Advances in Intelligent Systems and Computing 602

Ravindra S. Goonetilleke
Waldemar Karwowski *Editors*

Advances in Physical Ergonomics and Human Factors

Proceedings of the AHFE 2017 International Conference on Physical Ergonomics and Human Factors, July 17–21, 2017, The Westin Bonaventure Hotel, Los Angeles, California, USA

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Advances in Human Factors and Ergonomics 2017

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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 outcome of dedicated research by academics and practitioners aiming to advance theory and practice in this dynamic and all-encompassing discipline. A total of seven sections presented in this book:

I. Biomechanics and Ergonomic Modeling
II. Ergonomic Evaluation and Interventions
III. Physical Ergonomics Applications
IV. Risk Assessment and Management
V. Movement and Balance
VI. Applied Ergonomics in Fashion Design and Sports Technology
VII. Ergonomic Performance of Work Systems

Each section contains research that has been reviewed by members of the International Editorial Board. Our sincere thanks and appreciation to the Board members as listed below:

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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.

July 2017

Ravindra Goonetilleke
Waldemar Karwowski

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Hand Arm Vibration, Grip Strength Assessment and the Prevalence of Health Disorders Among Stone Crushing Workers

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Abstract. This research was conducted to analyze the hand-arm vibration exposure levels in the workplace and the effects of vibrations on the health of stone crushing workers. The results suggested that the levels of vibration for rock drilling operators, measured through two different types of systems, were exceeding the Threshold Limit Values. Therefore, a higher percentage of workers may be affected with hand-arm vibration syndrome. In addition, the Hand Activity Level score was calculated with the support of a physician in order to analyze the occurrence of musculoskeletal disorders. Prolonged exposures to hand-arm vibration may also lead to loss of grip strength and proper functioning of hand. A digital hand dynamometer was used to calculate the grip strength of the workers using powered drill machine. A significant decrease of 5.86 kg of force in average grip strength of the workers was found before and after 1 h of drilling.

Keywords: Hand-transmitted vibration · Hand-arm vibration · Hand grip strength · Vibration disorders · Musculoskeletal disorders

1 Introduction

During stone crushing activities, vibrations and noise produced by equipment are among the hardest hazards the worker has to cope with. Work related health problem with occupational vibration transmitted to the hand-harm system is usually termed as Hand-Arm Vibration (HAV) syndrome and affects the workers working with powered tools and machinery. HAV is one of the factors that can cause several diseases and permanent disorders in cardiovascular, musculoskeletal and nervous system of the body. The major disorder related to hand-arm vibration exposure is known as white finger disorder [1]. For example, white finger disorder was reported to be common amongst forest workers using chain saws [2].

The likelihood of occurrence of most common upper extremity cumulative trauma disorders (CTDs) is higher amongst those workers who are working using hand arm powered tools and equipment. Vibration also produces different diseases which are related to muscles and carpal tunnel syndrome and its effects become manifold with age [3].

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Effects of noise, low temperature and vibration are very dangerous for the workers. Chao et al. [4] discovered that the most dangerous of these factors (noise, vibration and low temperature) are noise and vibration. According to their research it is very difficult to assess the combined effect of noise, low temperature and vibration on the health of workers. Cardiovascular diseases and stroke in the elderly people are associated with the night time vibration and noise levels. The exposure to vibration and noise at night is more relevant for the start of cardiovascular disease than daytime vibration and noise exposure [5]. Low frequency noise affects the human health annoyance, and the occurrence of annoyance increases with higher sound pressure levels of low frequencies. Low frequency noise annoyance can cause diseases like headaches, unusual tiredness, lack of concentration, irritation, and pressure on the eardrum. Data suggest that also sleep may be negatively affected [6].

According to European legislation [7], the employers have to measure the vibration levels at appropriate intervals to lessen the risks at work. Due to practical constraints, it is very much difficult to measure for long periods; ISO 2631 standard allows the employers to take short term measurements of vibration exposure levels for evaluation [8].

Several studies have proved that the development of musculoskeletal disorders (MSDs) may be caused by vibration exposure, excessive biomechanical load and psychosocial factors [9]. Exposure to hand-arm vibration may cause white finger disorder which significantly affects the work ability of the workers. Stress and perception thresholds also play a vital role in determining the working capacity of the workers under HAV exposure [10].

Numerous studies have been conducted on noise levels and their adverse health effects on stone crushing workers. However, hand-arm vibration exposure due to powered drill machines, grip strength measurement before and after exposure to vibration and health issues associated with the vibration and other environmental factors were not discussed in detail in the literature.

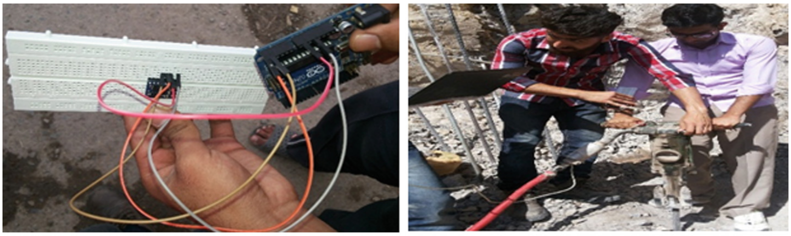
2 Materials and Methods

To study the effects of hand-arm vibration on stone crashing workers, we visited a stone crashing site on the Margalla hills (Pakistan). There workers were working with powered hand drills to break the stone. Official approval from the site owner and consent of the workers were taken to measure the vibration and grip strength of the workers, and collect health personal data. As recommended in the literature [11], in order to reduce possible sources of stress, the workers were informed about the way the data were going to be collected and for what purpose.

At first hand arm vibration data were collected using a 5340B USB Vibration measurement system. The data acquisition system includes 7543B USB accelerometer, 6330A-pin to USB cable and 9008 VibraScoutTM Triaxial measurement software program (DYTRAN INSTRUMENTS, INC). It also includes an onboard temperature sensor. For collecting acceleration data, the sampling frequency was set at 1600 Hz with an update rate of 0.20 s and recording duration of 60 s.

Then, an Arduino board was used for HAV measurement. The Arduino board is one of the emerging devices that can be used not only for measurement of hand-arm vibration but also for robotics, as goniometer for the body assessment, to measure the PH of soil etc. There are many different products of Arduino board, but the Arduino UNO product is used for the HAV assessment by connecting it with an accelerometer.

The Arduino is a hardware device which gathers data from the working environment. It consists of different parts like USB connector, Power Connecter, analogue reference etc. The Arduino board was connected with a computer through the USB COM port. The accelerometer was connected with the Arduino UNO through the analogue for connections and the power in port using jumping wires by bread board of sequence power in port of 5 V (5 volts) with VCC_IN of Accelerometer G285 and the GND (ground) with GND (ground) of accelerometer and Analogue. In A4 of Arduino with SDA of accelerometer and A5 of Arduino of with the SCL of the accelerometer. First, we installed the Arduino software, then we used the built-in code of accelerometer for Arduino UNO (Interface is shown in Fig. 1(a)) and integrated the code to take the reading. The measures were dynamic and in three reference axes X, Y and Z. The connections and adjustment of sensor on a worker are shown in Fig. 1(a) and (b).



(a) **(b)**

Fig. 1. (a) Arduino Board connections (b) Vibration reading during work.

For every worker, the measure for the first 5 to 10 s was the reference measure (along X, Y, Z axes), and the remaining measure up to 1 min was the actual measure. Then we made an Excel file to perform an analysis through Minitab software. We compared the results with international standards.

In addition, the grip strength of workers with white finger disorder was measured by means of the JAMAR® Plus+ Digital Hand Dynamometer (Fig. 2). The body of the dynamometer is made of aluminum with a scratch resistant UV coating. The dynamometer shows an isometric grip force from 0 to 200 lbs. (0–90 kg). The dynamometer is equipped with digital load cell technology which can calculate the average grip strength, standard deviation and coefficient of variation.

Fig. 2. JAMAR® Plus+ Digital Hand Dynamometer.

3 Hand-Arm Vibration Measurement

The basis for the evaluation of vibration risk is provided by ISO 5349-1:2001 [12]. The assessment of the level of exposure to vibration is based on the calculation of daily exposure A(8) expressed as equivalent continuous acceleration over an 8-h work period, that can be calculated through Eq. (1). For the determination of A(8) it is not necessary to measure over 8 h. It is sufficient to make short-term measurements during representative work periods. The results are normalized to 8 h.

$$A(8) = a_{hv}\sqrt{\frac{Te}{To}}. \qquad (1)$$

Where a_{hv} is the vibration total value of the frequency-weighted acceleration during the exposure to machine or process, T_e is the total daily duration of exposure and T_o is the reference duration of 8 h.

For hand-arm vibration, a_{hv} is calculated as the square root of the sum of the squares (vector sum) of the root mean square rms values a_{wx}, a_{wy} and a_{wz}. These are measured as the accelerations in three orthogonal directions and frequency-weighted. The vibrationtotal value $a_{hv}$is calculated as follows:

$$a_{hv} = \sqrt{a^2wx + a^2wx + a^2wx}. \qquad (2)$$

Figure 3 shows the coordinate system used to measure HAV. As a consequence, the 3 accelerometer channels were aligned with the powered drill machines.

35 stone crushing workers using powered rock drilling machines were selected for the measurement of hand-arm vibration and hand grip strength. Both older age workers as well as younger workers were involved in the study. The vibration readings were taken 3 times for 1 min for each worker in each axis and the average of the readings was used in the study.

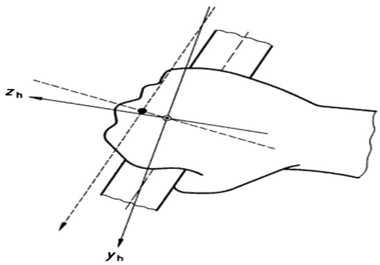


Fig. 3. Coordinate system used for HAV [13].

4 Results and Discussion

4.1 Vibration Levels

Figures 4, 5, 6 and 7 show time and frequency trends of vibration levels. Fluctuations in the HAV values are due to different types of rocks being drilled and the gripping of drill machines by the workers.

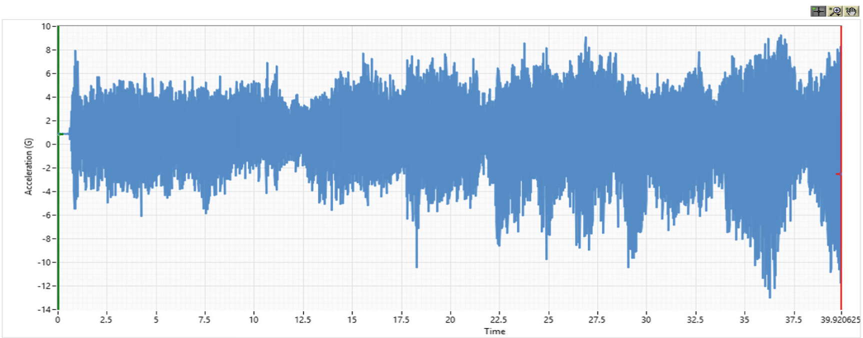


Fig. 4. HAV data from x-axis.

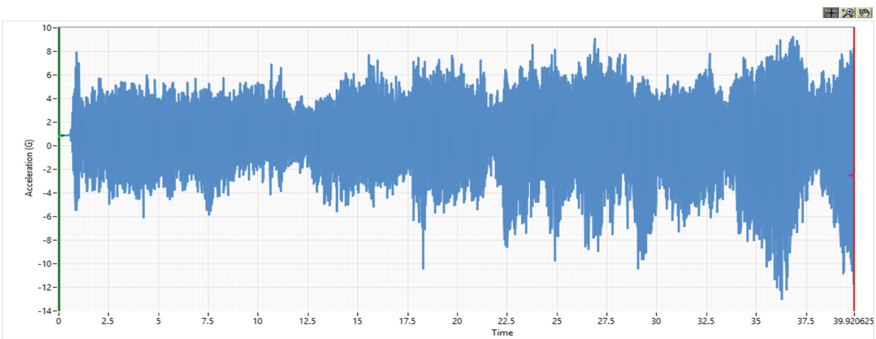


Fig. 5. HAV data from y-axis.

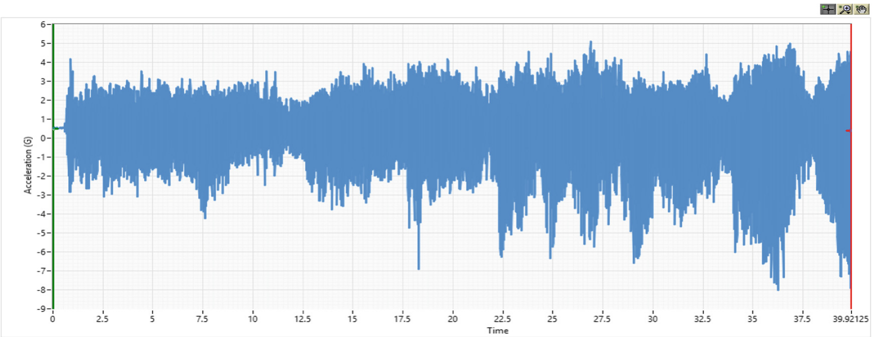


Fig. 6. HAV data from z-axis.

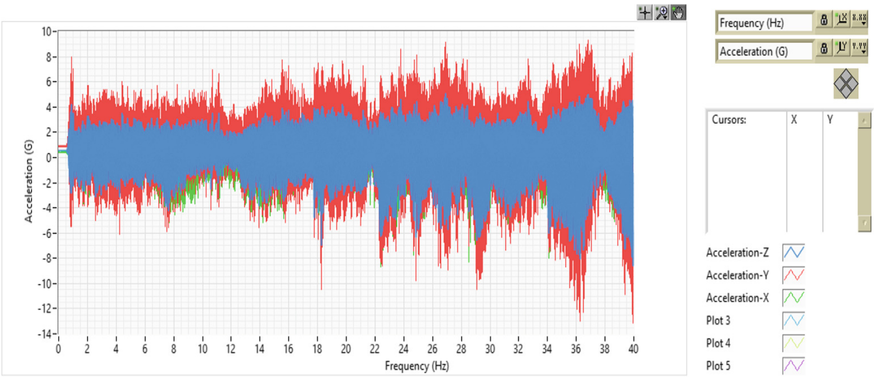


Fig. 7. HAV data from all the three axes.

The average maximum vibration levels found at x, y, z axes with the Arduino board and the USB accelerometer are shown in Table 1.

Table 1. HAV levels of stone crushers using hand drill machines.

	Arduino Board		7543B USB accelerometer	
	Avg. Max HAV (ms^{-2})	SD (ms^{-2})	Avg. Max HAV (ms^{-2})	SD (ms^{-2})
a_{wx}	16	2.22	8.5	1.53
a_{wy}	10	3.5	12.4	2.32
a_{wz}	24	3.74	8.1	1.43
a_{hv}	30.53	–	17.08	–

According to European legislation [7], for hand-arm vibration the daily exposure limit value standardized to an 8-h reference period shall be 5 ms^{-2}.

Based on Eq. (1), the maximum total daily duration of exposure T_e is around 0.2 h in the case of Arduino board and 0.7 h in the case of the USB accelerometer. These durations are extremely short and unlikely for stone crashing activity. These results are consistent also with the TLV recommended by ACGIH. Indeed, according to ACGIH the maximum value of the acceleration which shall not be exceeded for a total daily exposure duration less than 1 h is equal to 12 ms^{-2}.

4.2 Health Hazards and Working Conditions at Crushing Site

Only few workers out of the 35 included in the study have knowledge of vibration exposure and hazards related to noisy environment. A general survey form was used with the support of a physician to collect the data of health hazards of workers at crushing site. Figure 8 shows the percentage of workers affected from different types of occupational pain and diseases.

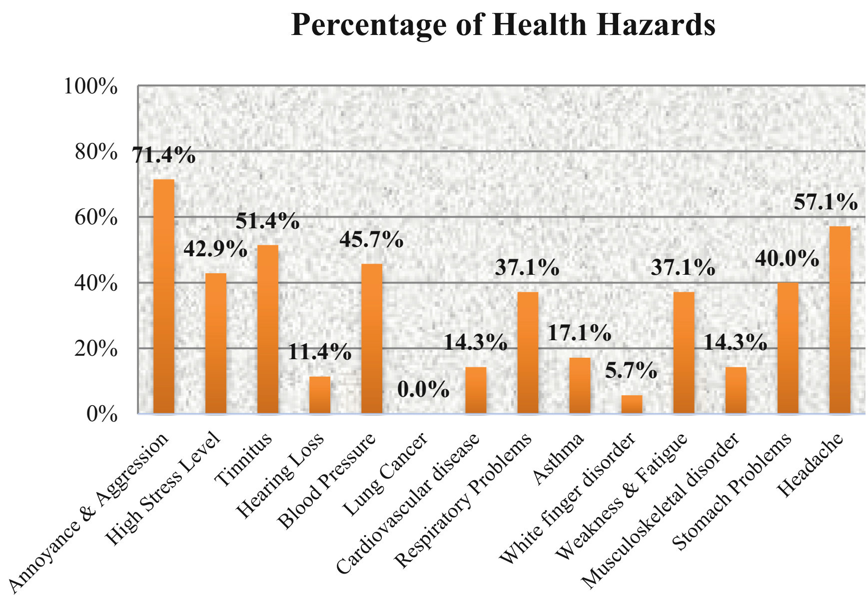


Fig. 8. Health issues of stone crushing operators.

Most of the diseases were found in old aged people probably due to their long exposure to difficult working environment. Annoyance & aggression was found in 71.43% of the workers and the main cause could be high noise level and high temperature at the crushing site. Long exposure to high noise levels can increase blood pressure which in turn produces annoyance and aggression. Also, nervousness, high stress level, muscle pain and hearing problem called “tinnitus” are due to noise from drill machines and other crushing machinery [14]. About 51.42% of workers were facing the problem of Tinnitus and around 11.42% were having permanent hearing loss. 5.71% of the workers were having white finger problem while cardiovascular and respiratory problems were also significant. This was supposed to be due to the lack of protection from dust. Indeed, only few workers were using dust filters during the work. Headache problem was found in 57.14% of the workers and the main cause of this problem was probably constant blasting of rocks and high noise levels at the site. Weakness and fatigue are also associated with that cause.

Due to poor job security, the workers looked afraid in sharing their health problems during the interview; therefore, the actual percentage of diseases could have been underestimated.

4.3 Grip Strength of Stone Crushing Workers

Hand grip strength of the workers was measured using Jamar digital hand dynamometer. Measures were taken before the start of work and after using the stone drill machine for one hour (see Table 2).

Table 2. Grip strength of stone crushing workers before and after using drill machine.

Sr. No	Grip strength at start (kg)	Grip strength after 1 h of work (kg)
1	72.5	50.7
2	46.9	43.6
3	49.4	42.2
4	58.7	45.6
5	49.3	40.0
6	85.9	72.2
7	49.2	41.5
8	63.2	54.7
9	43.2	43.6
10	47.5	39.7
11	78.7	62.8
12	57.5	59.5
13	48.5	42.1
14	63.7	70.2
15	56.5	57.7
16	47.9	49.0
17	57.2	55.5
18	69.0	55.2
19	81.0	74.5
20	48.0	53.5
21	64.2	55.3

(*continued*)

Table 2. (*continued*)

Sr. No	Grip strength at start (kg)	Grip strength after 1 h of work (kg)
22	67.8	67.3
23	55.0	44.8
24	51.0	40.4
25	69.8	54.5
26	41.8	44.7
27	75.5	64.5
28	41.6	35.9
29	48.2	37.1
30	50.6	48.7
31	62.3	64.5
32	54.9	51.6
33	56.8	54.8
34	61.6	60.2
35	62.8	54.8
Average grip	58.22	52.36

The results show a significant average difference of 5.86 kg of force in the grip strength of the workers. This confirms that the vibration level and fatigue level of worker significantly affect the grip strength of the workers.

4.4 Hand Activity Level (HAL) Score Levels

The ACGIH Threshold Limit Value for hand activity considers average hand activity level or “HAL” and peak hand force [15]. It represents conditions to which it is believed nearly all workers may be repeatedly exposed without adverse health effects [16]. Hand activity level was determined to know how difficult the task is and what are the health risks associated. It is aimed to monotask jobs with 4 or more hours of repetitive handwork. The HAL score was calculated only for those workers suffering from white finger disorder (see Table 3).

Table 3. HAL scores of stone crushing workers.

	No. of workers	Range	Minimum	Maximum	Mean	Std. Deviation
Age	35	24.0	18.0	42.0	25.93	5.23
Daily working time	35	4.00	8.00	12.00	8.22	1.25
Hand activity level	02	2.25	6.75	9.00	7.87	1.79

According to TLV an average HAL close to 8 does not cause adverse health effects only if the normalized peak force (ten times the ratio between peak force and the posture specific reference strength) of the activity is extremely low (<2), which is an unlikely condition for stone crushing workers.

5 Conclusions and Recommendations

This research has investigated the hand-arm vibration exposure levels in the workplace and the effects of vibrations on the health of stone crushing workers. In addition, the HAL score and the loss of grip strength were calculated.

The hand-arm vibration measurement results show that the measured values of vibration are notably high. Constant exposure to such levels of vibration can cause vibration induced health disorders, mainly the white finger syndrome among the rock drill operators. Similar results were found also for the HAL score. Furthermore, a significant reduction of the grip strength of the workers was observed.

The survey indicated that the health impacts on workers include hearing disorders, dermatological impacts, respiratory problems, eye irritation, headache and accidental injuries. From the results, it can be clearly deduced that stone crushing operators are prone to various hearing and vascular disorders which in long term can produce permanent disorders.

The time of exposure to hand-arm vibration due to powered drill machine should be significantly limited in order not to affect workers' health. It seems that the occupational diseases associated with vibration are not given much consideration in the site under examination, and probably in the stone crushing industry in Pakistan. Increasing workers' awareness of risks connected to the use of powered machinery and of the importance of using personal protective equipment is needed. In order to investigate all the causes of musculoskeletal disorders further analysis could be carried out using the tools and methods available in the literature (e.g. [17]).

