional response that occurs when the requirements of a job do not match the capabilities, resources, or needs of a worker. According to Karasek [3], job stress occurs because the 'demands' of employment exceed the ability of an individual to exert control in their work environment.

The Job Demand-Control (D-C) Model [3], and its expanded version, the Job Demand-Control-Support (D-C-S) Model [4, 5] have heavily influenced research on work stress for over 20 years. According to the D-C model, job strain results from the interaction of two main dimensions of a work environment: psychological demands and control. Over time, the way in which demands in the model are understood has evolved. At the beginning, they were operationalised mainly as quantitative demands and demands stemming from role conflict [3]. Later, additional elements were included, such as interpersonal conflicts [6], cognitive demands [7], qualitative demands and emotional demands. According to the D-C model the highest strain arises when demands are high and control is low [3]. The Demand-Control-Support (D-C-S) model assumes that job strain is a result of the interaction of two job dimensions: demands and control. When social support is added, the most adverse condition is defined as a situation with high demands, low control and poor support (Fig. 1). Social support has been defined as 'the overall level of helpful social interaction available on the job from both co-workers and supervisors' [5]. If the demands placed on a person at work are higher than the perceptions of control, job strain will occur [8].

The Karasek 'Demand-Control Job Strain Model' has highlighted two key workplace conditions that increase hypertension: high psychological demands combined with little control in being able to manage those demands. Employees who believe that they have little control over their work describe themselves as lacking the ability and/or authority to make decisions or have any impact upon their job. There are several studies which have attempted to apply the D-C-S models to nursing work [9–11]. It was found that job strain among nurses was associated with depression, low job satisfaction and some symptoms of burnout [9, 10] as well as elevated blood pressure and cortisol levels [11].

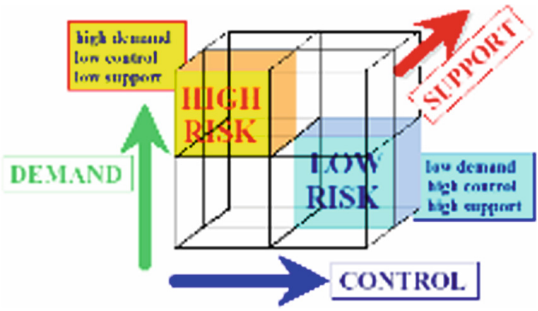

Fig. 1 The psychological stress model of Karasek and Theorell [5]

Several studies have shown that various sources of job stress, for example high work demands, lack of control over work and fear of job loss, are related to work-related upper extremity symptoms and disorders [12, 13]. Faucett and Rempel [14] described ergonomic factors such as awkward posture, workload and job stress (i.e., decision latitude and social support) that contributed to hand/wrist and neck/shoulder symptoms. From a review of 59 studies, Bongers et al. [15] concluded that monotonous work, high perceived workload, time pressure, low control on the job, lack of social support from co-workers and stress symptoms were related to musculoskeletal problems. Sauter et al. [16] (National Institute for Occupational Safety and Health (NIOSH) [17, 18]) have noted that a significant percentage of office workers experience discomfort at work. Cleaning work also has psychosocial risk factors such as workload, monotonous work, time pressure, and lack of control over work and rest [19–21].

The aim of the present study is to compare the levels of perceived work demands, decision latitude and social support among a group of cleaners with a group of administrative staff working at a Swedish university.

2 Method

A group of cleaners and a group of administrative staff completed a questionnaire. The cleaners work for a cleaning services company and the administrative staff are employed by a Swedish university. The Swedish short version of the D-C-S questionnaire was the questionnaire used for this study [22, 23]. The D-C-S questionnaire consists of three indexes: (i) psychological demand; (ii) decision latitude; and (iii) social support.

The psychological demand index consists of five questions which describe perceived quantitative and qualitative demands. The decision latitude index consists of six questions. The decision latitude questions have two components. The first component is skill discretion which has four questions and is used to describe perceived potential to exert control through job skills and, by virtue of this, possess the ability to take control in unexpected situations. The second component is authority over decision-making which consists of two questions and is used to assess perceived ability to exert influence work decisions [23]. Psychological demand and decision latitude have four possible responses that are based on frequency (how often). The social support index is measured by six questions which focus on workplace working environment. The social support index also consists of four responses which describe intensity (how strongly). The reliability and validity of the DCS questionnaire has been demonstrated in a number of studies [23]. A four point Likert scale was used for simple scoring summation [24].

2.1 Study Design

This study is a cross sectional study and data from a DCS questionnaire completed by cleaners and administrative staff was used for the analysis.