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Understanding Shoulder Injury

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Abstract. Discomfort, restriction of motion, pain, and injuries to the hard and soft tissues of the shoulder are a frequently reported occupational and non-work issue. Outside of trauma, shoulder-related issues often result from physical stressors in the individual's overall life, from individual and personal factors and lifestyle choices. This paper will discuss the ergonomic and individual/personal risk factors associated with the development of shoulder problems to improve understanding of the multitude of sources for shoulder pain and injury, and provide guidance toward reducing shoulder injury potential through effective task, tool, and work design as well as in educated injury and accident investigations.

Keywords: Shoulder injury · Risk factors

1 Introduction

The shoulder is one part of the biomechanical chain that begins with the hands and ends in the shoulder, neck/shoulder region. Loads, motions, and postures of the hands, forearm, and upper arm are balanced by the shoulder and to some extent by the region of the neck-shoulder region, so while this paper will address "shoulder" issues, the activities of the hands and arms and their impact on the shoulder and neck-shoulder region cannot be totally ignored.

Aches and pains in the shoulder region are not unusual and the overall frequency of shoulder-related disorders is second only to those for low back problems. Reported rates for shoulder problems are quite variable, depending on the definition of "problem," with typical prevalence rates from 6% to over 26%, incidence rates of from 0.9% to over 2.6%, and with occupations, lifestyles, or sports with higher shoulder overuse having higher rates of complaints. [1–6]

2 Basic Shoulder Anatomy

The shoulder joint is the most complex and flexible joint in the body and is designed to allow considerable joint flexibility and motion rather than for overall strength and load bearing capacity. The shoulder consists of three bones, the scapula (shoulder blade), the humerus (upper arm bone), and the clavicle (collar bone); a large number of muscles

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that support the scapula, the neck/shoulder region; and the actual shoulder joint and related supporting joints.

2.1 Bone Structure

The scapula is the origin for many of the power, stability, and motion generating muscles of the shoulder joint. There is a bone projection called the acromion that goes from the back of the scapula upwards to the clavicle where it forms the acromialclavicular (AC) joint and a second projection from the front facing side of the scapula called the coracoid process that angles upwards to the AC joint region. The gap between the AC joint and the clavicle is called the subacromial gap. The AC joint and upper end of the coracoid process are connected by a strong ligament that stabilizes the AC joint and the coracoid process and also creates a strong covering over the subacromial gap that contains bursa and through which tendons and nerves pass from the scapula to the shoulder joint.

2.2 Shoulder Joints

The primary joints in the shoulder are the Glenohumeral joint (GH) or the "shoulder joint" which is where the head of the humerus joins the shoulder joint on the scapula and three other shoulder supporting joints, the Acromialclavicular joint (AC), the Scapulothoracic joint, and the Sternoclavicular joint. These joints and associated muscles, tendons, and ligaments provide support and stability for the shoulder and the neck-shoulder complex. The GH joint is the primary joint involved in normal shoulder motion and the AC joint provides support and motion control of the shoulder and scapula, particularly with loads and awkward postures.

2.3 Shoulder Muscles and Their Actions

The flexibility, load bearing, and control of the shoulder joint rely on a number of muscles in the scapula, shoulder, upper arm, torso, and neck-shoulder region. The muscles of the scapula, upper arm, and torso allow stabilization, elevation, and positioning of the GH joint, and the rotator cuff muscles, and the deltoid and upper arm muscles allow further posture control of the GH joint and the forearm. The GH joint itself is a loose ball and socket joint that has the rounded head of the humerus held in a shallow socket in the scapula by the long tendon of the biceps, the deltoid, and the four muscles of the rotator cuff, the Infraspinatus, Supraspinatus, Subscapularis, and the Teres Minor. Additional joint stability comes from a ring of fibrous tissue around the shoulder joint socket, the labrum that deepens the socket joint and is an attachment point for a number of the tendons of the rotator cuff.

The rotator cuff muscles connect the scapula to the humerus with their tendons passing around the head of the humerus, through and around the subacromial gap and surrounding bursa to their attachments on the head of the humerus and labrum. Additional motion and stability of the shoulder joint is provided by a number of muscles, including the Deltoid, Pectoralis Major, Infraspinatus, and Latissimus Dorsi.

3 Shoulder Injury

There is a wide range of shoulder problems that can range from transient not well-defined aches, pains, and soreness of the soft tissues of the shoulder often called nonspecific disorders, NSD's, to more serious conditions such as impingement, tendonitis, bursitis, arthritic changes and tears of the rotator cuff. While rates of different types of shoulder injury vary, for purpose of this paper, the most commonly reported shoulder problems are summarized next.

3.1 Persistent Soreness, Pain

Persistent shoulder discomfort or NSD's are the most commonly reported shoulder problem and reflects the complexity of the shoulder and its response to overuse, aging, obesity, medical/personal issues, a more significant injury to the hard or soft tissues of the shoulder joint or, in some cases, radiating pain from a cervical spine injury. Psychosocial factors are also implicated in persistent shoulder soreness issues as stress can create static postures and loadings. NSD are of importance as they may reflect the early stage development of more significant injuries if exposures continue.

3.2 Shoulder Arthritis

Arthritis generally refers to degenerative changes of the cartilage including cartilage thinning, development of holes in the cartilage as thinning progresses, bone to bone contact after cartilage loss, bone spurs, and alterations in bone form associated with these changes. Shoulder arthritis generally appears in the GH or AC joints and its development is associated with heavy physical work, a history of shoulder overuse, sports, sub-traumatic injury to the shoulder, some individual or personal conditions or more commonly, a combination of the above. The term "degenerative changes" is also used to describe these injuries or changes in the joint as well as to the changes in the tendons with overuse, aging, or trauma.

3.3 Bursitis

Bursitis is the irritation and swelling of the soft lubricating sacs, the bursa, that surround the tendons and joints/bony projections. Bursa protect these structures and allow easy sliding of the tendons during shoulder and upper arm motions. Bursitis is associated with repetitive shoulder/arm motions, work with poor shoulder postures, static loadings, an impact or degenerative changes in this area, or more commonly, a combination of these factors. Age plays a role in bursitis as the lubricating power of the bursa decreases with age and with aging and overuse, the tendons also begin to wear and fray, possibly accelerating irritation of the bursa. While subacromial bursitis is most "common" due to the size of the bursa and its location in the subacromial gap, any of the other bursa can be affected.

3.4 Tendinitis

Tendonitis is an irritation or the damage/fraying of the tendons due to repetitive motion, outward arm rotation combined with abduction, overexertion, or static or awkward postures of the shoulder. The rotator cuff tendons and the supraspinatus tendon are particularly prone to this type of injury.

3.5 Impingement

Impingement (syndrome) results from the compression of the tendons of the rotator cuff, the subacromial bursa, and other soft tissues in the subacromial gap when the arms are extended overhead; with sustained or static work postures; hunched shoulders; and in tasks with the arms extended fully downwards with effort; Impingement can facilitate bursitis and arthritic changes in this joint region, bone spurs, thinning cartilage, fraying and tearing of the tendons in this region, and perhaps some types of frozen shoulder.

3.6 Frozen Shoulder (Adhesive Capsulitis)

This occurs when the joint capsule of the humerus head adheres to the shoulder blade, causing shoulder pain and stiffness. Static work with awkward or hunched shoulder postures and repetitive, heavy work with poor postures of the arms and shoulder and some types of bursitis are all linked to frozen shoulder syndrome.

3.7 Rotator Cuff Injuries

Pain, discomfort and injuries to the tendons and the muscles of the rotator cuff are a commonly reported problem and include discomfort/pain from tendonitis, changes in free movement, labrum tears, strains, degenerative changes, and tears to the rotator cuff muscles and tendons. A rotator cuff tear injury refers to the wearing, fraying, or degeneration of one of the four rotator cuff tendons, a physical tear of one of the tendons, a tear of the muscle itself or a partial or complete detachment of the tendon from its attachment point(s). Injuries to the rotator cuff result from an acute trauma to the shoulder, a fall onto an extended arm, regular or sudden rotation and abduction of the arm, a sudden heavy force on the hands when the arm is extended, exertion of effort with the hands with arms extended straight down, aging and general overuse of the shoulder. Injuries to the supraspinatus and infraspinatus are more frequently reported.

Rotator cuff tears/injuries are not always symptomatic and the rate of diagnosed non-symptomatic rotator cuff injuries is about two to three times the rate of symptomatic rotator cuff injuries. While tears are found in all age groups, individuals above 50 years of age show an increase in both symptomatic and asymptomatic [7–9].

4 Personal and Ergonomics Risk Factors

Personal or individual features and ergonomics stressors/risk factors are both significantly associated with an increased potential for development of shoulder problems of all types. Both types are usually present at the same time with the risk of shoulder injury related to the number of risk factors present [10].

Individual or personal factors such age, sex, BMI, sports, and home activities can influence the development of shoulder injury but the picture is far from conclusive, clear, or consistent due to how data is collected and interpreted. It is also not clear if the same sets of individual/personal risk factors apply to both sexes, suggesting other factors may be in play. Some general or least contested examples include the following:

4.1 Age and Sex

While shoulder injuries appear in both sexes across all ages with males generally having a higher rate than females, there is an increase in shoulder problems, injuries, and degenerative changes of the shoulder after 50-years of age with the type of injury often highly associated with occupation, years of exposure to shoulder stressing activities/work, lifestyle, sex, and perhaps psychosocial factors [1, 2, 4, 9–13].

4.2 Prior Upper Extremity Injury

A prior, significant musculoskeletal injury to the upper extremity is regularly reported as increasing the potential for a later upper extremity injury, including the shoulder [13] The exact reasons for this are not clear.

4.3 Obesity

This does not appear to be a singular issue independent of other medical issues, age, sex and occupation, but obesity does seem to become an issue in rotator cuff problems and "other shoulder pain and injury" as the BMI reaches 35.

4.4 Genetics

This is a complex and controversial issue as conclusions linking shoulder problems with genetic issues are often not well distinguished from effects of sex, age, and history of shoulder straining exposures [7, 14]. Genetics, as it applies to injury causality or association is an area beyond the scope of this paper.

4.5 Smoking

Smoking appears to have an adverse impact on shoulder pain, injury, and rotator cuff injury and tears, apparently due to the reduction in oxygen blood uptake in smokers that can delay healing of injury. Other well-constructed studies of shoulder injury do not find strong support for this position [4, 13].

4.6 Sports Activities

Outside of intense, shoulder straining sports, sporting activities seem to have a mixed impact on shoulder problems [15].

5 Ergonomics Risk Factors

Ergonomics risk factors associated with shoulder problems include posture, exertion of effort, frequency, static postures, and hand-arm vibration. Almost always, a multitude of these risk factors are present at any one time which makes determining any unique contribution more difficult outside of well-controlled field studies or in a laboratory. As noted above, there is an increasing risk of shoulder overuse/injury as the number of these risk factors present in a task/activity increases.

5.1 Posture

Posture of the shoulder and the upper arm is referenced to a neutral or relaxed posture of the body where the arms are alongside the body. Motions of the arms-shoulder from this neutral posture around the body are defined in terms of abduction, adduction, flexion and extension of the shoulder-arm, and lateral or medial rotation of the arm. Awkward shoulder postures are generally considered as those activities requiring overhead work, work with hands above the shoulder, work with arms/hands behind the midline of the body, abduction of shoulders/elbow away from the body, static work in these postures.

Awkward, static, or extreme postures of the shoulder/upper arm have long been linked with the potential for development of shoulder pain and injury, particularly when other risk factors are present [4, 16]. The reviews of the scientific literature on musculoskeletal disorders, and shoulders in particular indicate there is evidence for a significant increase in shoulder problems when shoulder flexion or abduction exceeds 60°, perhaps as low as 45° [4, 12, 17–20]. From a physiological perspective, there are significant reductions in blood flow and increased tissue fatigue with arm angles as low as 30° indicating a second limiting or cautionary posture threshold to be considered, possibly explaining the large number of shoulder problems with computer based work with abducted arms/elbows, extended, abducted and externally rotated arms for mouse use [21].

5.2 Repetition

Repetition is the frequency with which a shoulder/upper arm motion is repeated and may be referenced to duration of an activity, or a static posture. The various references on shoulder injury all indicate there is evidence for a general adverse effect of "high frequency" (repetition), and for static or long duration activities but that it must be considered with other risk factors [17–19].

5.3 Hand Arm Vibration (HAV)

Hand-arm vibration is usually combined with tool weight and static postures from holding the tool, and HAV intensity and frequency content. Occupations with high (intensity or duration) HAV exposures have higher rates of shoulder injuries, tendinitis and arthritis in particular [11, 15, 22].

5.4 Heavy Work, Exertion of Effort

Work that is defined or considered as heavy, intense, or "shoulder straining" by observation, employee reports, or actual loads reports is consistently identified as a risk factor for shoulder pain and injury. While there is little clear definition on what is an acceptable load/exertion to protect the shoulder in all types of work, an upper maximum of a 10 kg load lifted/handled overhead, 25 kg for straight arm exertions with hands below knee level, and 50-kg for pushing pulling tasks are common. The various review of shoulder injury all note that load/exertion is combined with the other ergonomic risk factors as well as personal ones.

5.5 Psychosocial Factors

Psychosocial factors are a grouping of job and job-related interpersonal factors or conditions that were once ignored or grouped into "job stress". These factors include, but are not limited to lack of control of work and work pace, job ambiguity, paced work, and co-worker and supervisory interpersonal issues. While these are not as clearly controlled or quantified as ergonomics or individual risk factors, they can have an impact on the development and reporting of neck- shoulder injuries.

5.6 Shoulder Safety Recommendations/Guides

There is a general understanding of the *outer* bounds of tolerable or least stressful shoulder straining activities and postures in work and lifestyle activities. But as discussed by a number of authors, there is a lack of consistency in defining ergonomics and personal risk factors associated with shoulder injury to allow highly specific, cross task, population and age definitions of acceptable exposures [6, 19].

However, there are a number of recommendations on task/postures and loadings that are recognized as having potential for shoulder overuse, recommendations that can be used to increase alertness and appropriate response to injuries or complaints of shoulder issues. These include the following:

- Regular, repetitive, or sustained work with hands at or above shoulder or head level.
- Work requiring frequent, long reaches in front of the body.
- Lifting loads of 10 kg or more above shoulder level.

- Work that requires regular, frequent or sustained awkward postures of the shoulders, arms.
- External rotation of the hand-arm with abduction.
- Tasks requiring regular or sustained hunched shoulders such as in computer work, hand assembly.
- Elbow-shoulder abduction of more than 20 – degrees.
- Using heavy, vibrating tools.
- Regular or frequent abduction or flexion of the upper arm of more than 60°.
- Exerting effort with arms extended below knee level.
- Pushing-pulling loads of more than 50-kg.
- Sustained work with elbows abducted more than 30° and abducted and extended more than 30°.
- Working for more than 10% of a work cycle with 90° or more of shoulder flexion or extension.

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Firing of a Cannon: Biomechanical Evaluation of Ergonomic Hazards

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Abstract. Musculoskeletal-related occupational illnesses and injuries are endemic in the military and make up a majority of medical visits resulting in decreased combat readiness and degraded human performance. Twenty-five U. S. Marines were involved in a two-day observational study of their live fire exercise. 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. Biomechanical modeling using Three Dimensional Static Strength Prediction Program 6.0.2 found elevated risk for the wrist and low back. The study also 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 · Biomechanical modeling · Crew fatigue · M198 155-mm howitzer · Ergonomic · Health hazards · Back injury · Exertion · Military · Manual material handling · MILSTD 1472F

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 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

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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 rounds fired in a designed time period 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 when not deployed.

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 or biomechanical loading 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]. In a previous paper we reported findings of self-reported levels of exertion, pain, and fatigue by gunners increasing throughout the day. 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. The symptoms of fatigue and pain associated with heavy exertion can also decrease worker morale and lead to increased errors and reduced work quality [9].

In response to anecdotal reports of personnel becoming injured during routine training activities, the U.S. Marine Corps contacted our ergonomics consultant group to study the "Call for Fire" exercise in order to answer three questions (1) What are the injury experiences of gunners during non-combat training activities; (2) what is the biomechanical loading on the spine and other joints; and (3) are these symptoms leading to increased errors and decreased morale of the artillery crews? Our approach was to observe and obtain data for assessment using ergonomic tools. This paper described the biomechanical analyses.

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" Exercise

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
   The recorder announces the fire order
2. The powder man adjusts the propellant
3. The type of round to be fired is verified
4. A round is removed from the ready board and laid into the loading tray
5. The two loaders pick up the round
6. The rammer places the ram at the back of the round
7. The breach is opened
8. The loaders bring the round up to the breach
9. The rammer pushes the round in the breach
10. The loader on the right side of the loading tray releases his grip
11. The other loader steps back and to the left of the gun
12. The powder man brings up the powder and hands it to the A-gunner
13. The A-gunner verifies the amount of powder (propellant) and places it in the breach
14. The A-gunner closes the breach and places a primer in the priming hole
15. The lanyard is attached and then pulled and the gun fires
16. 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 in standard operating procedures (SOPs) provided to the ergonomics team prior to the assessment [10].

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 97 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 97 lb round and loading tray

Fig. 2. Two handlers position the tray in front of the barrel as the rammer forces the round into the barrel

3 Procedures

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 and video recorded on the following two days by the research team to assess gunners' biomechanical loading as well as worker moral and errors. Minimally invasive methods were used to avoid interference with the mission. Videos were recorded at random times during the course of both days on all three guns and then later analyzed using biomechanical modeling to determine if moving the rounds produces an increased risk of injury for the combination of force and posture. Although the marines performed many physically demanding task during the exercise, moving of the rounds was the most frequent exposure.

The set-up, exercise training, breaks and teardown work of each crew was directly observed by a researcher and compared to the SOPs. Errors in the procedures were noted by the researchers, as was the time they occurred. 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.

The following assumptions were made to model the handling tasks and employ the MIL-STD 1742F [11]:

- The combination of lifting tasks is not accounted for in any analysis
- Length as fired (with fuse) 24 in., weight 97 lbs
- Male population
- 400 rounds were fired by each gun over a two-day period
- Each round is moved a minimum of three times

(1) Staging to pallet – carried a single with a lifting tool by one person. Starting and ending position of hands 36" from ground.
(2) Pallet to loading tray – lifted from the center of the round and placed into the loading tray by one person. Starting position of the hands 16" from the ground. Ending position of the hands 6" from the ground
(3) Loading tray into gun barrel by two persons. Starting position of the hands 6" inches from the ground Ending position of the hands 46"

Three Dimensional Static Strength Prediction Program 6.0.2 [12] was used to model the task as well as comparing the round weight, gunner posture, frequency and duration to the weight handling limits in MIL-STD 1472F [11].

4 Results

4.1 Artillery Crew Injury Experience

Finding from a previous study seen in Table 1, support the biomechanical findings for risk of injury to the back from the loading tasks. Sixteen of 25 (64%) reported becoming injured during a routine training exercise after returning home from deployment, and four (16%) were on limited duty. Of the sixteen previously injured personnel, nine (56%) reported injuries of the back. Ten of the sixteen (62%) previously injured personnel recalled becoming injured while lifting or moving cannon rounds. The population was exclusively male between 23–31 years of age, mean 23 years (STD 1.9).

Table 1. Injury experience

	Injured during training exercise	Injured to back	Injury while moving rounds	Limited duty because of training exercise
Yes	16	9	10	4
No	9	7	6	21
Total	25	16	16	25
Percentage (%)	64	56	62	16

4.2 Biomechanical

Based on the biomechanical modeling, moving the round from the pallet to the staging area produces an increased risk of injury to the wrists, Table 2 and Fig. 3. Moving the round from the pallet to the loading tray produces the greatest spinal compression due to the squatted posture and twisted torso, Table 2 and Fig. 4. Loading the gun with the loading tray produces a moderate risk of spinal injury. The risk found with all these tasks is considered under evaluated because repetition (200 per day for 2 days) and a duration 3–6 h of lifting is not included in the biomechanical evaluation.

Table 2. Results of biomechanical modeling

Body segment	Compressive forces	Result
Carrying one round from the staging to pallet		
L5/S1	506 lbs ± 30 lbs	Spinal compression *below* the action limit
Population capable of performing the task		
Wrist	15%	Above hazard threshold
Elbow	76%	Below hazard threshold
Shoulder	98%	Below hazard threshold
Torso	97%	Below hazard threshold
Hip	95%	Below hazard threshold
Knee	99%	Below hazard threshold
Ankle	96%	Below hazard threshold
Moving the round from the pallet to the loading tray		
L5/S1	1762 lbs ± 124 lbs	Spinal compression *above* the action limit
Population capable of performing the task		
Wrist	23%	Above hazard threshold
Elbow	75%	Marginal
Shoulder	50%	Above hazard threshold
Torso	77%	Below hazard threshold
Hip	62%	Marginal
Knee	97%	Below hazard threshold
Ankle	84%	Below hazard threshold

(*continued*)

Table 2. (*continued*)

Body segment	Compressive forces	Result
Moving the round and loading tray to gun (start of the task)		
L5/S1	869 lbs ± 61 lbs	Spinal compression *above* the action limit
Population capable of performing the task		
Wrist, Elbow, Shoulder, Torso, Hip, Ankle	95%–99%	Below hazard threshold
Knee	78%	Below hazard threshold
Moving the round and loading tray to gun (end of the task)		
L5/S1	359 lbs ± 21 lbs	Spinal compression *below* the action limit
Population capable of performing the task		
Wrist	69%	Below hazard threshold
Elbow, Shoulder, Torso, Hip, Ankle, Knee	97–100%	Below hazard threshold

Lifting analysis using the Department of Defense Design Criteria Stand for Human Engineering (MIL-STD 1492F) Sect. 5.9.11.3 [11] produced similar results as seen in Table 3, biomechanical modeling.