2.2 Procedure

A total of 150 DCS questionnaires were given to cleaners and 100 to administrative staff. For the cleaners, the questionnaires were given to the supervisor who then informed the cleaners about the study and asked them cleaners to voluntarily complete the questionnaire. An identical distribution technique was used for administrative staff. Out of 150, a total of 40 cleaners returned a completed questionnaire. Among the 100 administrative staff given the questionnaire, 40 returned completed copies (another 10, which were not completed, were not included). Among cleaners only one respondent was male and among administrative staff four were male. The average age was 43 for administrative staff (range 24–58) and 44 for cleaners (range 21–63) (Table 1). From the administrative staff about 58 % had at least their first university degree and 42 % had completed their upper secondary education. Among the cleaners, 52 % had completed their lower secondary education, 45 % had completed their upper secondary education and one cleaner had a university degree.

The data was computed—coded and then analysed using statistical software (SPSS version 11.0). The analysis included descriptive statistics. A paired t-test was used to determine the differences between administrative staff and cleaners for psychological demand, decision latitude and social support. A probability value of $P < 0.05$ was accepted as being statistically significant.

3 Results

Table 2 shows the results of the analysis of differences between administrative staff and cleaners (Fig. 2).

Table 1 Characteristics of the respondents

	Administrative staff (N = 0)				Cleaners (N = 40)			
	Mean	SD±	Max.	Min.	Mean	SD±	Max.	Min.
Age(yrs)	43	8.90	58	24	44	11.06	63	21
Job experience	6.9	6.78	30	1	12.17	9.270	21	1

Table 2 Mean score for demand-control-support between administrative staff and cleaners (n = 40)

Variables	Administrative staff		Cleaners		P value
	Mean	SD±	Mean	SD±	
Psychological demand	15.10	2.42	13.55	2.28	0.007*
Decision latitude or control	18.02	2.40	16.35	2.44	0.006*
• *Skill discretion*	12.35	1.62	9.88	1.78	0.000*
• *Authority over decision*	5.75	1.31	6.4	1.21	0.023*
Social support	20.43	2.20	19.90	3.07	0.353

*Significance difference at $P < 0.05$

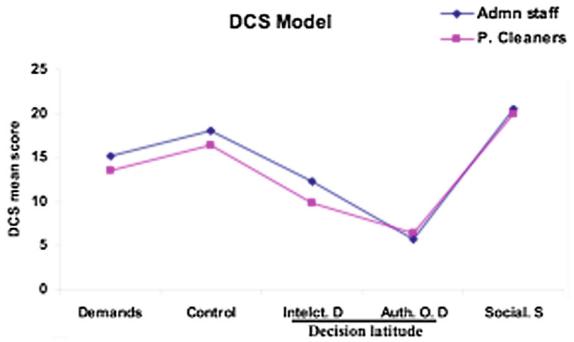

Fig. 2 Demand-Control-Support score between administrative staff and cleaners

A significant difference was found between the cleaners and administrative staff for the psychological demands values. The administrative staff reported higher demands at work (mean 15.10) than the cleaners (mean 13.55). Higher scores indicate higher psychological demands at work. Decision latitude has two components: skill discretion and authority over decision-making. The decision latitude among administrative staff was higher (mean 18.02) than among the cleaners (mean 16.35). The difference was statistically significant.

For skill discretion, the mean value (12.35) for the administrative staff was shown to be much higher than for the cleaners (9.88). The difference was statistically significant.

Good authority over decision-making is associated with higher means. The mean for the administrative staff (5.75) was shown to be lower than for the cleaners (6.40).

Good social support is evidenced by high mean values. There was no significant difference between the two means.

4 Discussion

4.1 Psychological Demand

In the study described here there was a significant difference between administrative staff and cleaners which suggests that the administrative staff group perceived a higher demand level (15.10) at work than did the cleaners (13.55). The nature of the work of administrative staff and cleaners is recognized as being quite different. The work demands of cleaners is more physical (e.g. mopping, dusting, vacuuming and similar physically demanding work) than that of the administrative staff (e.g. computing work, financial work and other analytical activities). Theorell et al. [25] found similar patterns among more physically active jobs; for example, the mean score for psychological demand among female waiters was 14.1. It may be that the work of cleaners and waiters is more physically demanding with less discretionary task variation. In a study by Lottridge [26], found that Uddevalla Volvo plant workers had high psychological demand s because of a complex assembly task set and additional responsibility at work.