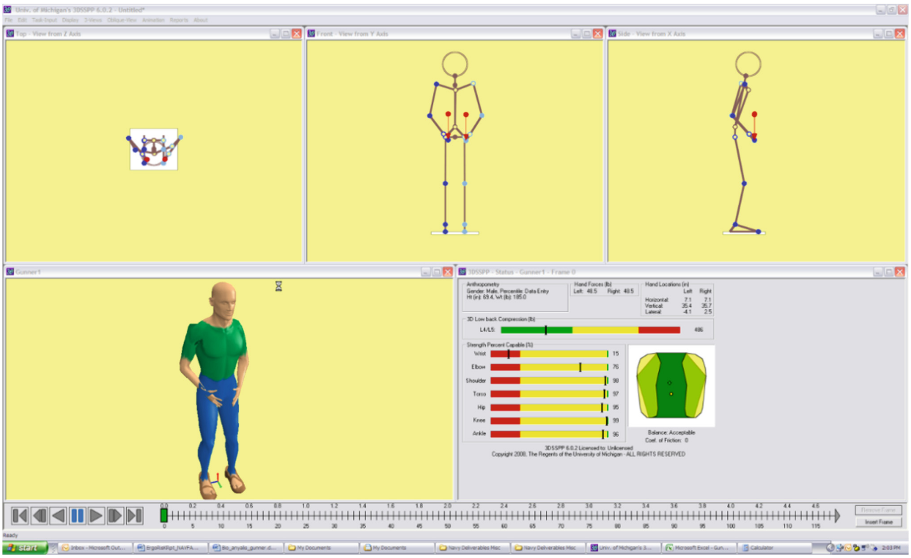

Fig. 3. Carrying one round from the staging area to the pallet

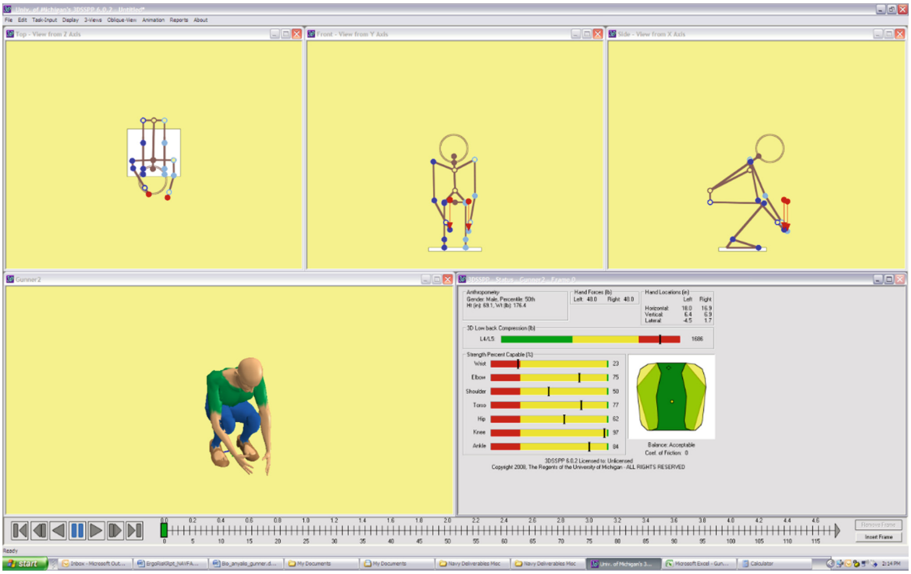

Fig. 4. Moving the round from the pallet to the loading tray

Table 3. Result of MIL-STD evaluation

Weight limit	Task factors	Result
Move one round from staging to pallet and move one round from pallet to loading tray		
64 lbs	Recommended weight limit for a one-man carry is 82lbs under optimal conditions. This value is discounted (reduced) by 22% due to the frequency of the exposure. Assume 200 lifts in a 9 h day (2.7 lifts per minute)	Round weight exceeds recommended carrying weight, the task is therefore considered above hazard threshold
Moving the round and the loading tray to the gun (start of task)		
136 lbs	Recommended weight limit for a two-man lift (below 36") is 174 lbs under optimal conditions. This value is discounted (reduced) by 22% due to the frequency of the exposure. Assume 200 lifts in a 9 h day (2.7 lifts per minute)	Round weight does not exceeds recommended lifting weight limit, the task is therefore considered below hazard threshold

(*continued*)

Table 3. (*continued*)

Weight limit	Task factors	Result
Moving the loading tray to gun (end of task)		
87 lbs	Recommended weight limit for a two-man lift (above 36") is 122 lbs under optimal conditions. This value is discounted (reduced) by 22% due to the frequency of the exposure. Assume 200 lifts in a 9 h day (2.7 lifts per minute)	Round weight exceeds recommended lifting weight limit, the task is therefore considered above hazard threshold

4.3 Errors and Crew Morale

Table 4 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. A previous study found as fatigue, pain and exertion increased throughout the day, so did the number of errors [10]. A decrease in crew morale throughout the day was also observed, as evidenced by the in-fighting, swearing and rough handling of equipment.

Table 4. 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).

5 Discussion and Conclusions

The injury experience of the artillery company after returning home from combat was exceptionally high, with 64% 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 97 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. 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 97 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 ergonomists 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 [10]. 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. 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 and a suggestion to elevate the loading tray. The Basic School was briefed at the conclusion of the study and supported the decision to utilize additional help.

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The Effects of a Combined Hip Flexion and Pelvis Movement Intervention on Postural Stability, Spinal Loading and Lumbar Flexion When Reaching and Lifting

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Abstract. Poor balance (instability) and flexing the lumbar spine towards end range of motion are risk factors associated with low back injury. One method used by educators to improve stability and lumbar posture when reaching and lifting is to promote hip flexion and posterior movement of the pelvis.This study investigated the effects of a short-term training intervention combining hip flexion and pelvis movements on postural stability, lumbar flexion and the bending moment on the spine when reaching to lift up an object. Ten healthy male participants performed the lifting task using: (1) self-selected method; (2) the taught intervention; and (3) a preferred lifting technique. Displacement of the centre of mass and lumbar flexion were significantly reduced when using the taught and preferred lifting techniques, compared to the self-selected technique ($P < 0.05$). In contrast, the bending moment was significantly higher for the taught intervention compared to the other two methods ($P < 0.05$).

Keywords: Lumbar spine · Lifting and reaching · Postural stability · Lumbar kinematics · Training

1 Introduction

Low back injuries are a major cause of work-related ill-health [1]. The aetiology of low back injuries associated with manual handling are complex, with up to 15% of LBP injuries being attributed to a loss of balance [2]. When reaching to lift up an object, postural and spinal instability combined with the high forces acting on the lumbar spine increase the risk of injury [3].

Epidemiological evidence suggests that up to a fifth of low back injuries can been attributed to situations where postural stability is compromised [4]. When reaching beyond arms-length the centre of mass (CoM) moves forward towards the boundary of support [5] and the trunk inclines forward increasing the bending moment on the spine

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[3]. The latter leads to increases in spinal compressive and shear forces. If trunk inclination is primarily achieved through lumbar spine flexion, this results in increased loading on the passive tissues of the spine [6]

Ergonomic interventions aiming to improve postural stability and reduce spinal loading have traditionally focused on redesigning the work environment to accommodate reach zones. In a number of work environments, adjusting workstation design to prevent extended reach is not always possible [7]. An alternative approach has been to promote 'safer' manual handling techniques that optimise postural stability and reduce loading on the lumbar spine. One such technique places emphasis on hip flexion [3] and posterior movement of the pelvis when inclining the trunk forward. This is believed to constrain the CoM within the base of support [8]. This study investigated the effects of using a combined hip flexion and pelvis movement technique on postural stability and spinal loading when reaching to lift a load. It compared a self-selected forward reaching technique with a prescribed reaching technique ('intervention') in order to determine the effects on postural stability and spinal loading.

2 Methods

2.1 Participants

Ten healthy adult males aged between 20 and 31 years participated in the study. Participants were excluded from the study if they had: back pain within the last six months; undergone any previous spinal surgery; any cardiovascular or neurological condition; or a musculoskeletal injury at the time of the study. The Auckland University of Technology ethics committee approved the study.

2.2 Design

The study used a repeated measures design. Participants were randomised into two groups (Group 1 and Group 2), and the sequence of exposure to the intervention differed between groups (Table 1). The independent variable was reaching technique (self-selected, instructed, and preferred) and the dependent variables were CoM displacement, trunk angle and bending moment on the trunk.

Table 1. Randomisation of trials

Group			Order		
Group 1	5 × self-selected technique (1)	Intervention	5 × instructed technique	5 × self-selected technique (2)	5 × preferred technique
Group 2	5 × self-selected technique (1)	5 × self-selected technique (2)	Intervention	5 × instructed technique	5 × preferred technique

3 Procedure

3.1 Maximal Functional Reach

A modified functional reach test was used to determine the maximal reach distance for each participant. During this test participants were required to stand with each foot on an AMTI (Advanced Mechanical Technology Inc., USA) force platform with their feet shoulder width apart, their toes pointing slightly outwards and their arms relaxed by their side. Foot position was marked on each of the force plates to ensure standardisation throughout the subsequent reaching and lifting trials [9]. In an upright standing position, participants were instructed to flex their shoulders to 90° while keeping their elbows extended and their hands clenched. From this position participants reached as far forward as possible. If participants lost their balance or took a step forward the test was repeated [9]. The distance achieved (maximum functional reach) during the test was calculated as the difference between the starting and final reach positions of the third metacarpo-phalangeal joint.

3.2 Reaching and Lifting Task

The reaching and lifting task was performed in the same starting position as the modified functional reach test. From this position, participants were instructed to reach forward and lift a box (mass of 2.6 kg), with handles, located on a table at elbow height and at 60% of their maximum function reach. The box was lifted vertically so as to be just above the table, where it was held for two seconds before being lowered back onto the table. After 2 s, participants returned to an upright standing position. Participants were given no instructions about the lifting technique to adopt (self-selected technique).

3.3 Training Intervention

Prior to repeating the lifting task, participants underwent training by a physiotherapist in the use of a technique that involved hip flexion and posterior movement of the pelvis. Participants were instructed to keep their head level and eyes looking forward throughout the task. Participants were taken through a series of progressive training steps in which key concepts were conveyed to them: "counterbalance using backward movement of the hips", "move the hips backwards until you feel a tug in your hamstrings"; "let your knees go soft"; and "raise your arms forward as you initiate hip flexion". During the intervention, the participants were asked to think about what would happen if someone were to give them a nudge and where the weight in their feet was when in the reach position. The training lasted for approximately 10 min.

3.4 Randomisation of Trials

All participants were initially required to perform five reach and lift tasks using a self-selected technique. They then underwent training in the instructed technique. They were then randomised into two groups. Group 1 received the intervention followed by five trials of the task using the instructed technique, followed by five trials using their original self-selected technique. Group 2 initially repeated the task using their self-selected technique, followed by five trials using the instructed technique. Following exposure to self-selected and instructed techniques participants were asked to perform a set of five trials using the preferred technique (Table 1).

3.5 Kinematic and Kinetic Analysis

During the reaching and lifting task 3-dimensional (3D) kinematic data was collected at a sample rate of 60 Hz using a nine-camera motion analysis system (Qualysis Medical AB, Sweden). Retro-reflective markers were attached to the skin surface of participants to identify and track the position and movement of the head, trunk, and upper and lower limb body segments. Markers attached to anatomical landmarks were used to calculate dimensions and axis of each body segment. Trunk angle was defined as the angle between the trunk and the pelvis. Three markers were attached to the box to track its movement and orientation. An initial recording of the participant in an upright standing position was used as a 'static' trial and reference posture for subsequent biomechanical modelling.

Throughout the reaching and lifting task participants stood with their feet on two AMTI (Advanced Mechanical Technology Inc., USA) force platforms. Each force platform recorded 3D ground reaction forces and moments, sampling at a rate of 1200 Hz. Kinematic and kinetic data were synchronised and collected for each trial. Raw kinematic and kinetic data were smoothed using a Butterworth lowpass, recursive filter with a cutoff frequency of 6 Hz and 12 Hz, respectively.

3.6 Biomechanical Model

A 15 segment, 3D rigid-link dynamic biomechanical model of the head, trunk (thorax and abdomen), pelvis and right and left upper and lower limbs (hand, forearm, upper arm, foot, shank and thigh) was constructed in Visual 3D (C-Motion Inc, USA) based on the anatomical and cluster markers. Body segments were represented as geometric objects and scaled according to each individual's anthropometry. Dempster's anthropometric data were used as input parameters for estimating the mass and CoM of each body segment [10]. An overall estimate of the body's CoM was determined based on the position of each body's segment's CoM. The body's CoM displacement was the distance of body's CoM from the most anterior aspect of the base of support (a line intersecting the most anterior point of the feet). A smaller distance indicated greater forward displacement of the CoM (i.e. CoM closer to the most anterior aspect of the base of support). The peak bending moment about the base of spine (L5) was calculated for the lift using inverse dynamics (Fig. 1).

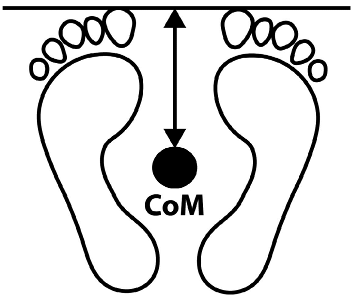

Fig. 1. Centre of mass (CoM) distance from the anterior point of the feet. A smaller distance represents a greater anterior excursion of the CoM.

3.7 Statistical Analysis

A one-way analysis of variance (ANOVA) with repeated measures was used to determine differences between lifting and reaching technique (self-selected, instructed and preferred reaching) for CoM displacement, trunk angle and bending moment. The between subject factor was group (group 1 versus group 2) and the within subject factor was reaching technique (self-selected, instructed, and preferred). Statistical analysis was performed using SPSS version 21 (IBM SPSS Statistics) with an alpha level set at 0.05.

4 Results

4.1 Centre of Mass

There was a main effect of technique on CoM displacement ($p < 0.05$). Post hoc analysis showed that the instructed technique resulted in less anterior excursion of CoM than the

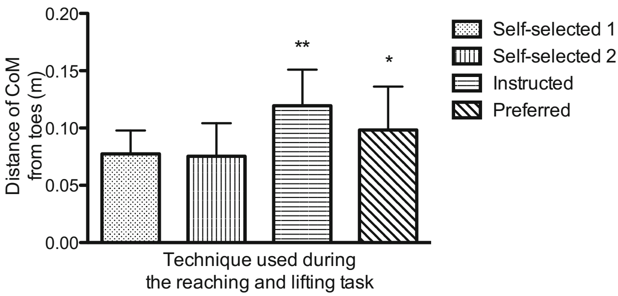

Fig. 2. Centre of mass displacement by reach technique during the lift phase. A lower value represents increased forward displacement of the CoM. NB: ** significantly different from all other conditions ($P < 0.05$). * significantly different from self-selected 1 and 2 ($P < 0.05$). CoM = Centre of Mass.

preferred reaching technique, which in turn produced significantly less displacement than the original self-selected technique ($p < 0.05$) (Fig. 2).

4.2 Lumbar Bending Moment

A main effect of technique was also found for peak bending moment ($p < 0.05$). Figure 3 shows that when using the instructed and preferred techniques, peak lumbar bending moments were significantly higher than the self-selected techniques ($p < 0.05$).

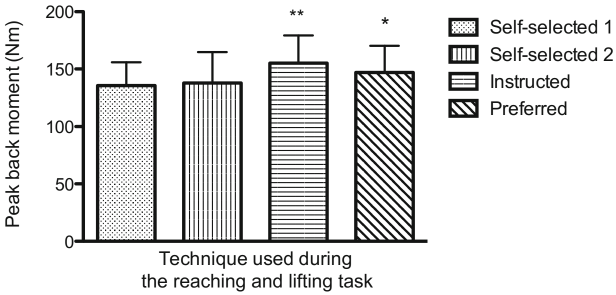

Fig. 3. Peak bending moment for each lifting technique. NB: ** significantly different than self-selected 1 and 2 ($P < 0.05$). * significantly different than self-selected 1 ($P < 0.05$).

4.3 Peak Trunk Flexion

Main effects were found for lifting technique and peak trunk angle ($p < 0.05$). Figure 4 illustrates that peak trunk flexion was significantly lower for the instructed and preferred techniques than for the self-selected lifting technique (Fig. 4).

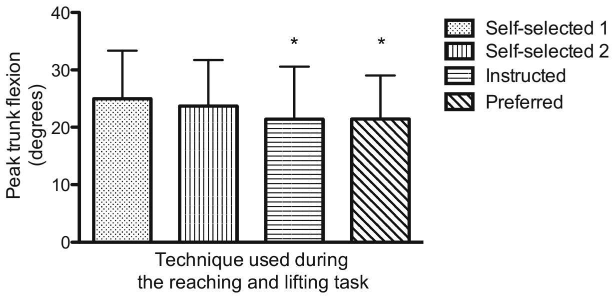

Fig. 4. Peak trunk flexion for each lifting technique. NB: * significantly different than self-selected 1 ($P < 0.05$).

5 Discussion

This study found that a simple intervention focusing on hip flexion and posterior movement of the pelvis resulted in reduced anterior displacement of the body's CoM during a reaching and lifting task. Kozak et al. [11] showed that during rapid reaching participants adopted a strategy to reduce anterior displacement of the CoM by inclining the thigh posteriorly. From a postural stability standpoint, a reduction in the anterior excursion of CoM may act as a means to improve the 'stability margin', which is defined as the minimal distance from the CoM to the toes [12]. An increase in the stability margin reduces the likelihood of the person losing their balance and provides a 'safety' buffer for any sudden external anterior perturbation of the trunk [12].

Whilst the intervention improved stability, bending moments at the lumbar spine increased for the instructed technique compared to the self-selected and preferred techniques. A study comparing novice and experienced workers found that experienced workers are prepared to adopt lifting postures that improve postural stability at the expense of increased spinal loading [13]. The increased bending moment during the instructed technique most likely stemmed from the increased lever arm between the load and the lower back as the hips moved posteriorly. Whilst peak bending moments were higher using the instructed technique, the magnitude of the bending moment was comparable to lifting a load of approximately 5% of an individual's lifting capacity [14].

An important factor to consider when interpreting bending moments is the amount of stress placed on the passive tissues of the lumbar spine. This is primarily determined by the extent to which the lumbar spine flexes [15]. Findings from the current study showed that the instructed and preferred lifting techniques produced significantly less peak trunk flexion than the self-selected technique. Less trunk flexion is likely to lead to less lumbar flexion. A reduction in lumbar flexion, particularly near the end range of motion, has been shown to reduce the stresses on the passive tissues of the spine [15]. Furthermore, reducing lumbar spine flexion places the lower erector spinae muscles in a more mechanically advantageous position to resist anterior shear forces [16].

This study showed that participants were able to adopt and make changes to their handling technique within a short period of time. When exposed to the intervention, it appeared that participants were able to make distinctions between the self-selected and instructed technique, and elected to adopt a similar technique to the new approach when given the opportunity (i.e. preferred technique). The intervention appeared to offer benefits to the handler. However, further work is needed to determine long-term retention from training in real work situations.

6 Conclusions

A training intervention focusing on hip flexion and posterior displacement of the pelvis lead to improved postural stability and reduced trunk flexion. These benefits may outweigh the detrimental increase to bending moments on the lumbar spine, particular when handling low loads. Thus, promoting hip flexion and posterior displacement of the pelvis when reaching and lifting may be of value in some situations (e.g. moderate weights and unstable load), particularly when clients present with poor postural stability and increased lumbar flexion when lifting.

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A Pilot Study of Gender Differences on Anthropometric Measurements in Singapore Population

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Abstract. This pilot study aims to collect 37 body dimensions within 12 standing and 25 sitting posture from 100 subjects and to investigate the gender difference of the subjects, aged from 17 to 60 years old. The mean stature, weight, and body mass index were 173.2 cm, 69.5 kg and 23.2 kg/m^2 for the Singapore males, and 161.1 cm, 56.8 kg and 21.9 kg/m^2 for the Singapore females, respectively. The t-test results showed that gender effect was significant in 36 measurements, except sitting elbow height, chest depth and head breadth. Singapore males had larger body dimensions than females; differences between genders were about 0.7 to 17.4 cm. In addition, the correlations between selected dimensions was also demonstrated. Overall, the anthropometric data of this study can be utilized in ergonomic product, equipment and workstation design.

Keywords: Gender difference · Body dimensions · Anthropometry · Singaporean

1 Introduction

Some problems of musculoskeletal disorder, occupational injury and pain are caused by inappropriate designs, tools and workstation. Applying adequate anthropometric data is a way to redesign products and workstations more friendly and ergonomically. Anthropometry is the study of human body measurements and its applications. Recently, anthropometry has been considered as the basic concept when designing products, tools, apparatuses and workstations to enhance users' comfort, efficiency and safety. Various groups of researchers have investigated into the relationship between anthropometric data and product/workstation. For instance, Wang et al. [1] conducted a large anthropometry survey on Taiwanese workers and pointed out the standards of primary dimensions for work environment layout planning. The application of anthropometry on product and workplace design has been reported by Hanson et al. [2] for Sweden. Kozey et al. [3] investigated the effects of human anthropometry on personal protective equipment design. In addition, Tharig et al. [4] and Gouvali and Boudolos [5] focused on comparing dimensions of students and school furniture and found that improper dimensions were been used to design desk and chair. Moreover, Vyavahare and Kallurkar [6] measured male agricultural workers' body dimensions

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and suggested that modifying and redesigning of existing equipment for the workers is needed. Therefore, a lack of anthropometric consideration in workstation or tool design may result in work-related psychological discomfort [7], physical fatigue or musculoskeletal disorder problems [8]. As shown in the previous studies, anthropometric data has the great values in design and health applications.

The anthropometric data is influenced by various factors, such as gender, age, culture, nutrition, social development and population. Due to the diversity characteristic of human body dimensions, it is meaningful for each country or population to develop its own anthropometric database for providing proper and accurate measurements. Many of adult anthropometric databases have been collected from different populations including Taiwanese workers [1], Australian [9], Algerian farmers [7], Portuguese workers [10], elderly Chinese living in the Beijing [11], Filipino workers [12], Thai people [13], Turkish people [14], Sri Lankan [4], Bangladeshi male [15], Malaysian [16], male Agricultural workers of western India [6].

However, few anthropometric data and studies have been reported based on Singapore population so far. Lim et al. [17] measured body dimensions of civilian Singaporeans, but the anthropometric data collected in 1990 is old and outdated. Singh et al. [18] conducted an experiment to measure anthropometric data of Singaporean and compared the results with USA, UK, Israel and Japan population; however, the subjects in the study are limited to candidate aviators. In recent year, Chuan et al. [19] collected anthropometric data of Singaporean adults from 315 students and focused on investigating the differences between groups (overall, Singapore citizens and Singaporean Chinese) and ethnics (Singaporean versus Indonesian), excluded genders. There was a noticeable absence of research projects dealing with gender effect on body dimensions of Singaporeans.

Since anthropometric data of Singaporeans is still lacking, therefore, the main objective of this study was to establish an anthropometric database consisting of 36 body dimensions and weight of Singaporeans. This research was also investigated the gender differences on body dimensions of Singaporean adults and evaluated the correlations of the dimensions associated with stature and body weight.

2 Methods

2.1 Subjects

One hundred subjects (50 males and 50 females) were recruited in this study. Most of them were students or employees of Nanyang Technological University, Singapore. Due to the ethnic composition of Singapore is divided into several populations and the majority of ethnic is Chinese, the data of Chinese subjects were collected and analyzed in this study firstly. The age of the subjects was under 60 years old. The average age of male and female subjects was 35.5 ± 13.5 and 33.4 ± 14.3, respectively. All subjects in this study were healthy and without any problem in normal mobility. The demographics data of the subjects are shown in Table 1. For privacy issue, all subjects were asked to sign an agreement for fully understanding the data collection and to be measured with light clothing in a room.

Table 1. Demographic distribution of subjects in this study

Age group	Male (n = 50)	Female (n = 50)
<20	0%	12%
21–30	50%	46%
31–40	16%	14%
41–50	16%	12%
51–60	18%	16%
Occupation		
Students	14%	17%
Industrial workers	11%	9%
Bankers	5%	3%
Employees	13%	13%
Doctors	2%	3%
Others	5%	5%

2.2 Body Dimensions

In total, body weight and 37 body anthropometric dimensions were collected in this study. Each measurement definition was referred to the previous studies [19–22]. Eleven measurements and 25 measurements were taken in a standing posture and in a sitting posture, respectively. Standing measurements of this study were stature, weight, eye/shoulder/elbow/hip/knuckle/fingertip height, vertical/forward grip reach, span and elbow span. Twenty-five sitting measurements were sitting height, sitting eye/shoulder/elbow/thigh/knee/popliteal height, sitting vertical grip reach, abdominal/buttock-knee/buttock-popliteal/Chest depth, shoulder-elbow/elbow-fingertip/upper limb/shoulder-grip/head/hand/foot length, and hip/biacromial/bideltoid/head/hand/foot breadth. Anthropometric dimensions could be measured from both side of a body, but only the right side measurements were taken for future data analysis.

2.3 Apparatus

The traditional manual anthropometric apparatuses were utilized in this study due to reliability, accuracy and portability considerations. The relative high accurate and precise measurements can be taken by manual measuring method when collecting anthropometric data [23–25]. Therefore, a measuring tape and two digital calipers were adopted as the apparatus to measure the 36 body dimensions. Non-stretchable measuring tape (range: 0–300 cm, resolution: 0.1 cm) was applied to measure the vertical distance to the floor, for instance, eye and shoulder height. One larger sliding caliper (range: 0–70 cm, resolution: 0.01 cm) was used for length of limbs and width measurements due to higher accuracy as compared to using the measuring tape, and the other small sliding caliper, measuring range is from 0–20 cm with resolution 0.01 cm, was used for hand and foot dimensions. A digital weighing scale (range: 0–150 kg, resolution: 0.1 kg) was used to taking body weight measurement. When measuring sitting-relative dimensions, an adjustable chair was provided to each subject. Before data collection, each apparatus was calibrated follow its' measuring standards.

2.4 Procedure

Before data collection, the subjects were informed of the aim of the study, all measurements, and procedures. Each subject has the right to quit the measurements at any time. The subjects were barefooted and wore light clothing during the data collection. All subjects were asked to perform in the same standing/sitting posture and body swings during measuring were minimized. The sequence for measuring the 37 measurements was selected randomly. The measurements were collected on the same day starting in the afternoon.

For data collection accuracy and consistency consideration, only one well-trained experimenter was asked to conduct all anthropometric measurements. The measuring tape was taped to the wall to keep it in place. The vertical dimensions were taken by eye level with the aid of a ruler to prevent parallax errors. For dimensions that are higher than eye level, the experimenter will stand on a stair for recording the measurements in order to prevent the underestimating value.

2.5 Statistical Analysis

For experimental design, the independent variable in this study was gender. Thirty-seven body dimensions were used as dependent variables. A single-factor experiment design was used to evaluate the differences between genders in the 37 measurements. The mean and standard deviation of body dimensions were reported. The gender effect on the dimensions was evaluated by t-test. The correlation coefficients among the selected measurements were calculated. All data was analyzed using SPSS 22 software package and the significance level was set at $\alpha = 0.05$.

3 Results and Discussion

3.1 The Anthropometric Measurements of Singapore Males and Females

The descriptive statistics of the 37 measurements, such as minimum (Min), maximum (Max), mean and standard deviation (SD), were calculated. Table 2 presents a summary of the anthropometric measurements for Singaporean males and females. Results show that the mean stature and weight was 173.2 ± 6.8 cm and 69.5 ± 9.6 kg for males. The mean stature and weight were 161.1 ± 6.1 cm and 56.8 ± 7.2 kg for females. Moreover, body mass index (BMI) is a common way used to estimate whole body fat. The calculation of BMI is dividing body weight (unit in kg) by stature squared (unit in m^2). The Singapore males' and females' BMI was 23.2 kg/m^2 and 21.9 kg/m^2, respectively. It means that Singaporean males and females are in the healthy range (BMI: 18.5–24.9 kg/m^2), categorized by James et al. [26] as a standard for the Asian population.

3.2 Gender Differences in the 37 Body Measurements and Compared to Previous Studies

The t-test was performed to determine the gender differences between mean values of males and females. Table 2 shows that Singaporean males had greater body dimensions than females in all the standing measurements, the differences ranged from 3.5 cm (fingertip height) to 17.4 cm (vertical grip reach). For sitting measurements, the result indicates that there were significant differences between genders in most of the selected measurements. No significant differences were observed in sitting elbow height, chest depth and head breadth between males and females.

The findings of this study have implications for product and workstation design. For example, males had higher anthropometric data than females with difference about 4.2 cm in sitting knee height and 3.2 cm in sitting popliteal height, respectively. Therefore, workstation design for males and females differ substantially as both heights for the chair and the desk will be higher for males as compared to females. This implication of measurements is to ensure that the male population has enough thigh clearance under the desk and to increase the sitting comfort as well.

In addition, two Singaporean anthropometric data, measured by Lim et al. [17] and Chuan et al. [19] were also used for comparing current and past anthropometric data of Singaporeans. The differences between two mean measurements were applied to the comparison. Results showed that more than 50% of the dimensions differed to more than 1.0 cm when comparing current study and Lim et al. [17], particularly in stature, eye height, sitting height, sitting eye height, shoulder breadth (bideltoid) and head length. The findings are in agreement with the conclusions reached by Chuan et al. [19] that there existed generation differences in Singaporeans' anthropometric data. The results also suggested that current Singaporean (both in the 2010 and in 2015) males and females are larger than those in the 1990s. Although only 100 subjects (half of each gender) were measured in this study due to time limitation, the anthropometric data in 2015 and 2010 seems to be quite similar, except for hip breadth dimension (difference about 4.5 cm). The difference might be resulted from different apparatus were used to measure body anthropometric data and different sample size [25].

3.3 Correlations Between Stature, Weight and the Other Selected Measurements

The results of the correlations between stature, weight and the other 35 body dimensions are shown in Table 3. For both genders, the results indicated that the standing measurements correlated positively with stature ($r = 0.55$ to 0.96, all $p < 0.001$) and body weight ($r = 0.37$ to 0.64, all $p < 0.001$). In addition, the majority of body dimensions with sitting measurements also associated to stature ($r = 0.30$ to 0.84, all $p < 0.05$) and to body weight ($r = 0.29$ to 0.69, all $p < 0.05$). It seems that the stature was highly related to the body dimensions in comparison with body weight. Nevertheless, no statistically significant correlation between stature and 10 of the selected measurements were obtained, such as sitting elbow height, abdominal depth, chest depth, head breadth, etc. Similar results were found in the correlations between weight and the sitting measurements.

Table 2. The 37 anthropometric data and gender differences for Singaporeans

Dimensions	Male (n = 50)				Female (n = 50)				Difference	p-value
	Min	Max	Mean	SD	Min	Max	Mean	SD		
Standing measurements										
Stature*	156.0	190.0	173.2	6.8	149.0	175.0	161.1	6.1	12.1	***
Weight (kg)	51.0	95.0	69.5	9.6	42.0	76.0	56.8	7.2	12.7	***
Eye height	147.0	187.5	161.6	7.5	139.6	165.8	150.3	6.0	11.3	***
Shoulder height	129.0	164.5	145.3	6.8	124.0	149.6	134.3	5.8	11.0	***
Elbow height	99.6	124.6	109.7	5.7	91.6	116.0	101.8	5.1	7.9	***
Hip height	82.0	106.5	97.0	5.5	82.6	103.7	92.7	5.0	4.3	***
Knuckle height	66.1	87.8	76.4	4.9	62.3	82.2	71.5	3.9	4.9	***
Fingertip height	57.2	78.3	66.0	4.5	54.8	73.3	62.5	3.9	3.5	***
Vertical grip reach	181.2	225.7	204.9	10.0	171.2	203.1	187.5	8.5	17.4	***
Forward grip reach	59.0	80.0	69.2	4.7	57.2	73.8	64.2	4.5	5.0	***
Span	158.8	195.2	176.5	7.5	148.2	173.8	161.0	7.3	15.6	***
Elbow span	80.6	98.8	88.6	4.2	66.4	89.7	80.8	5.5	7.8	***
Sitting measurements										
Sitting height	76.0	97.5	88.3	4.5	72.5	93.8	84.1	4.6	4.2	***
Sitting eye height	65.0	87.2	77.1	4.8	61.8	82.5	72.7	4.3	4.4	***
Sitting shoulder height	49.3	71.1	61.4	3.6	45.6	65.0	57.4	3.9	4.0	***
Sitting elbow height	19.0	29.4	23.1	3.0	17.5	30.0	23.1	3.1	0.0	NS
Sitting thigh height	10.2	16.0	12.9	1.3	8.7	17.0	12.3	1.6	0.6	*
Sitting knee height	46.5	68.0	52.8	3.8	42.3	56.6	48.6	2.8	4.2	***
Sitting popliteal height	39.7	49.3	43.3	2.3	35.0	45.7	40.2	2.5	3.1	***
Sitting vertical grip reach	105.0	130.5	119.5	6.2	93.2	124.7	109.7	6.5	9.8	***
Abdominal depth	17.2	29.5	21.9	3.3	14.2	31.0	19.2	3.3	2.7	***
Buttock-knee depth	47.0	62.4	55.4	3.7	43.2	60.0	52.0	3.7	3.4	***
Buttock-popliteal depth	35.6	50.8	44.9	3.5	33.9	49.7	42.3	3.5	2.6	***
Hip breadth	25.0	37.1	31.5	2.3	23.3	35.0	30.5	2.4	1.0	*
Shoulder-elbow length	29.0	41.7	37.3	2.6	29.7	39.3	34.6	2.1	2.7	***
Elbow-fingertip length	41.2	52.0	46.5	2.4	37.0	49.0	42.3	2.4	4.2	***
Upper limb length	71.0	85.5	79.0	3.7	64.0	78.7	72.0	3.5	7.0	***
Shoulder-grip length	62.0	76.4	69.4	3.5	56.0	69.5	63.2	3.4	6.2	***
Chest depth	18.7	34.1	22.4	3.2	16.5	32.0	22.0	3.5	0.4	NS
Shoulder breadth biacromid	27.5	36.8	31.6	2.1	24.6	34.2	28.4	2.0	3.2	***
Shoulder breadth bideltoid	39.9	53.3	44.9	3.0	36.7	44.1	39.8	1.8	5.1	***
Head length	16.3	20.4	18.3	0.9	15.0	19.0	17.5	0.7	0.8	***

(*continued*)

Table 2. (*continued*)

Dimensions	Male (n = 50)				Female (n = 50)				Difference	p-value
	Min	Max	Mean	SD	Min	Max	Mean	SD		
Head breadth	10.2	15.0	12.9	0.9	11.0	14.0	12.6	0.7	0.3	NS
Hand length	16.0	20.5	18.4	0.9	15.4	19.4	17.1	0.9	1.3	***
Hand breadth	7.0	9.2	8.1	0.5	6.4	8.3	7.1	0.4	1.0	***
Foot length	24.0	30.2	26.4	1.4	21.7	26.3	23.6	1.1	2.8	***
Foot breadth	8.3	11.4	10.3	0.7	8.0	11.1	9.2	0.6	1.1	***

#; All dimension are in cm; *; $p < 0.05$; ***; $p < 0.001$; NS: non-significant

Table 3. Correlations between stature, weight and the other 35 body dimensions

Dimensions	Stature		Weight	
	Male	Female	Male	Female
Standing measurements				
Eye height	0.963**	0.959**	0.593**	0.531**
Shoulder height	0.922**	0.922**	0.638**	0.556**
Elbow height	0.887**	0.890**	0.622**	0.561**
Hip height	0.750**	0.804**	0.550**	0.369**
Knuckle height	0.795**	0.739**	0.550**	0.488**
Fingertip height	0.764**	0.732**	0.586**	0.443**
Vertical grip reach	0.887**	0.881**	0.583**	0.563**
Forward grip reach	0.672**	0.550**	0.542**	0.384**
Span	0.856**	0.805**	0.604**	0.556**
Elbow span	0.740**	0.719**	0.398**	0.402**
Sitting measurement				
Sitting height	0.669**	0.545**	0.329*	0.196 NS
Sitting eye height	0.609**	0.627**	0.335*	0.174 NS
Sitting shoulder height	0.517**	0.572**	0.306*	0.241 NS
Sitting elbow height	0.182 NS	0.132 NS	0.169 NS	0.180 NS
Sitting thigh height	0.481**	0.031 NS	0.608**	0,184 NS
Sitting knee height	0.769**	0.839**	0.655**	0.529**
Sitting popliteal height	0.818**	0.690**	0.623**	0.401**
Sitting vertical grip reach	0.725**	0.648**	0.471**	0.328*
Abdominal depth	−0.057 NS	−0.150 NS	0.574**	0.526**
Buttock-knee depth	0.740**	0.581**	0.377**	0.471**
Buttock-popliteal depth	0.608**	0.606**	0.378**	0.498**
Hip breadth	0.460**	0.047 NS	0.751**	0.545**
Shoulder-elbow length	0.645**	0.675**	0.346*	0.477**
Elbow-fingertip length	0.661**	0.765**	0.551**	0.636**
Upper limb length	0.802**	0.737**	0.491**	0.610**
Shoulder-grip length	0.781**	0.698**	0.471**	0.470**

(*continued*)

Table 3. (*continued*)

Dimensions	Stature		Weight	
	Male	Female	Male	Female
Chest depth	0.085 NS	−0.111 NS	0.562**	0.484**
Shoulder breadth biacromial	0.320*	0.255 NS	0.463**	0.352*
Shoulder breadth bi deltoid	0.404**	0.391**	0.645**	0.693**
Head length	0.398**	0.137 NS	0.290*	−0.074 NS
Head breadth	0.136 NS	0.205 NS	−0.010 NS	0.198 NS
Hand length	0.647**	0.543**	0.519**	0.521**
Hand breadth	0.211 NS	0.300*	0.130 NS	0.312*
Foot length	0.436**	0.685**	0.610**	0.557**
Foot breadth	0.283*	0.078 NS	0.222 NS	0.212 NS

*; $p < 0.05$; **; $p < 0.001$; NS: non-significant

In general, stature and weight are highly associated with body dimensions. The results of this study were inconsistent, especially in sitting measurements. A partial explanation for this is that a common office chair with adjustable foam seat was used for body dimensions collecting experiment. The soft material of seat may lead to body surface deformation when sitting on the chair. Moreover, to maintain the same sitting posture during body dimension collecting (in total about 10 min) for each subject is difficult and it may also have contributed to the results of measurements [27, 28]. Furthermore, one possible reason for there being no statistical significance in correlation analysis may lie in the small sample size.

3.4 Limitations and Future Researches

Singapore is a multi-cultural society populated by people of different ethnic groups including Chinese, Malay, Indian and others. This pilot study only measured and compared Chinese population with small sample size (n = 100). In future, the collection of Malay and Indian populations are necessary in order to increase the sample size and representative of the entire population of Singapore. In addition, it may be of interest for future research to collect and develop an anthropometric database of elderly population.

4 Conclusions

To conclude, the present study is preliminary research on evaluating differences of anthropometric data between Singaporean males and females. Not so surprisingly, Singaporean males have larger dimensions than females in the majority of the selected anthropometric measurements. It also points out each population has specific anthropometric characteristics. In addition, the body dimensions of current Singaporean are also larger than past Singaporeans affecting by several factors, such as nutrition or ethnic composition. This can be a reason that sustainability collecting and updating of anthropometric data is needed. The findings of this study could be applied to improve the product design as well as workstation layout in Singapore for improving quality of life. Due to the limitations of this study, i.e. time and resource constraints, a collection would be conducted to gather more samples in the future.

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Anthropometric Evaluation of the Design of the Classroom Desk for the Eighth and the Ninth Grades of Benghazi Schools

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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 fourth phase of the project covering the eighth and the ninth grades. Anthropometric data was gathered for a total of 139 students of the eighth and ninth grades from several schools in Benghazi. 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 relatively high percentages of mismatches between several desk dimensions and students' anthropometry.

Keywords: Schoolchildren · Anthropometrics · School furniture · Classroom furniture · Children anthropometry

1 Introduction

This article reports the outcomes of the fourth 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 designs with the objective of developing the furniture design(s) that would best fit students' anthropometry. Results of the first three phases covering the first to the seventh grades are reported in [1–3]. This article covers the results of the sixth and the seventh grades.

Anthropometric evaluation procedures of school furniture have been applied in many studies [4–13]. 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

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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. [4] and was further developed and applied later by Gouvali and Boudolos [5] and Agha [6]. A similar procedure was used in the first three phases of this project study [1–3] 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 eighth and the ninth 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 139 students aged between 13 to 19 years old. The sample was randomly selected from four 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.

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 three phases of the study [1–3] are used in this current study. They are similar to the procedure used in [4–6]. The procedure uses several equations relating body dimension(s) to 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 [1–3]. All were originally adopted from [4–6] with very few adjustments to fit requirements of the current case.

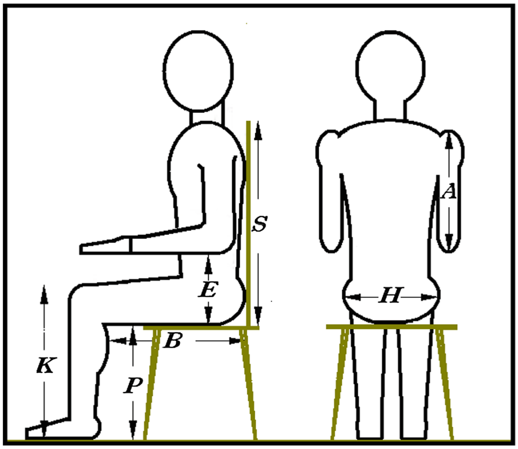

Fig. 1. The measured body dimensions

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

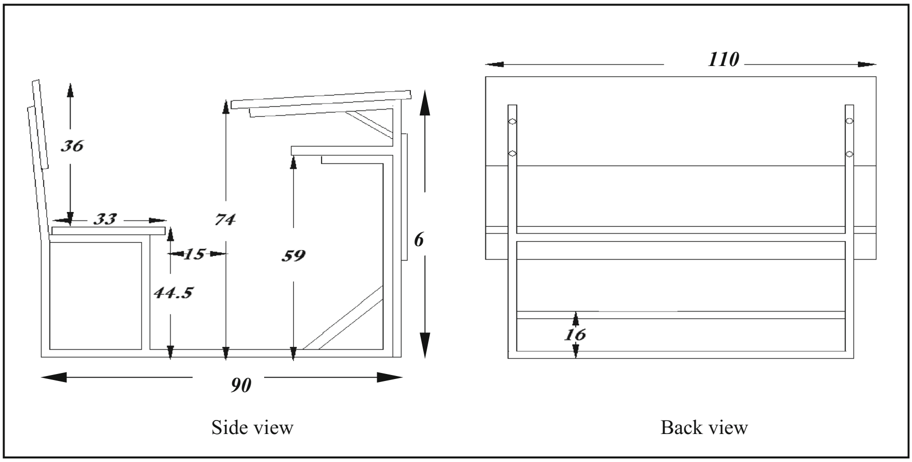

Fig. 2. Dimensions of the classroom desk (in cm).