In administrative work there is always the risk that mistakes made when preparing or finalising reports can result in considerable financial loss. In contrast, mistakes made while cleaning almost never result in any significant financial loss. If cleaners neglect to clean an area one day, it can be cleaned the next day. In contrast, the higher psychological demand scores of administrative staff may be an indicator that they felt that they work under pressure to not make mistakes. The number of students has increased in recent years without a commensurate increase in staff. This may have increased the administrative staff's workload. In contrast, the level of workload for cleaners has remained essentially the same. Over slightly more than the past decade, there have been ergonomics interventions for cleaners that sought to reduce physical and mental loads (e.g. [27–29]). Hopsu et al. [29] found that with a developmental ergonomic process, cleaning methods and tools were improved plus time spent on floor cleaning decreased from 30 to 25 % of total work time. It could be that for the group of cleaners studied there was some improvement in cleaning tools and/or methods which reduced work demands.

4.2 Skill Discretion

The difference in skill discretion between administrative staff and cleaners was shown to be significant. There was a higher mean score for the administrative staff (12.35) compared to the cleaners (9.88). This means that administrative staff reported a higher perceived level of skill discretion. The reason could be that administrative staff may have better education and knowledge about their present work which enhanced their ability to exercise skill discretion. One study reported that cleaners are more likely to be women, of a lower social status, with less education, at a lower income level and less able to obtain social support [30]. This

study found that the majority (about 52 %) of the cleaners had a lower secondary education. In contrast, among administrative staff 58 % were educated at the university level. This could be one reason why the cleaners in this study reported experiencing a lower skill discretion level at work. Theorell et al. [25] also found that the mean score for waitresses was 8.7. This similarity in scores between waitresses and cleaners could be an indicator that both jobs are viewed as ones where advanced education is not necessary for successful completion of job tasks.

4.3 Authority over Decision-Making

Perceived authority over decision-making differed between administrative staff (mean 5.75) and cleaners (mean 6.4). The difference is significant. It may be that cleaners had some freedom to decide when to do what and how to perform any particular cleaning activity. In contrary, the work patterns for administrative staff might be predefined and thus not allow them the freedom to decide what and how to perform a task. They must follow an exact sequence and procedure.

4.4 Decision Latitude/Control

The overall mean score for perceived decision latitude was significantly higher among administrative staff than among cleaners. It may that administrative staff had better training, education, knowledge and information about work when compared to cleaners. As cleaning work is often described as a low status job requiring little education, it could be that the group of cleaners surveyed lacked the necessary education, knowledge, training and information about their work to enable them to exercise decision latitude opportunities. In a similar study done by Lottridge [26] found high decision latitude among workers at Dadeville Volvo plant due to usage of a wide skill set, self-management and self pacing.

According to Toivanen et al. [31] cleaning is considered to be at a low level in occupational hierarchies; which creates strain at work.

4.5 Social Support

Social support scores were similar for both groups. There was no statistically significant difference in social support scores between the administrative staff and cleaners. The possible reason for this could be that the administrative staff and cleaners in this study may have been working as cooperative groups able to frequently interact with co-workers. Cleaning is usually a full or part time job mostly carried out alone but sometimes as a group or team [32]. In this study, the cleaners

worked in groups or teams and interacted with their co- workers and supervisors often. They thusly rated their social support as high. Many studies (e.g., [30]) found that cleaners often have limited support from their supervisors. Eisenberg et al. [33] found that employees in various branches with high- discretion job conditions reported better organizational support when compared to employees in low-discretion jobs. In this study, cleaning tasks were performed in groups and thus motivated the cleaners to work cooperatively in order to complete cleaning tasks in effective and efficient ways. This then acted to increase perceptions of morale support. It may be also the case that cleaners divided tasks within a group; enhancing understanding within the group through cooperation.

5 Conclusions

In this study it was found that mean scores for psychological demands and decision latitude were higher among administrative staff when compared to the scores of the cleaners. However, the results can not be generalised to larger populations of administrative staff or cleaners due to the small sample size and the relatively low response rate. Another consideration that may have influenced scores is the absence of direct contact with subjects when questionnaires were distributed. Supervisors may have made comments that discouraged completion or not accurately represented study goals; both may have influenced subject behaviours. Despite these weaknesses, it still seems reasonable to conclude that differences between the two groups is likely due to perceptions of work environments and the perceived ability to exert influence upon undesired work environment conditions to cause desired change.

The results of this study raise issues concerning perceptions of working conditions and how these factors directly or indirectly affect worker health; particularly among cleaners—a group of marginalised workers. Additional research is needed to more precisely identify psychosocial factors operating on cleaners when compared to other worker groupings. The results reported here can be useful in the design and administration of the additional research being recommended. What appears to be important at this point is the recognition that a variety of factors plays upon worker attitudes and have an effect upon health and job satisfaction.

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