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)[a]
Backrest height (BH)	36
Desk height (DH)	74
Under desk height (UH)	59

[a] 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)	$(P + 2)\cos 30° \leq SH \leq (P + 2)\cos 5°$ (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)	$E + (P + 2)\cos 30° \leq DH \leq (P + 2)\cos 5° + 0.8517\ E + 0.1483\ S$ (5)
Under desk height (UD)	$(K + 2) + 2 \leq UD \leq (P + 2)\cos 5° + 0.8517\ E + 0.1483\ S - 4$ (6)

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.

Table 4. Summary of the measured dimensions (mean (standard deviation), in cm).

Body dimension	Grade 8			Grade 9		
	Female (N = 42)	Male (N = 30)	Total (N = 72)	Female (N = 41)	Male (N = 26)	Total (N = 67)
Age (in years)	14.1 (0.8)	13.4 (0.5)	13.8 (0.7)	15.2 (0.7)	15 (1.0)	15.3 (0.8)
Stature	155.1 (4.9)	163.1 (4.5)	158.5 (6.2)	158.2 (5.7)	166.8 (9.4)	161.6 (8.4)
Popliteal height	39.8 (2.2)	47.9 (1.2)	43.2 (4.4)	40.6 (2.2)	45.6 (2.6)	42.5 (3.4)
Popliteal-buttock length	44.0 (2.9)	49.1 (1.4)	46.1 (3.5)	45.6 (2.8)	49.3 (4.4)	47 (3.9)
Shoulder height sitting	57.1 (3.5)	49.8 (1.7)	54.1 (4.7)	57.7 (3.2)	56.2 (3.3)	57.1 (3.3)
Knee height	47 (2)	51 (1.8)	48.3 (2.9)	48.3 (2.3)	53.8 (3.6)	50.4 (3.9)
Elbow height sitting	21.7 (3.1)	19.8 (0.8)	20.9 (2.6)	22 (2.0)	19.6 (2.3)	21.1 (2.4)
Shoulder to elbow length	38 (2.1)	30.6 (1.6)	34.8 (4.0)	37.8 (2.1)	38.6 (3.1)	38.1 (2.6)
Hip breadth	43 (5.7)	42.1 (3.3)	42.6 (4.8)	48 (5.8)	44.8 (6.1)	46.7 (6.1)

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 5. Mean and standard deviation of the upper and lower acceptable limits (mean (standard deviation), in cm).

Desk dimension	Existing measurement	Limit	Grade 8			Grade 9		
			Female	Male	Total	Female	Male	Total
Seat height	44.5	Upper	41.6 (2.1)	49.7 (1.2)	45.7 (1.7)	42.4 (2.2)	47.5 (2.6)	44.9 (2.4)
		Lower	36.2 (1.9)	43.2 (1.1)	39.7 (1.5)	36.9 (1.9)	41.3 (2.3)	39.1 (2.1)
Seat depth	33	Upper	41.8 (2.7)	46.6 (1.4)	44.2 (2.0)	43.3 (2.7)	46.8 (2.3)	45.1 (3.4)
		Lower	35.2 (2.3)	39.3 (1.1)	37.2 (1.7)	36.5 (2.2)	39.4 (3.6)	37.9 (2.9)
Seat width	55	Upper	–	–	–	–	–	–
		Lower	85.7 (6.2)	77.7 (3.6)	81.7 (4.9)	90.7 (6.8)	88.4 (7.7)	89.6 (7.3)
Backrest height	36	Upper	45.7 (2.8)	39.8 (1.4)	42.8 (2.1)	46.1 (2.6)	45.0 (2.6)	45.5 (2.6)
		Lower	34.3 (2.1)	29.9 (1.0)	32.1 (1.6)	34.6 (1.9)	33.7 (2.0)	34.2 (2.0)
Desk height	74	Upper	68.6 (3.9)	73.9 (1.5)	71.3 (2.7)	69.7 (3.1)	72.5 (3.9)	71.1 (3.5)
		Lower	57.9 (3.8)	63.0 (1.3)	60.4 (2.5)	58.8 (2.9)	60.9 (3.5)	59.9 (3.2)
Under desk height	59	Upper	64.6 (3.9)	69.9 (1.5)	67.3 (2.7)	65.7 (3.1)	68.5 (3.9)	67.1 (3.5)
		Lower	51.0 (2.5)	55.0 (1.8)	53.0 (2.1)	52.3 (2.3)	57.8 (3.6)	55.0 (2.9)

3.3 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 8			Grade 9		
		Female	Male	Total	Female	Male	Total
Seat height	Match	10	87	42	10	85	39
	Mismatch	90	13	58	90	15	61
	Above	90	0	53	90	7.5	58
	Below	0	13	5	0	7.5	3
Seat depth	Match	7	0	4	7	0	4
	Mismatch	93	100	96	93	100	96
	Above	2	0	2	0	0	0
	Below	91	100	94	93	100	96
Seat width	Match	0	0	0	0	0	0
	Mismatch	100	100	100	100	100	100
	Above	–	–	–	–	–	–
	Below	–	–	–	–	–	–
Backrest height	Match	88	100	93	88	88	88
	Mismatch	12	0	7	12	12	12
	Above	0	0	0	0	0	0
	Below	12	0	7	12	12	12
Desk height	Match	7	47	24	7	31	16
	Mismatch	93	53	76	93	69	84
	Above	93	53	76	93	69	84
	Below	0	0	0	0	0	0
Under desk height	Match	90	100	94	95	65	84
	Mismatch	10	0	6	5	35	16
	Above	10	0	6	5	0	3
	Below	0	0	0	0	35	13

3.4 Analysis and Discussion

As shown in Table 6, high percentages of mismatches were found with several desk dimensions. High above the upper acceptable limits mismatches were found, for female students, with both seat height and desk height in both grades. This indicates that female students are sitting on a desk with both seat and desk surface too high for them.

For male students, much less percentages of mismatches with seat height were found and below the lower acceptable limit mismatches were also found. This indicates that seat height is suitable for relatively large number of male students however, still for many students seat height is either too high or too low.

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 matches are found with both backrest height and under desk height. However, with backrest height mismatches are found below the acceptable limits. This indicates that backrest height is small for many students that have larger body sizes. For under desk height, mismatches are found both above and below the acceptable limits, with percentages of mismatches above the limits in the eighth grade and higher percentages of mismatches below the limits in the ninth grade. This indicates that under desk height changes from being large to being small for students as they grow larger with age.

The above results show clearly that the desk dimensions are not appropriate for all of the students. The one size fits all idea is not a proper choice. 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 seven grades [1–3], with the eight and ninth grades, the evaluation revealed high percentages of mismatches between several desk dimensions and students' anthropometry. These disk dimensions include seat height, seat depth, seat width and desk height. Students are sitting on desks with seats and tables that are too high and too narrow for most of 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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The Biomechanics and Ergonomics of the Impact of Anti-fatigue Mats on Decreasing Whole Body Vibration

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Abstract. The standardization effort in vibration's field has unfolded the interests of industries. This research aimed at better understanding of the impact of vibration on human body. In the past years, healthcare centers and manufacturers started to equip the workplace with Anti-fatigue Mats (AFM) for the improvement of the working conditions and quality at work. This study analyzed the impact of AFM on the reduction of vibrations transmitted during the weekly activity of manufacturing workers. Seven AFM marketed by Notrax Premium Superior Manufacturing Group were tested. The laser vibrometry technique was used in order to measure vibratory displacements at various points. Under the effect of the vibrations, AFM behaved differently according to their structure and geometries. In comparison, the values obtained showed that AFM absorbed the vibration. It permitted to decrease the risks of ligamentous, or articular pathologies, which can affect employees at work. Taking into account, different results obtained showing that AFM could be used effectively in different areas of workplace, such as in medical or manufacturing settings, in order to improve working conditions.

Keywords: Biomechanics · Comfort · Ergonomics at work · Mats · Whole body vibration atigue

1 Introduction

At work, the human body experiences stress and fatigue that can negatively affect work performance and efficiency. The load-bearing, trampling, monotony, performance productivity, acoustic and vibrations' effects are many contributing factors on articular, ligamentous and muscular dysfunctions. For instance, the standing position at work for extended period of time is required for workers in many occupations, including health care workers such as nurses and surgeons [1–3]. The results can assist in the appearance of pathology that requires work obstruction, which is expensive for industries.

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During the past years, Anti-fatigue Mats (AFM) has appeared in the industry and was capable of improving working conditions of many professionals and workers in daily tasks.

Considering many parameters and their improvements, AFM can improve the workers' daily lives. AFM has noteworthy mechanical behavior assisting to decrease joint stresses at work and reduce discomfort caused by prolonged standing [4], since they can damp the effect of vibrations on full body motion. Indeed, due to their smart material aptitude to return to initial position, AFM has the shape-memory capacity to benefit workers by decreasing loads. This is possible according to the variation of the plantar pressure. The human body, therefore is more balanced standing on AFM in comparison to hard ground. The objective of this study was to assess and predict the mechanical behaviour of AFM vibration's effect in human.

2 Literature Review

The experimental results in biography highlighted in-significant effects on the impacts of AFM [5], nevertheless other results confirmed a positive impact on human mechanics' and behavior [6–12, 14, 15]. Concerning the effect of vibration, it is estimated that 1.7–3.6% of the European work force are exposed to vibrations transmitted to hand which have adverse effects on health and well-being. According to the results of a recent British investigation, more than one million workers are exposed to vibrations of intensity higher than expected. Estimates in the Netherlands indicate that 4 to 7% of the workers are exposed to vibrations transmitted to the whole body. The 3rd European investigation on the work conditions carried out by the Foundation of Dublin [16], confirms that the exposure to the vibrations remains an issue and widespread in Europe.

3 Methods

A noticeable link exists between vibrations transmitted to the hand-arm system, whole body transmission and Musculo-Skeletal Body Disorders (MSBD). The mechanical vibrations transmitted to the human body generate disorders which can affect health and comfort both in short and long term periods. The vibrations transmitted to the whole body are by mobile machines (vehicle) and certain fixed machines (work station) and the vibrations transmitted to the hand-arm system are by portable machines guided with the hands.

Mainly two vibrations exposure modes were distinguished in this study. These exposures generate disorders which are, (1) mode of vascular exposure such neurological and musculoskeletal and (2) those types related to lumbar pains, back pain, neck or shoulders pain. Recent standards permit a better control of the impact on body's vibration (e.g. standards ISO 2631; ISO 7962 and ISO 5345). The dynamic behavior was evaluated for 7 mats, which have different structures or properties. The modal frequencies, damping and amplitudes allows to comprehend the behavior of the mats in front of solicitations type - trampling and/or in a vibratory environment.

4 Materials

4.1 Reducing Stress

The material properties are very important to better understanding how mats can reduce stress on human joints. The mats, which were investigated in this study, stimulated continuous micro-movements with cushioning effects. The mats ergonomic design spreads body weight evenly and supports balance, beveled edges prevent tripping on the mat. Moreover, slip resistant surface prevent slips and falls (see Fig. 1). Different tests have been conducted in order to describe the mats and their contribution in terms of accelerated wear test, protection from electrostatic discharge, static coefficient of friction, fabric graves tear strength and the compression deflection comparison.

Fig. 1. Description of the mat

5 Experimental Investigation: Mats Vibration

The dynamic behavior of 7 mats with a rectangular form of size 1000 × 700 mm were compared. A piezoelectric sensor triaxe DJB4524 by Brüel & Kjær-Denmark- Sound and Vibration Measurement A/S- was positioned at the center of each mat. A model was fixed with adhesive cyanoacrylate. A shock hammer provided with a force cell type 208C02 (PCB Piezotronics, USA) and used to generate the impacts needed (see Fig. 2a and b).

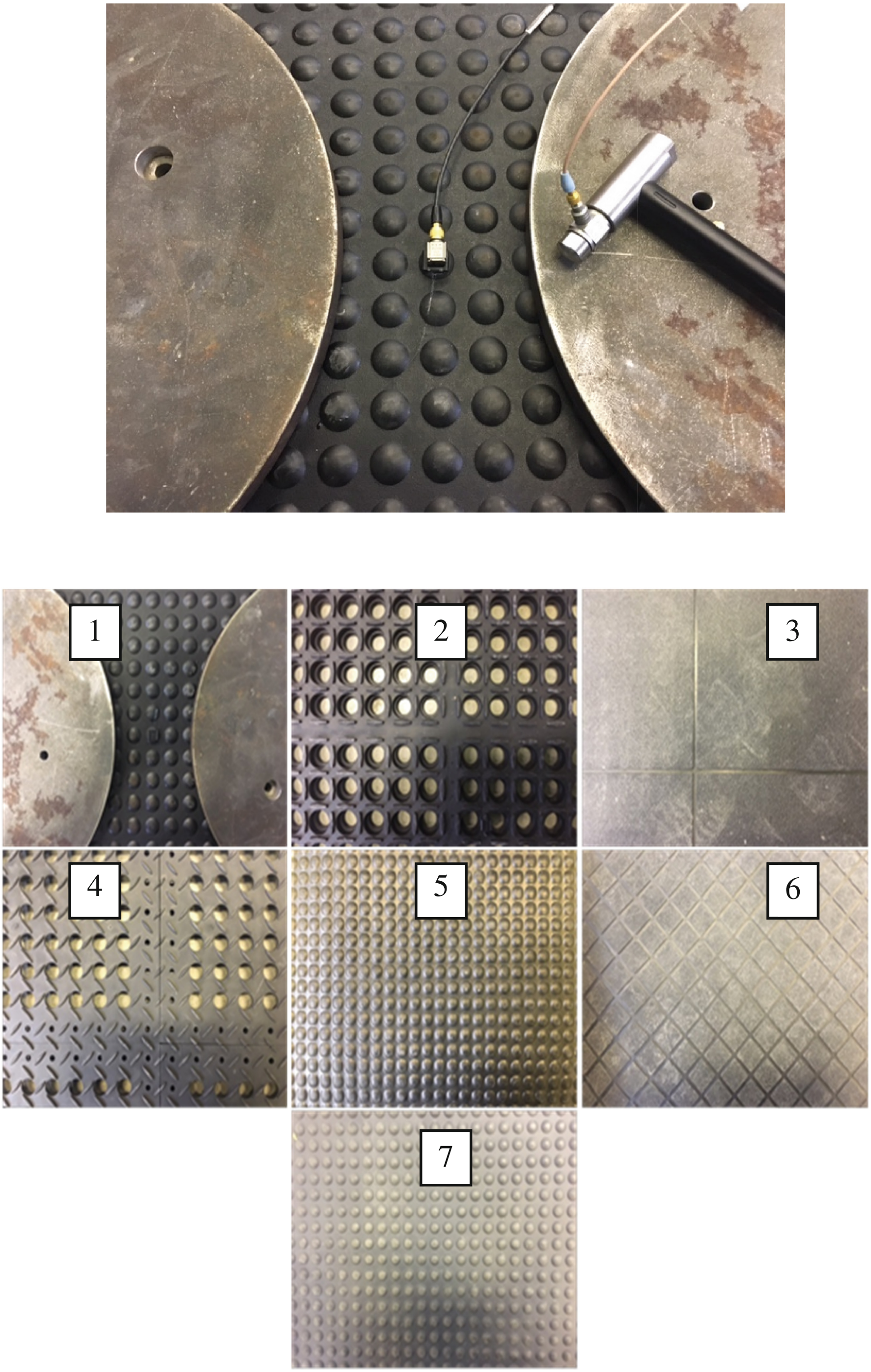

Fig. 2. a: Tri-axial accelerometer and shock hammer experimentation, **b:** seven different mat models (1–7 from upper left)

The data was collected by a data sink OR34 (OROS, Grenoble) with a sampling rate of 2560 Hz frequency. Each measurement lasts 1 s. The data was analyzed using the Matlab software version 7.11 (Mathworks, USA). The transfer function, see Eq. 1, was produced with a set of 5 impacts with the frequency band 0–1000 Hz. These values correspond to the frequency band recommended by the standard ISO2631. This standard related to the exposure of the whole body vibrations.

$$T_{xy}(f) = \frac{P_{xy}(f)}{P_{xx}(f)} \tag{1}$$

The transfer function is the quotient of the cross power spectral density (P_{yx}) of x and y and the power spectral density (P_{xx}) of x.

The dynamic behavior of each model was represented by its frequency, its modal damping and its amplitude. The average of T_{xy} was calculated on the study zone showing the absorbing characteristics of each mat. The frequency bands where T_{xy} was lower than 0 dB was noted, these values mean a damping of the frequency band.

Modal identification was carried out with EASY Mode software identification based on the Line-Fit method (SDOF method) giving the natural frequency, the Loss Factor and the modal constant. A Nyquist diagram and T_{xy} diagrams helped with the analyzing results and decision as for the identification.

6 Results and Discussions

The experimental results are summarized in Table 1 with identified modal parameters (frequencies, damping, amplitude) on the range 0–1000 Hz Frequencies range.

Table 1. Identified modal parameters (frequencies, damping, amplitude) on the range 0–1000 Hz. Frequencies range where T_{xy} is inferior to 0 dB. Mean transmissibility on the range 0–1000 Hz, $\overline{T_{xy}}$.

	Modal frequency (Hz)	Modale depreciation (%)	Modal amplitude (dB)	Zone where $T_{xy} < 0$ (Hz)	Mean $\overline{T_{xy}}$ (dB)
Mats 1	397/566/680	3.15/2.90/5.59	34.0/39.2/37.8	0–200	28.89
Mats 2	280/348/430	4.32/4.68/2.81	13.4/13.3/14.3	0–145; 485–1000	1.41
Mats 3	453/619	2.45/3.44	33.5/27.5	0–245	6.79
Mats 4	-	-	-	0–375	2.91
Mats 5	377/527	9.55/6.92	25.0/24.3	0–175	8.12
Mats 6	450/629	2.75/3.60	17.5/18.7	0–275	1.98
Mats 7	-	-	-	0–140	6.53

One can observe that up to 3 modes in the range 0–1000 Hz existed. Modal depreciation occurs in between 2.90 (weak damping), 9.55 (strong damping) and the modal amplitudes in between 13.3 and 39.2 Hz. The mats had very different structural properties according to their composition and geometry. The analysis of the T_{xy} average showed that the mats #1 was the most unfavorable for insulation with regard to the vibration at 28.89 dB. The mat models #2 and #6 were the most powerful on the range 0–1000 Hz. It is noted that mats #2 had a range of broader frequency where, $T_{xy} < 0$ i.e. the mat absorbed the vibrations. Mats #4 and #7 offered the similar characteristics on the whole studied frequency band due to none structural presented resonances.

The results showed that the AFM perform differently under the effect of vibrations. AFM can be a sufficient means for the reduction and prevention of pathological risk that employees and workers could undertake at the workplace. Indeed, the absorption of vibrations by AFM can decrease the possible stress risk, joint micro traumas and ligamentous. The benefit of AFM was illustrated in studies such as Taiar et al. [4] which indicated that the use of anti-fatigue mats has supported the benefits of new materials on the optimization of human mechanics. Under the present study, investigation of AFM's impact domain on the improvement of the human mechanical efficiency continues. The recognizable result in this work was the quantification of AFM vibratory damping decreased the negative effects.

7 Conclusion

The effects of the vibrations on seven AFM from the market were studied and quantified in this study. The results revealed that mats damping effect depends on composition and geometry. The AFM is used increasingly in industry with aims to improve operational comfort. In spite of the benefits shown in different studies, the AFM requires more investigations in industrial setting such as medial (e.g. surgical procedures) or Manufacturing processes (e.g. car manufacturing facilities). This study demonstrated the impact of vibration on mats.

Future research will analyse the effects of the vibrations on consumers over extended period of time. The approach will be by experimentation and simulation. First part "biomechanical simulations" which is the quantification of muscle contributions on the whole musculo-skeletal system will be utilized. The model is expected to permit adapting the AFM according to the operator's specification and type of process or need (i.e. custom mat fabrication and design to optimize results). Second part "experimental" biomechanical variables in relation to the workers' behaviour aimed to determine the objective impact of the AFM at work. The example could focus on the evolution of Center Of Pressure (COP) during the working day. The results will permit to contradict or confirm the results of other studies in reference to work done by Gregory and Callaghan [17] and Cham and Redfern [10].

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Ergonomic Evaluation and Interventions

Development of an Ergonomic Evaluation Tool for Health-Promoting Physical Workplaces

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Abstract. There is evidence that modern sedentary lifestyle is a risk factor for health, while ergonomics tends to overprotect the work force by limiting physical activity during working hours. The paper reports on the development of an Ergonomics assessment tool for simulation and field analysis. It follows a bandwidth approach targeting a balanced physical workload and is based on a review on existing evaluation methods for physical aspects of work routines and on health promotion. A workload and health-monitoring cockpit with live display and replay functionalities was developed as well as an aggregation and summary report for the comparison of variants of working sequences. First tests of the prototype showed that the implementation of the bandwidth model supports a health promotion paradigm in ergonomic workplace design. It is concluded that more research is needed to adjust and balance recommendations of physical activities and upper workload thresholds.

Keywords: Human factors · Ergonomic evaluation · Biomechanics · Health promotion · Workplace design

1 Introduction

Ergonomic evaluation tools are well-established in the field of ergonomics and are used widely in companies for the design and optimization of physical workplaces. Most of these tools were initially developed to analyze existing workplaces using a corrective approach trying to minimize the musculoskeletal load [1, 2]. Digital anthropometric human models used these same methods and tools as a fallback for an ergonomic evaluation, not making use of advanced computational capabilities. Typically, postural stress as well as lifting and handling loads and exertion of forces are evaluated [3]. All of these methods rely on observable or easily measurable factors. Methods for evaluating internal forces like muscular or tendon forces are not yet widely used.

Additionally, established ergonomic evaluation tools do not adequately consider current scientific findings [4–7] and expert views [8] on health risks resulting from the sedentary lifestyle as well as the trend to sedentary workplaces. The ergonomic assessment methods therefore contradict modern advice on healthy work. While ergonomics tries to protect the worker by enforcing upper limits regarding physical work, sports

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medicine recommends extensive physical activity to prevent risks from a sedentary lifestyle. Current ergonomic evaluation tools fail to notice this salutogenic factor until now.

This paper therefore presents the development of an ergonomic evaluation system containing not only well-established ergonomic methods, anthropometry, posture, handling loads and initiating forces, but also inner muscular and tendon forces in the musculoskeletal system. Additionally, the evaluation system will recognize physical underload and recommend measures for designing workplaces more ergonomically and preventing risks from a sedentary lifestyle. The tool is developed within the context of the Fraunhofer research project “EMMA-CC”, creating a cognitively controlled biomechanical human model.

2 Methods

Based on literature review as well as preliminary work in the EMMA-CC project a bandwidth model regarding physical load and stress is developed. The bandwidth model will allow recognizing both overload and underload and help to prevent these two extremes [9]. Furthermore, the literature research lays the foundation for finding and evaluating existing ergonomic methods and defining necessary data for an ergonomic evaluation. The different methods are then combined and adapted to create one summarizing evaluation tool.

This collection of evaluation methods is implemented into prototypical evaluation software to automatically analyze data generated by a human model simulation or motion capturing. We strive for a high level of usability so that industrial engineers with limited knowledge of human models and ergonomic evaluation are able to apply the tools correctly and successfully. The methods and the software are validated with various use cases of the automobile industry.

3 Results

Using a top-down principle, results were determined on three different levels of abstraction. Firstly, general requirements concerning all evaluation methods are defined. The different methods are then presented in detail and finally processed to be comprehensible and accessible for the user in a human-computer-interface.

A digital, musculoskeletal human model within the framework of the EMMA-CC project provides the input for the evaluation methods. As the evaluation methods and tools are decoupled from the human model, the data can also be input by means of motion tracking and EMG.

3.1 Bandwidth Model

The core concept of this evaluation tool is the bandwidth model, which, in contrast to the classical load and stress model not only prevents damage by physical overload (Fig. 1, left) but also considers damage by physical underload (Fig. 1, right). The evaluation methods are designed in order to ensure that work processes take place in the optimal, harmless band. Thus, a health-promoting work design is supported. The exact position and dimension of this central band is specific to individual and affected by factors such as age, level of fitness, and more. This fact is taken into account in the evaluation methods by supporting a sample of workers (personas) to analyze each task.

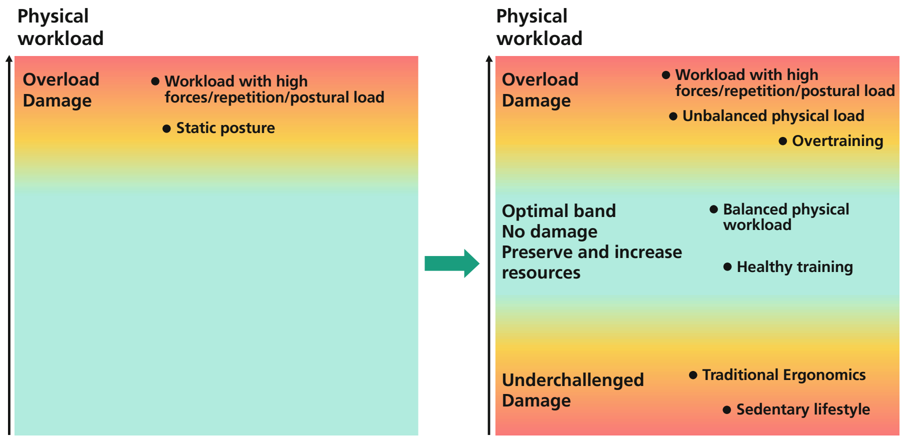

Fig. 1. Left: Established ergonomic model minimizing overload. Right: Bandwidth model

3.2 Evaluation Methods

The work process is evaluated separately in the categories "posture", "muscular stress", "metabolic stress", "cognition" and "fitness". These five categories were chosen to provide a compromise between comprehensibility for non-experienced users and accuracy of the evaluation. Furthermore, the separation into different categories allows a work process to be optimized selectively, e.g. increasing the fitness level while keeping the posture evaluation on an acceptable level.

Focusing on the upper body as well as the hand-arm system, RULA ("Rapid Upper Limb Assessment", [10]) was selected as the postural evaluation tool. Accordingly, only the postural component of RULA is used, as RULA only includes a rudimentary muscular load evaluation which is covered in greater detail by the muscular evaluation component of this tool.

Muscular data provided by simulation of hill-type muscles or by EMG is evaluated using the ratio of actual to maximum muscle force F/F_{max} (also known as "%MVC", percent of maximum voluntary contraction). The muscular evaluation is carried out both for each point in time (checking F/F_{max} against given limits) as well as summarily over the entire work sequence. Latter is achieved by verifying that each muscle is in a rested state before being activated again.

For the metabolic evaluation the approach of Garg et al. [11] is used, which determines the metabolic load during physical work based on the task description and various personal parameters of the human being. The metabolic base load is determined by means of the task description, followed by an adjustment based on activity parameters (duration, movement of the work piece, working height, body weight, etc.) and personal parameters (gender, body weight, and walking speed). For a sequence of several activities, the individual metabolic loads are calculated separately and then weighted over time. In addition to the previously discussed, protective ergonomic methods, this tool processes requirements of sports and health sciences [12]. This fitness assessment includes, but is not limited to, the requirement for 10 000 steps per day (adapted to the duration of the activity, [13]) and hourly movements of the entire body to avoid unilateral stress.

3.3 User Interface

The user of the evaluation tool obtains a so-called Live Evaluation with a graphical user interface (GUI) as well as a concluding evaluation in a printable report format. These two formats supplement each other and shall be comprehensible for an industrial engineer without in-depth human factors knowledge and knowledge in digital human simulation. We only present the Live Evaluation in the following.

The Live Evaluation allows a replay of critical parts of the working scene as well as the entire simulated or recorded working scene. The user opens the recorded data or simulation file and selects a specific person (e.g. a 95th percentile male) or a group of sample personas. A digital human, shown here in the left part of the window (Fig. 2) will replay the scene. If multiple rather than one person is chosen, the "bottleneck"

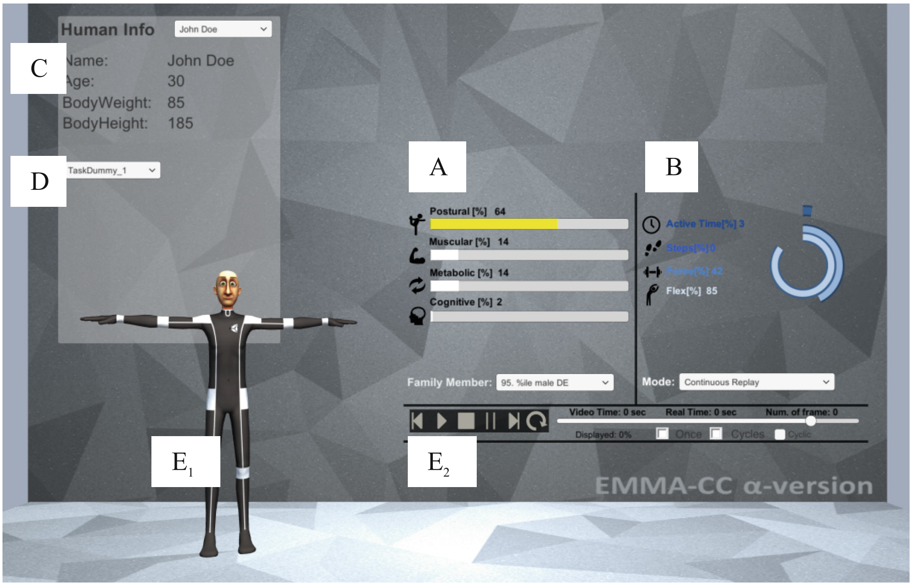

Fig. 2. User interface displaying the simulation on the left-hand side and the live ergonomic evaluation on the right-hand side. A: "Workload", display for upper limit warning of postural, muscular, metabolic and cognitive overload. B: "Health & Activity", display for lower limit warning of physical underload (active time, steps, force, and flex). C: Anthropometric adjustment of human model. D: Selection of different simulation for same task for comparison of two variants $E_{1,2}$: Replay of human model simulation and video controls

person with the worst evaluation is show. This part of the interface allows the user to understand which movement patterns lead to the good or bad evaluation scores. These scores are presented on the right-hand side in the data "cockpit". On the left-hand side of the evaluation panel bar graphs with green-yellow-red color coding are shown as bar graphs for the four workload criteria "Postural", "Muscular", "Metabolic" and "Cognitive". They represent the conventional ergonomic evaluation with low workloads displaying in green, while high workloads are displayed red. On the right-hand side hand, circular diagrams represent measurements as known from today's activity tracking devices. A full circle means that the minimum recommended activity dose is reached. There are four concentric ring segments standing for "active time", "number of performed steps", "exerted forces", and "flexion of joints". The scene controls allow to run the entire scene, or to jump from critical scene to critical scene, where yellow and/or red ratings occur. In this case, only short "videos" of the related situations are shown.

4 Discussion

While the upper thresholds of the bandwidth model are well validated in applied human factors and ergonomics and are considered as assured human factors knowledge, this is not the case for the lower boundaries of recommended minimal physical activities. The evidence of health risks due to sedentary lifestyle is, in the meantime, widely acknowledged in life sciences. The recommended minimum doses of physical activities are, however, not very well established. Recommendations like "10 000 steps a day" cannot be considered as scientifically validated. In particular, there is a lack of long-term experience and longitudinal studies on the effect of physical activity promotion, e.g. by using activity trackers. Thus, the implemented recommendations for physical activities in our tool must still be considered as preliminary.

Another issue of the presented approach of translating the recommendations of daily activities to work shifts is that it could lead to frustration in work design. Manufacturing today is related with divided and repetitive labor. It is designed for productivity and efficiency and not for promoting physical fitness. Under given restrictions in the industry it will not be possible to reach the physical activity thresholds for most work tasks. It might therefore become necessary to adapt the objectives to boundary conditions and live with the fact that health promotion cannot be integrated as part of the working day [14].

The implementation of two forbidden bands, attempting to avoid overload with certainty on the one hand, and to promote physical activity on the other hand, might lead to contradictory interpretations of working situations. While human factors methods only in very rare conditions complain about low workload, currently known activity-tracking algorithms never warn from overload. Therefore, some work tasks appear beneficial for health, because the required minimal activities are reached. At the same time, conventional ergonomics might diagnose an unacceptably high workload at the same time. Further research is needed to clarify how practitioners will get along with such results and whether formal working situations without a green band might occur.

Concerning planned future work, the current prototype will be further developed. The cognitive workload simulation and measurement needs still to be implemented and further testing with complex working tasks will be conducted.

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A Study of Incentive Stimulating Human Error Activity on Public Service

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Abstract. Public services, for example Railroad service and hospital service, have carried out safety activities to provide safety service for users aiming "accident zero". However, safety activities can't go well in the actual enterprises. For the reason why safe activity can't work, it is caused by the fact that employees' motivation to safety activities decreases. However, the safe managers misunderstand it caused by a lowering of the safe consciousness of the employees and perform activity for the purpose of the improvement of the safe consciousness. Therefore, the safe activity in the actual enterprises cannot be readily activated by employees because of the gap of the recognition of the safe managers. We suggest that managers should evaluate the safety of the public service by an enhancement degree of the safety activity instead of employee's safe consciousness in the enterprise. And, this study shows that the safe managers should expand new explanation to employees when I they teach how to do safety activities.

Keywords: Human factors · Human error · Public services

1 Introduction

1.1 The Necessity of the Safety Activities for the Public Services

Decreasing birthrate and aging population becomes the problem in Japan, and each city faces a decrease in population. The decrease in population has an influence on the public services, and the drop of the income by users decreasing is not avoided. The point of approaching this problem for the public services is to get stable incomes as in the past by holding current users instead of trying to increase incomes. It is necessary to make users recognize that public service is safe to hold current users. The user expects an available thing for public service becoming a part of the life without holding uneasiness and distrust. Therefore, the public services should struggle safety activities not to let users have uneasiness and distrust, and it must aim at the stabilization of the income.

1.2 The Necessity of the Safety Activities for the Public Services

The motivation for the safety activities of the spot employees decreases while safety activities is essential for public services. The possibility that a big accident occurs now

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is very low because a rail technology has developed. However, public services must work on the safety activities aiming “accident zero”, and employees have consciousness not to have possibilities to get up as for the accident when the spot does not many check lists and thimble checks. And they think that the time has spent by handling a check list and the measures that increase whenever human error rises and feel that those prevent works. In addition, there are few opportunities when the spot employee receives the positive evaluation from users because the public service exists as a matter of course and it is with a part of a natural thing in everyone’s life. Therefore, it is hard for employees to realize the fact that safe activity helps users. From these reason, as for the spot employee, motivation for the safe activity decreases. Incentive to stimulate motivation for their safe activity is necessary. However, the incentive is not money and pays my attention to way of thinking and how to catch for the safe activity.

1.3 The Necessity of the Safety Activities for the Public Services

The spot employee cannot keep motivation for the safety activities, but safe consciousness does not fall. Most employees understand the necessity of safety activities. However, the safe managers think that employee’s safe consciousness decreases and carries out an action to achieve safe consciousness in the spot. As for the safety activity of the public service, there are the present conditions that cannot be readily activated by a gap of the recognition by safe managers.

2 Suggestion

2.1 The Evaluation Method of the Safety Activities of the Public Service

The reason why safety managers misunderstood that employee’s safety consciousness is decreasing is that they think the safety of public services are evaluated by “height of the security consciousness of the spot employee”. However, it is not the thing which in the first place a manager and an organization should estimate as the safe consciousness of the spot employee. It is originally evaluated by people using the public services such as a user or the community. In other words, you should arrest size of the trust that the users have for public service as “height of the security consciousness of the employees”. When the users can feel “the public service is safety”, in the enterprise the safe consciousness of employees are enough high. Therefore, it is necessary to evaluate it by “an enhancement degree of the safety activities” not the safe manager evaluating the safety of the public service in qualitative what’s called “safe consciousness”.

2.2 The Reputation for the Public Company

At first, we need to know the reputation influencing to the public company. Recently, many company interest in ‘corporate reputation’ as the thing which it makes the financial performance of the company. It is because the company values are defined by intangible assets such as intellectual assets or corporate reputation. The characteristic of corporate reputation is raised based on results of past of managers and the employees and the present and future predictive information by various stakeholders.

2.3 The Reputation for the Public Services

In this study, we suggest that public services need to introduce the way of thinking reputation to the safe activities and expand to the employees. The managers should explain that reputation is 'trust' from users and community and employees try to understand user's feeling when they use public services. As those effects, they can remove 'reputation risks', the facts of user's anxiety, and they aim to the public services which has images 'comfortable and safe' for users.

The image show the difference of explanation for safety activities (Fig. 1).

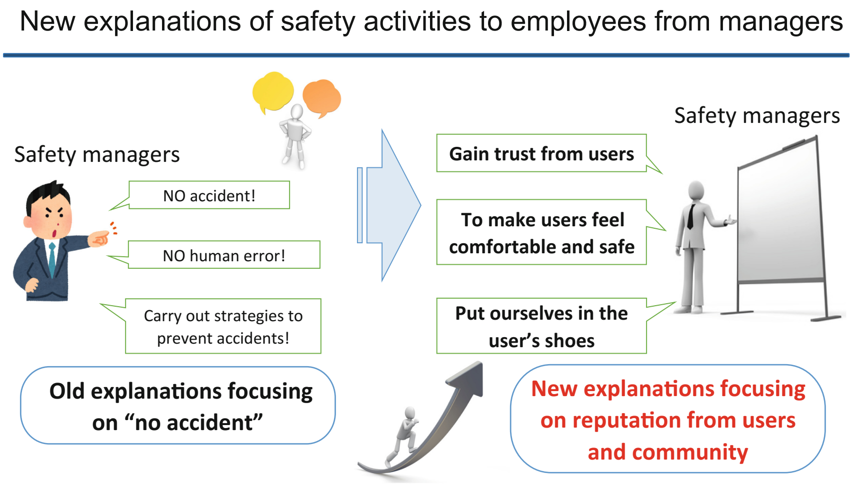

Fig. 1. New explanation of safety activities to employees from managers

The next image show that the new explanation including thinking of trust from users and social community (Fig. 2).

2.4 The Effects to Social Community

In addition, I can contribute to the activation of the community by thinking about reputation of the public services. The activation of the following areas is anticipated by a population decline by reputation of the public services rising at the present when the local depopulation becomes the problem, and finding the flow of the stable person (Fig. 3).

Fig. 2. The new explanation that managers should expand to spot employees

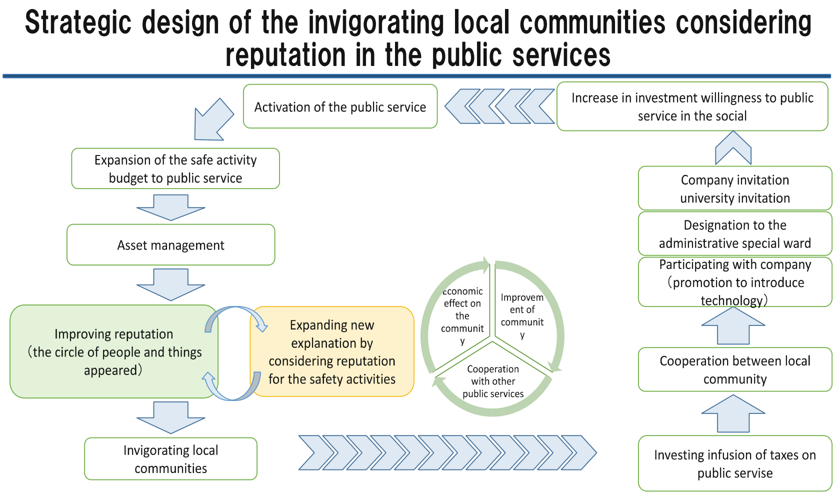

Fig. 3. Strategic design of the invigorating local communities considering reputation in the public services

3 Suggestion

HEMAS has an employee answer the questionnaire of the attitude survey consisting of 55 questions and is the system which evaluates the actual situation of the accident prevention activity of the organization by adding up a result. The feature is that it is the whole investigation for all employees belonging to the organization.

Among 55 questions, there are 20 questions which asks you a question whether you can understand a basic way of thinking for the safe activity. We carried out HEMAS in Japanese railroad company A and compared the difference in understanding degree in 20 questions. It is the year when railroad company A has begun to enforce HEMAS in 2009. Because ratios of ‘enough understanding’ increase, it is showed that the understanding degree for the safe activity of the employee increases. And this is a result using the ways of thinking public service reputation. Therefore, it may be said that understanding degrees to the safe activity of the employee increased by introducing a way of thinking reputation from users and local community. We cannot show it that the motivation of the employees went up only by the result of the questions, but it is apparent that a way of thinking of reputation contributes to activation of the safe activity of the company (Fig. 4).

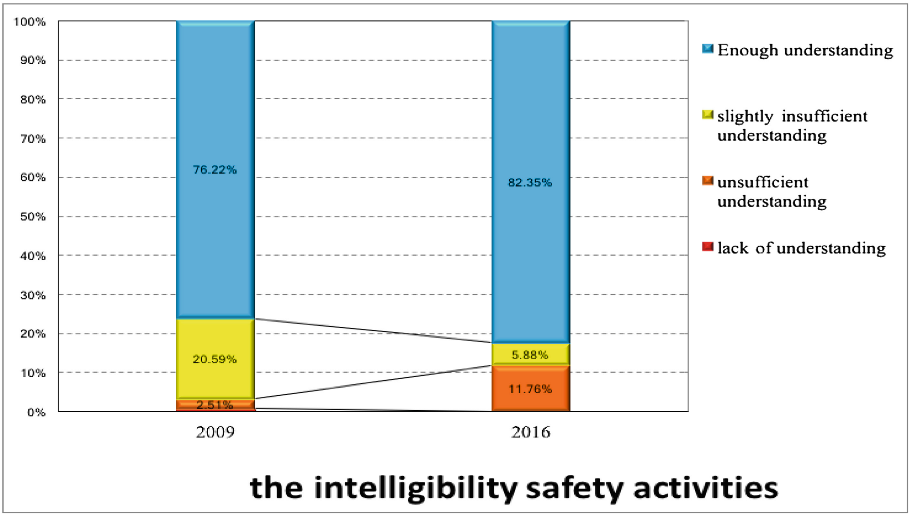

Fig. 4. The result of HEMAS which shows degree of employee’s understanding for safety activities

4 Conclusion

When the safe managers explain safe activities to employees, the understanding degrees for the safe activity of the employees was shown to rise by using a thought reputation. We can’t show clearly that explanation of new safety activity gives the motivation of the employees at this stage. However, it must be that there was a change of the consciousness of the employees for the safe activity by referring to rising of understanding degree. We want to analyze the remark of a result and the employee of HEMAS carrying out with other railroad companies and medical institutions in future what kind of change consciousness for the security activity traces for the cause. And it is necessary to reveal how reputation of the public service contributed to the motivation of the employees.

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An Interview Study on Children's Spectacle Frame Fit

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Abstract. Although studies have examined problems with spectacle frame fit, little is known about appropriate frame design for children. To identify practical problems in this area, semi-structured interviews were conducted in Hong Kong with dispensing opticians, children who wear glasses, and the children's parents. The data analysis showed that frame width, nose pads, and leg shape were related to fit problems. However, there is no fit standard between faces and frames, and the temple width was the main reference used by dispensing opticians to help children choose spectacle frames. In conclusion, dispensing opticians are important actors in the selection of more appropriate spectacle frames for children, but they might be unable to solve fit problems in the nose area and ears due to deficiencies in frame design. As little research has been conducted on problems in children's spectacle design and fit, further studies on spectacle frame design should investigate children's facial features and special needs.

Keywords: Semi-structured interview · Spectacle fit · Children

1 Introduction

An increasing number of children wear glasses for visual correction and protection [1, 2]. Researchers have long been concerned with frame fit problems. Although some research has led to advancements in spectacle frame design, previous studies have indicated that research results based on adult facial dimensions cannot be used for designing children's frames, as children are not sized as miniature adults [3–6].

Children's heads change with age, more so than those of adults [7], posing difficulties in the design and fitting of comfortable headwear and facewear for children. To improve the design of these products, a standard for the head–face dimensions of Chinese minors [8] has been introduced in China. However, the standard provides only 15 head–face dimensions, which are insufficient for improving the morphological fit of spectacle frames. In addition, foreign and domestic studies have been conducted to record one-dimensional measurements of children's facial changes for the design of specific products, such as spectacle frames, helmets, and oxygen masks [5, 6, 9–11].

Among these studies, a quantitative method involving the collection of facial measurements has been the dominant means of determining the relationships between head and product measurements. The main problems of children's spectacle frame fit are still unclear, although previous studies have discussed morphological fit problems on Caucasian children [5] and Chinese children [6]. The limited amount of research means

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that existing fit problems and necessary improvements in children's spectacle frame design are still unclear.

The quantitative method is useful for investigating a variety of work and research questions [12] and has been widely applied in ergonomics studies in fields such as footwear [13] and personal protective eyewear [14]. In terms of eyeglass design, a previous study demonstrated the general needs of children through the storytelling method [15].

This study employed interviews to obtain a more thorough understanding of this area of concern. The major research question was: what are the existing practical problems in children spectacle frame fit? Because fit preference is influenced by the style, material, and weight of spectacle frames, in addition to size [16], three subsidiary questions were posed: What are the practical problems of fit between facial and frame dimensions? What are children's needs regarding weight, material, and style? Do they have any other requirements when choosing frames?

2 Method

2.1 Participants

A total of 23 groups of children and parents were interviewed. The children recruited had different levels of vision problems and all needed to wear glasses. Because children might not listen and respond to questions as seriously as adults [17], parents were included in the interviews to improve the quality of answers, assisting or substituting for their children and replying to questions based on their parenting experience. Three dispensing opticians took part in this study, all of whom had more than 3 years' working experience in prescribing glasses. All participants were recruited from an optometry clinic.

2.2 Interview Design

Two semi-structured interviews were designed. The format rendered the investigation process more flexible, as the interviewer could develop questions beforehand and vary them depending on situational demands [18]. Two different questionnaires were developed for interviewing children and their parents and interviewing dispensing opticians.

The child–parent questionnaire was aimed at understanding the practical problems that children encounter when wearing a pair of glasses, and contained 24 questions. The first questions concerned basic information: gender, age, number of years having worn glasses, eyesight, number of frames worn, frequency of changing frames, and reasons for changing frames. To understand facial dimensions and fit problems, three questions were asked regarding facial discomfort, poorly fitted frames, and other discomfort. Then, based on a literature review, further questions were designed regarding the following four aspects: size (nose pads, frame legs, frame rims, and joints), weight, materials, and style. Participants were required to rank these factors and provide detailed explanations of their ranking. Subsequently, the children's frame-wearing experiences were investigated, including their difficulties in selection, inconveniences in daily life, and favorite frames.

Another questionnaire was developed to collect the views of dispensing opticians on children's spectacle frame fit problems; it contained 21 questions. Three questions on gender, age, and years of working experience were designed to acquire basic information. Practical circumstances were understood through four types of questions: standard process (prescribing glasses, fit standards, and sizing), working experience (necessary questions before prescribing, parent and child needs, preferences, and complaints), fit according to facial dimensions (current fitting problems, frame measurement, and fit) and current spectacle design (recommended products, as well as advice for spectacle frame design).

The results from these two types of interviews were compared and combined to de-rive answers to the research questions.

3 Result

3.1 Interviews with Parents and Children

General Information. A total of 23 groups of parents and children took part in this investigation, including 12 boys and 11 girls aged from 4 to 16 years old (average of 8.9 years, standard deviation of 3.2). All of the children suffered from vision problems, including myopia only, astigmatism only, hyperopia only, amblyopia only, both hyperopia and astigmatism, and both myopia and astigmatism (Fig. 1). Their levels of eyesight varied as well, from 100° to 600° (Fig. 2). A total of 17 of the children had been wearing a pair of glasses for more than 2 years, and 17 had bought more than two pairs of glasses. This indicated that the respondents had adequate wearing experience for the purposes of this study.

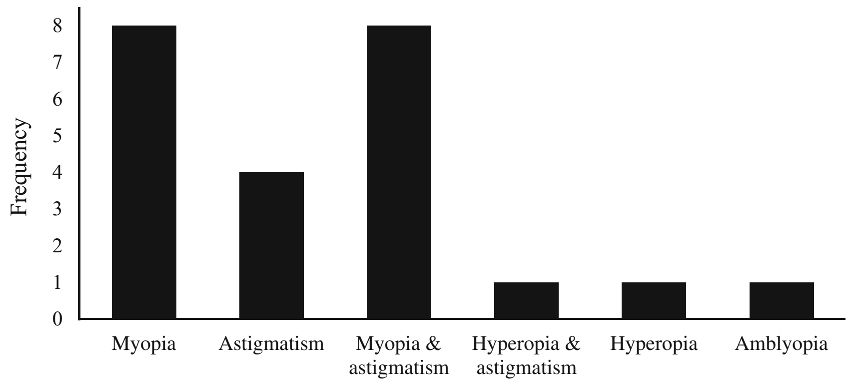

Fig. 1. Frequency of children's vision problems

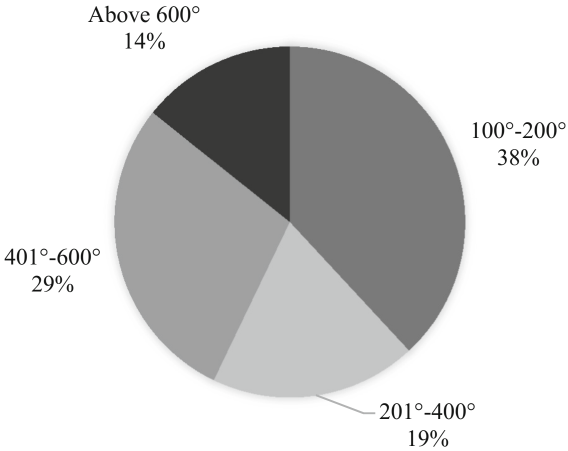

Fig. 2. Proportion of children's eyesight level

Fit Problems. Although the majority of the children (22) had bought another pair of glasses due to a change in vision, four of them also reported that they had done so in response to head growth. Rim width and leg length were unsuited to the children's temple width and the distance from front to bend. Complaints about the frame being uncomfortable were mostly lodged by the older children (aged at least 7 years), accounting for 52% of participants. Pressure and pain on the nasal bridge (30%) and ears (22%) were the main reasons provided. In addition, six participants stated that the nose pads did not fit their noses and three participants indicated that the curves of the legs did not match the shapes of their ears. However, respondents who reported frame-induced discomfort did not necessarily think that there were any problems with the frame measurements, and vice versa.

Special Needs. To understand how parents, who usually make final frame-purchasing decisions, considered frame selection, parents were required to rank factors from most important (one) to least important (five). The mean rankings are shown in Table 1. Frame size was the highest-ranked consideration. The mean rankings of materials and weight were similar, followed by style; price had the lowest ranking. Parents were also required to provide detailed explanations of their rankings. Parents paid attention to frame size, but many of them (six) depended heavily on dispensing opticians' opinions when making such a decision, stating that they might lack knowledge in this area. Further information regarding preferences for frame components (nose pads, legs, and rim) was also explored. A total of 13 parent–child groups said that the nose pads required adjustment; six of these groups indicated that adjusted nose pads were an improvement; and 10 of them preferred to have the legs rest on the outer ears to keep the frame stable on the face, but two of them complained that this type of leg hurt their ears. Preferences for frame rims varied. Considerations of weight, durability, safety, and deformation meant that plastic frames were the most popular, with 19 children wearing them. Although frame style preferences varied, all participants chose full-rim frames and 22 groups preferred lighter frames.

Table 1. Rank of factors which influence the choice of spectacle frames

Factors	Mean of rank
Size of frame	2.23
Materials	2.64
Weight	2.74
Style	3.0
Price	4.09

Wearing Experience. Many children (19 respondents) had had negative experiences when wearing glasses. For example, 12 children had experienced frames slipping on the nasal bridge, causing discomfort and even injury to the nose. A total of 10 respondents stated that they might wear their normal frames even when participating in sports. Among all participants, 65% thought that their current frames were optimal in terms of style, size, material, and comfort level.

3.2 Interviews with Dispensing Staff

General Information. Three male dispensing opticians who had been working in the industry for 3–10 years were interviewed.

Standard Process. When helping children to choose appropriate frames, interviewees suggested that vision and temple width were the main reference measurements, because frame width depended on these two factors. Furthermore, one of the opticians stated that unlike nose pads and legs, frame width was not adjustable. Children may try every recommended frame until they find one that matches their temple width, although their temple width will not be formally measured. In addition, all interviewees stated that there is no fit standard between the face and the frame, but they suggested that children use plastic full-rim frames with adjustable nose pads for reasons of safety and durability.

Working Experience. In the opticians' working experience, children generally need new frames owing to vision changes. The opticians would inquire as to the children's habits before recommending glasses types, because it would be safer for an active child to wear glasses with plastic frames. In their experience, parents often ask about frame size problems and are concerned about safety problems, weight, and price. When participants were asked what parents and children frequently complain about, one interviewee indicated discomfort in the temple, nose, and ears, and another noted frame quality.

Fit Problems. Fit problems regarding facial dimensions and frame measurements were also investigated in the interviews. All of the opticians suggested that the main fit problem was whether the frame width could match the child's temple width. An appropriate frame should fit a child's nose shape, outer ear shape, and temple width also.

They reported that if the frame components could be adjusted, they would need to change the angle of the nose pads or the shape and length of the frame legs.

Current Spectacle Design. Currently, no unified size chart exists for children's spectacle frames. However, all opticians recommend a particular brand (Tomato Glasses) that has a relatively wide variety of size specifications. One interviewee also suggested that this brand of glasses tends to closely fit a child's low nasal bridge even though its nose pads cannot be adjusted, and its frame legs can sit comfortably on the ears to prevent the frame from slipping on the nose. Furthermore, they opined that this brand of frames uses materials relatively soft materials, which are safer than others, suitably tough, and do not easily become deformed. As a result, customers are likely to give positive feedback on this brand.

4 Discussion

4.1 Morphological Fit Problems

The findings of this interview suggest that only eyesight problems and temple width are considered when children choose frames. Although some types of frames have adjustable nose pads and legs, some children still experience nose and ear discomfort. This problem has been mentioned in studies focusing on adults [19]. However, among children, most complaints were lodged by participants aged 7 years or older, whereas those younger than 7 years were apparently more satisfied with their frames. This may be because younger children can adapt to pain more quickly than older children, leading to the faster alleviation of symptoms [4]. Another reason may be that children younger than 7 years old could be too young to express their feelings on the matter, considering how some of the younger children's parents noticed marks on the children's nasal bridges. Researchers indicated that nasal bridges are usually low in Caucasian children aged 5 to 7 years [5]. The same is likely true in Chinese children, as many participants reported that frames slip on their noses. However, few studies have provided information on how the growth patterns of children's nose are incorporated into spectacle frame design. The interviewees also reported outer ear discomfort. Previous studies [3–6] have mostly focused on children's facial measurements and ignored outer ear shape, which could have influenced frame leg design. This indicates the need for further study on the relationship between the shapes of frame legs and children's ears.

4.2 Comparison of Interview Statements

Comparing the responses from both the parent–child and dispensing optician interviews, both categories of interviewees were concerned about size problems in children's frames, with dispensing staff reporting that this problem is not often observed in adult frames. Surprisingly, parents thought that the suitability of frame size is very important; this view was especially prevalent among those who had experience wearing glasses. Both categories of interviewees suggested that plastic frames are more suitable for children, because they may be lighter, safer, and softer than metal frames. Parents and dispensing opticians also indicated that lighter frames are more comfortable to wear than heavier frames. Frame weight preference is thus a worthwhile topic for further exploration.

By contrast, parent–child groups and dispensing opticians had different opinions on choosing nose pads and frame legs. The opticians suggested that children should choose nose pads that could be adjusted to their smooth nasal bridges. Although some parents and children thought adjustable nose pads were necessary, some reported that the adjustable nose pads were easy to deform and had smaller areas of contact than the fixed nose pads did, leading to discomfort that caused them to prefer frames with fixed nose pads. Adjustable nose pads may temporarily solve morphological fit problems on the nose, but other factors such as design and children's needs in daily life should also be considered. Children tend to be more active than adults and may not comply with recommendations for spectacle frame use. Thus, frames that can be fixed to their faces and cannot be adjusted might be comparatively suitable.

5 Conclusion

This study investigated practical problems in children' spectacle frame fit through interviews with parents and children and opticians, providing an overall understanding of current problems in this field. Practical fit problems, considerations involved when choosing and wearing a pair of glasses, and current spectacle design can help with further studies of children's spectacle frame design that can identify research gaps and design opportunities. The findings of semi-structured interviews suggest that the lack of guidelines of how to choose an appropriate frame leads to confusion in dispensing process. The importance of the relationship between children's outer ear shape and frame leg design was demonstrated, implying that the results of previous studies have been insufficient for solving all spectacle frame fit problems. Future research must further explore preferences for spectacle frame weight, a concern mentioned by the interviewees. With technological development, the number of spectacle-like products such as Google Glass may increase. Research in this area will not only improve spectacle frame design but also provide information for the design of related products.

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A Comparative Study of the Effects of Electrical Stimulation and Intermittent Compressive Forces on Soft Tissue Mechanical Properties

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Abstract. We aimed to investigate and compare the effects of electrical stimulation and intermittent compressive forces on soft tissue mechanical properties. Four healthy individuals were recruited into this study. A transcutaneous electrical stimulation device was used to apply a pulse duration of 2.5 ms, a frequency of 2 Hz, and the amplitude to a maximum of 30 mA. The intermittent compressive forces were applied at a period of 20 s with forces ranging from 0 to 70 mmHg. The effective Young's modulus was calculated to characterize mechanical properties of forearm soft tissues. The results showed that forearm soft tissue properties might decrease effective Young's modulus after the treatments of electrical stimulation and intermittent compressive forces.

Keywords: Scar · Effective young's modulus · Indentation test · Ultrasound

1 Introduction

Scar healing is a complex soft tissue repairing process. It is a continuing challenge in the field of skin injury and rehabilitation research [1]. Each year, up to 100 million people in the developed world suffer skin scarring as a result of soft tissue injury [2, 3]. The intermittent compressive forces are one the treatments that remodels collagen fibers of soft tissues and improves the healing process of scar [4, 5]. Recently, the electrical stimulation has demonstrated the potential for managing symptomatic scar healing.

Electrical stimulation improves skin blood flow, and may promote the directional migration of cells and signaling molecules via electrotaxis [6]. The electrical stimulation significantly reduces the symptoms of pain and pruritus in patients with scar [7].

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Although the treatment of intermittent compressive forces has been previously investigated in the effect of soft tissue mechanical properties [8, 9], it has not yet been compared to the effects of electrical stimulation. The main purpose of this study was to investigate the changes of soft tissues at the forearm in response to electrical stimulations and intermittent compressive forces. The results of this study can contribute to the management of the scar.

2 Methods

2.1 Subjects

For comparison purposes, we need to know the treatment effects in normal skin before the scar soft tissue. Four subjects recruited and performed both treatment task: electrical stimulation and intermittent compressive forces (N = 4; mean ± SD: age, 22.8 ± 3.6 years; height, 158.0 ± 5.9 cm; weight, 49.3 ± 3.8 kg; body mass index, 19.7 ± 1.1 kg/ m^2). Study protocols were reviewed by the Institutional Review Board at University.

2.2 Instruments

A portable two-channel conventional mode transcutaneous electrical nerve stimulation (TENS) (KS-138 Microcomputer Therapeutic Apparatus, Body Care Resort Inc., CA, USA) was used. The operated function we used was VIBRATION with a pulse duration of 2.5 ms, a frequency of 2 Hz, and the amplitude to a maximum of 30 mA (Fig. 1A). Four standard disposable self-adhesive stimulation electrodes (4 × 4 cm) were used to transmit TENS to the subject. Amplitude was increased slowly to the subject's tolerance without causing discomfort, and adjusted to induce the muscle contraction for all subject. ON time was set to 10 s with 0.001 s of rise and decay and an OFF time of 2 s.

(A) (B)

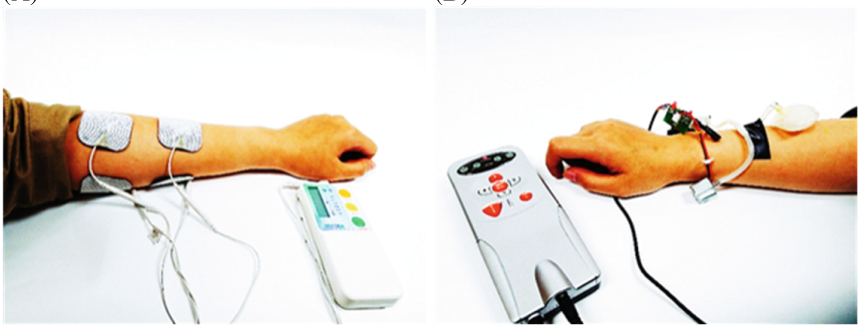


Fig. 1. (A) Electrical stimulation task and (B) intermittent compressive forces task

The intermittent pneumatic compression system mainly consists of pneumatic devices (Eye Massager KN-800A, Kuonao Co., Ltd., Taipei, Taiwan) (Fig. 1B). The frequency of the intermittent compressive forces was chosen at 2 time/min in one intermittent pneumatic bag with the diameter of 3 cm. The sequentially inflated and deflated pressures were regulated from 0 to 70 mmHg [10]. The compression system was in series applied to the soft tissue of the forearm 20 min for simulating the common massage protocols [11].

We used the motor-driven ultrasound indentation system for the indentation tests. It was conducted the effect of the before and after treatment. The motor-driven ultrasound indentation system mainly consists of four parts: ultrasound system, load cell, stepper motor, and standoff holder. The indenter was motor-driven [12] onto the skin surface to apply programmable compressive forces and assess soft tissue mechanical properties and responses. The test itself very much resembles that of palpation of the plantar soft tissues [13, 14]. Details of the indentation system have been described in our previous publications [8].

2.3 Experimental Procedure

In the electrical stimulation task, the skin of the left forearm was cleaned and moistened with an alcohol swab to reduce skin resistance when the subject arrived at the lab. Self-adhesive stimulation electrodes were placed bilaterally over the bulk of the muscle of extensor carpi ulnaris (ECU) and flexor carpi ulnaris (FCU) in involved upper limb. TENS was applied for 20 min.

In the intermittent pneumatic compression task, The compression system was in series applied to the soft tissue of ECU muscle of the right forearm 20 min for simulating the common massage protocols [11].

Evaluating elastic properties of soft tissue before and after treatment, we used the indentation tests. Three forearm postures corresponding to different states of muscular contraction. The subject was asked to sit with the elbow extension and forearm prostrated on a supporting table. The forearm resting on the table with three conditions position for the test, including a. wrist at a neutral position, b. wrist at the maximal extension of the subject, and c. the hand holding a 1 kg weight (Fig. 2).

After a preload force of less than 0.5 N was applied on the skin over the dorsal forearm perpendicularly, a load of 5.0 N or less if the indentation had reached 20% of the total thickness from the real-time ultrasound images was applied on the same location [14, 15]. The indentation velocity was set to be about 1 mm/s and the maximum indentation was about 20% of the initial bulk soft tissue thickness, as evaluated by ultrasound signals with a minimum loading of 0.1 N [16]. Eight seconds per loading cycle with 4 s rise and 4 s decay were applied on the skin of the forearm (Fig. 3). Each position we measured 5 cycles for the further calculated.

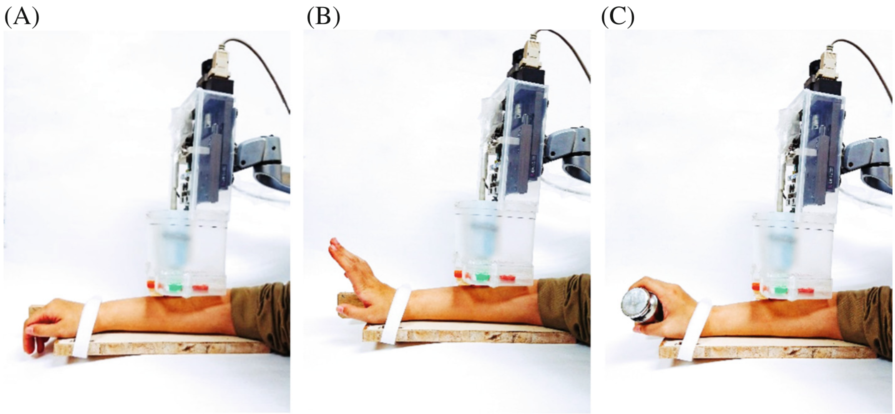


Fig. 2. Three conditions of forearm, including (A) the forearm resting on the table with the wrist at a neutral position, (B) the forearm resting on the table with the wrist at 90° of extension or the maximal extension of the subject, and (C) forearm resting on the table with the hand holding a 1 kg weight.

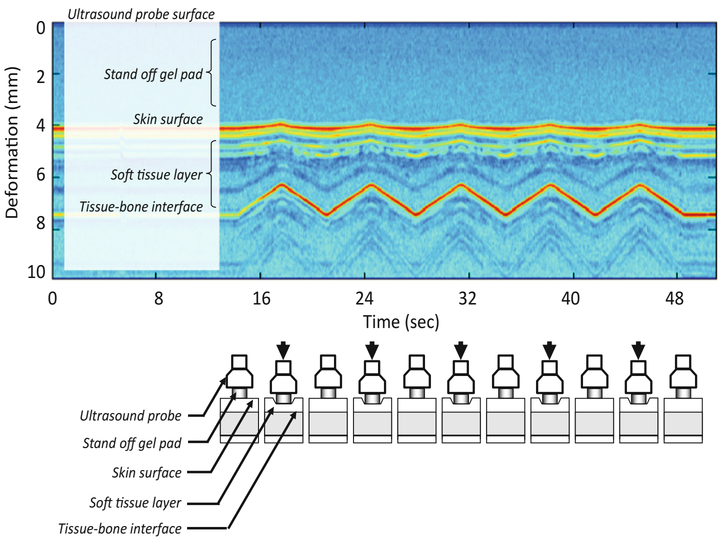


Fig. 3. Motor-driven ultrasound indentation system. It shows the ultrasound echo trains. After the standoff pad, the first echo is associated with the ultrasound standoff-skin interface while the second one represents the tissue-bone interface. The thickness of the soft tissue is present by the distance between the first and second echoes.

2.4 Data Analysis

The ultrasound image and indenter force were recorded by the motor-driven ultrasound indentation system. In the ultrasound image, the first ultrasound echo is associated with the standoff pad and skin interface while the second one represents the tissue-bone interface. The thickness of the soft tissue was presented by the distance between the first and second echoes [8, 15] (Fig. 3).

To quantify elastic properties of soft tissues, we used the effective Young's modulus (E). It is a traditional material constant for response to stiffness of soft tissue property [8, 9, 16, 17]. To extract effective Young's modulus E, the equation was defined as below.

$$E = \frac{(1 - v^2)}{2a \cdot k(v, a/h)} \cdot \frac{P}{w} \quad (1)$$

v, Poisson's ratio; a, the indenter radius; k, a scaling factor dependent on the Poisson's ratio (0.45) [17], indenter radius (4.5 mm), and soft tissue thickness [16]; h, the soft tissue thickness; P, the force of pressure loading (indentation); w, the depth of indentation (Fig. 4).

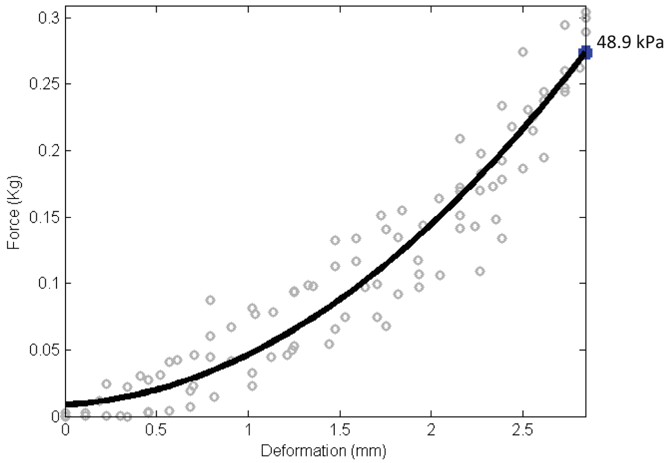
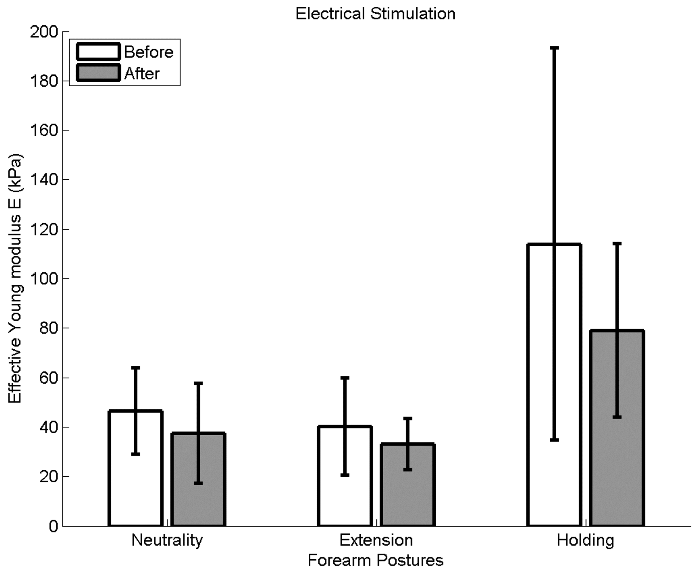


Fig. 4. The effective Young's modulus (E).

Paired samples t tests were used to compare the effective Young's modulus between before and after task of electrical stimulation task and intermittent compressive forces under each forearm postures (wrist neutral position, wrist extension, and hand holding). The statistical tests were performed using SPSS 22 (IBM, Somers, NY) at the significance level of 0.05.

(A)



(B)

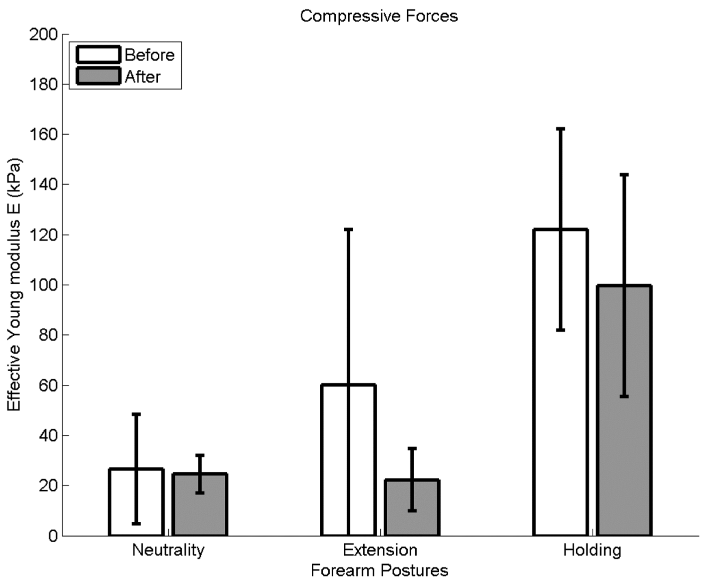


Fig. 5. Comparison of effective Young's modulus under the three forearm postures (wrist neutral position, wrist extension, and hand holding) responded to before and after treatment. (A) Electrical stimulation. (B) Intermittent compressive forces.

3 Results and Discussion

The effective Young's modulus was calculated to characterize of stiffness in mechanical property of forearm soft tissues. Even the stiffness soft tissues property have been trending down after treatment not only electrical stimulation treatment but also intermittent pneumatic compressions, there were no significant pairwise differences between before and after with electrical stimulation treatment or intermittent pneumatic compressions.

Before the electrical stimulation treatment, effective Young's modulus of conditions a, b, and c was 46.5, 40.3, and 114.0 kPa, respectively. After the treatment, the effective Young's modulus of wrist neutral position, wrist extension, and hand holding was 37.4, 33.2, and 79.1 kPa, respectively. They were reduced by 20%, 18%, and 31%, respectively (Fig. 5A).

Before the intermittent compression treatment, effective Young's modulus of conditions a, b, and c was 26.5, 60.1, and 122.1 kPa, respectively. After the treatment, the effective Young's modulus of wrist neutral position, wrist extension, and hand holding was 24.6, 22.3, and 99.6 kPa, respectively. They were reduced by 7%, 63%, and 18%, respectively (Fig. 5B).

Zheng and colleagues demonstrated that the soft tissue mechanical property (effective Young's modulus in this study) was significantly dependent on the posture. According to our results, soft tissue mechanical properties were different among three forearm positions (wrist at a neutral position, wrist extension, and hand holding) [18]. The effective Young's modulus of the forearm was increased when the holding a weight by the hand [19].

The limitations of this study are as follows: (1) four subjects were recruited into this study. Future work should test the efficacy of intermittent compression treatment in a larger sample size.; (2) the future work should investigate the long-term effect of the treatment on modulating soft tissue property in patients with hypertrophic scars.

4 Conclusions

The findings of this study indicate that the soft tissue mechanical properties might be modulated through the treatments of electrical stimulation and intermittent compressive forces. The results showed that forearm soft tissue mechanical properties may decrease the effective Young's modulus after the treatments.

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Prospective Design of Seating Systems for Digitalized Working Worlds

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Abstract. The increased prevalence of digital mobile devices has not only changed how people communicate but it has also led to a significant changing world of work and therefore to a new consideration of ergonomics of office workplaces. Studies show that the use of mobile devices leads to a different stress profile dependent on new work postures. As a consequence of the described change, seating systems have to be designed considering the demands of digitalized working worlds. In this paper, a design approach of an innovative seating system for a prospective health maintenance is presented that supports active sitting during sedentary work.

Keywords: Posture · Digitalized workplace · Sedentary work · Seating system · Industry 4.0 · Active sitting

1 Introduction

Today the digital transformation has not only changed how companies produce goods and offer services, it has changed the whole working world of the employees, too. The increased emergence of digital information and the use of digital devices have led to a change of work and increased efficiency of the employees' work. As a result of this, known working models with fixed working hours and work areas have changed to a more flexible and individual way of working. This development has not only an effect on the employees' work life but on his or her health as well. The use of light and mobile digital devices enables the employee to work at varying locations and thus to be more independent of a fixed work area. Despite of the advantages and help digital tools offer to the employee, the working still requires long term sitting in front of computer screens. And this development will increase in future as the work environment is becoming more and more digitized.

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With the help of an intelligent seating system that recognizes prolonged sitting in an unaltered posture and then guides the seated person to an advantageous posture health preservation for sedentary work can be benefitted.

2 Biomechanical View of Prolonged Sitting

Prolonged sitting has been connected to health issues like lower back pain (LBP). LBP is one of the most common musculoskeletal disorders [1]. While prolonged sitting has not been connected to the onset of LBP [2], it is thought to promote the symptoms [3]. Therefore, it is important to design a seating system that reduces the risk of developing LBP.

There is a big variety of seating concepts that can be used in office, home or other environments. Most of these concepts promise a more ergonomic way of sitting, the reduction or prevention of LBP or simply a healthier way of sitting. This is achieved in one or more of the following ways:

1. Reducing the need for continuous muscle activation in the back by using a backrest.
2. Prevent 'static' seating and therefore promote continuous, subtle changes in the seating posture.
3. Reducing the forces exerted on the spine and the intervertebral discs in particular by promoting a seating posture with a straight back.
4. Providing a lumbar support to reduce the urge of getting into a "slumped position"

There have been several studies examining each of these points and it is of high importance to understand their efficiency in reducing LBP to develop a modern seating design.

Sitting straight, without the support of a backrest, requires a continuous contraction of the back's muscles (e.g. m. erector spinae). Continuous muscle activation might lead to "localized muscle tension, muscle strains, muscle fatigue, and other soft-tissue damage" [4] as well as a reduced blood flow [5] with LBP as a symptom. Backrests support the back and therefore reduce the required muscle activation [6, 7]. A backrest might on the other hand mislead the user to persist in the same sitting position. This is called static sitting and has been connected to LBP as well. It has been shown, that "subjects with LBP assume more static, sustained postures while sitting and use large infrequent shifts in posture rather than small, subtle spinal movements regularly" [8]. Without these subtle changes, the muscle recruitment pattern in the back does not change, leading to localized muscle fatigue and tension [4]. Dynamic sitting has been recommended as counteraction. Changing the sitting position only very subtle, but very frequently, should alternate the recruitment pattern of the small, deep muscles in the back [8]. This should enable muscle to rest and prevent fatigue. Designs incorporating functions to promote dynamic sitting, range from stability balls [9, 10] to systems that passively move the lumbar spine while sitting [11–13]. Studies on such designs reveal mixed results, showing no real difference in muscle activation or reduced LBP [8, 9].

Another point that has been studied as a source for LBP are the forces acting on the intervertebral discs. Several studies have used in vivo pressure measurements to quantify these forces [14–16]. These studies show that the pressure is lowest, while sitting with a straight back or leaning against the back rest (~0.3 MPa) [16]. They also show, that an unsupported flexion of the trunk leads to an increase in disc pressure of roughly 100% [15]. Although these findings should be taken into consideration, intervertebral discs can withstand pressures of more than 2 MPa [17]. Therefore, the disc pressures while seating in any position can be seen as not harmful.

This raises the question why subjects sitting in a "slumped position" with high trunk flexion and low muscle activation experience LBP. Since the muscle activation stays low while sitting in this position [18, 19] and disc pressure is low [16], it is likely, that the body relies on passive structures. These structures can get overloaded when subjects remain in such a slumped position [4] leading to LBP. Certain key elements can be extracted from the above findings:

– Intervertebral disc pressure changes with sitting posture but is not high enough to endanger the discs in any posture.
– Sitting in a slumped position can be tolerable for a certain amount of time but increases the risk to develop LBP.
– Static sitting increases the risk of developing LBP due to fatigue of local muscles.
– The use of a backrest reduces muscle activation and therefore makes prolonged sitting easier.

These findings show the need to combine different features in a seating design to prevent LBP. While the use of a backrest is mandatory to ensure a usage of several hours, the prevention of static sitting as well as preventing a continuous slumped sitting position should be focused.

3 Seating System for New Work

Actual office chairs in the market offer different designs depending on their usage. Some existing chairs focus on ergonomics and on a high variability of possible sitting postures with flexible back elements. Others use special mechanics to support body movements. The major difference lies in the seat back and its structure varying from a massive design to a lightweight one reducing material and size. Modern chairs for new work usage prefer a reduced size with a segmented optic or partly transparent material to not block the open view into the room.

Few new products use apps to complement sitting and provide health management observing sitting times and postures. First steps into digital sitting are done so that the users get in touch with digitalized seating systems but without holistic approach regarding the user, working surroundings, physical constitution and the seat itself.

Overall aim of modern seats is to provide dynamic seating in order to generate passive movement while sitting and working.

Customer journeys have shown that the following aspects are most relevant for a healthy and comfortable sitting: individual situation and physical constitution, type of work, awareness of healthiness and body fitness, mood and willingness to change posture, seat that acts in the background without disturbing work processes.

Different types of users can be defined from those who don't care where they are sitting on and how to the users who consider adjustments that can be changed to the users who are willing to learn about their body constitution and sitting types in order to improve healthiness and performance.

A sitting system supporting healthy sitting for individual needs should be able to adapt to the different surroundings and working situations as well as to the user. In times of new work and changing workplaces persons change seats requiring a flexible systems which can adapted to the physical needs. The design has to fit into modern working areas meaning reduced style which integrates into open structures with changing spatial patterns as well as home working spaces with cozy furniture (Fig. 1).

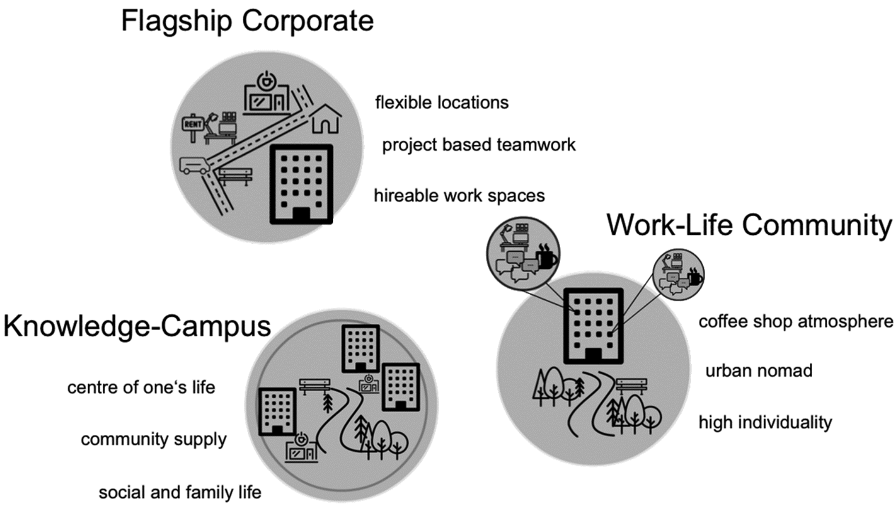

Fig. 1. Most significant areas of new work: hierarchical work space structures are broken to increase creativity and productivity.

4 Design Approach

Actual seating systems do not fulfill the requirements of an individual ergonomic support to prevent static sitting and promote health preservation.

To respond the identified needs, a seating system with ergonomic and visually appealing design has to be designed that uses an innovative sensor and actuator concept to promote posture changes for dynamic sitting with low disruption.

The main idea is not to inform the seated person of a poor posture by visual information like LED display or vibro-tactile alert that captures the user's attention to change the posture but particularly to guide the user to an advantageous posture with low intrusion in work and privacy. Studies [20] have shown that people often feel disrupted by tactile movements that create a certain discomfort.

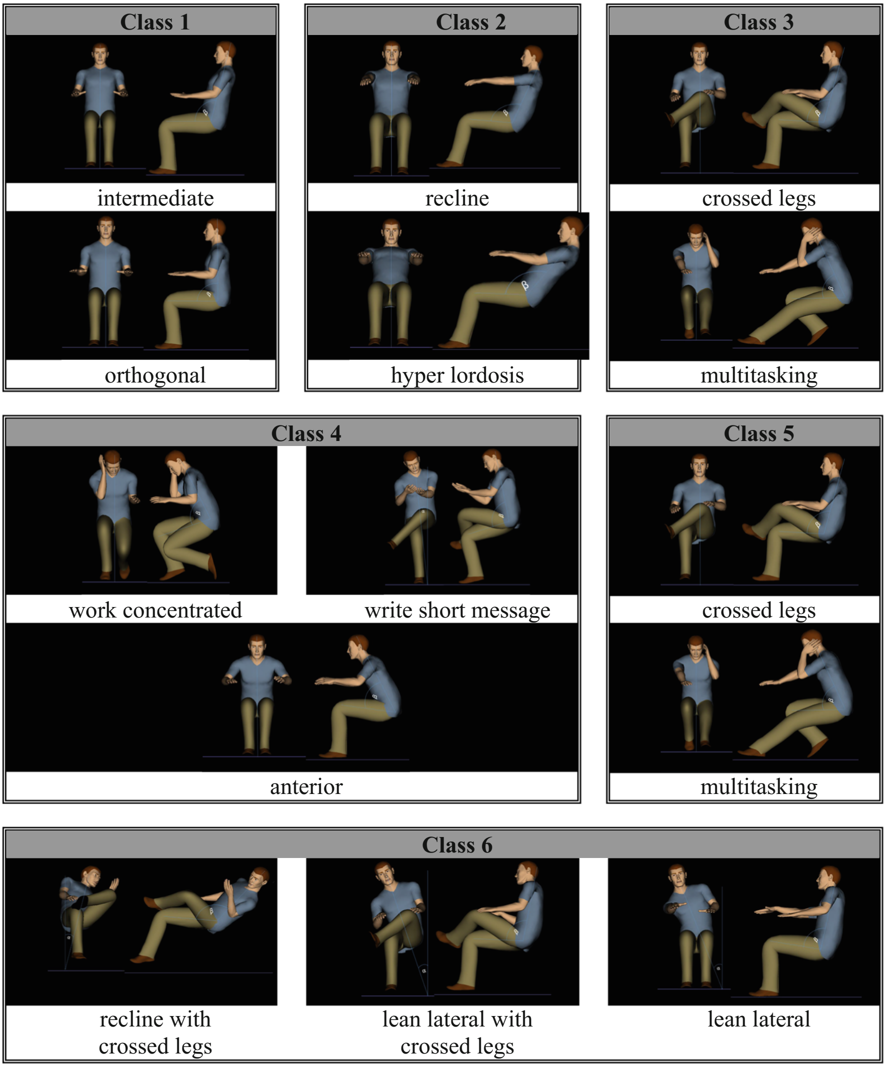

Fig. 2. Classification of posture in load classes from low (class 1) to very high load (class 6)

The findings on static sitting and on the causes of muscle fatigue (see Sect. 2) lead to the approach of a targeted posture change based on a theoretical ideal sitting profile adjusted to office working. First the number of different posture over a certain period of time e.g. a working day has to be captured. To distinguish the effects of the different sitting postures it is necessary to classify them into load classes (Fig. 2) so that with the frequency of postures and the load classes a load spectrum can be generated. Because of the varying number of tasks during an office working day an exact frequency distribution of postures is hardly possible to create so that the frequency of postures is normally distributed (Fig. 3). The thus created ideal sitting profile forms the basis for the algorithm of posture changes of the designed seating system. To fulfill the prospective concept of the seating system common postures and new postures due to digitalized working worlds are considered as well in the sitting profile.

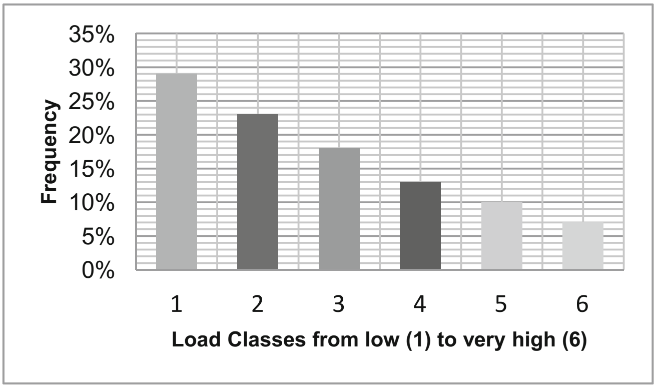

Fig. 3. Normal distribution of postures dependent on load during average office work day

By classifying postures into load classes a load spectrum is generated that shows the distribution of common sitting postures and new postures. Figure 2 shows the classification of posture in musculoskeletal load classes.

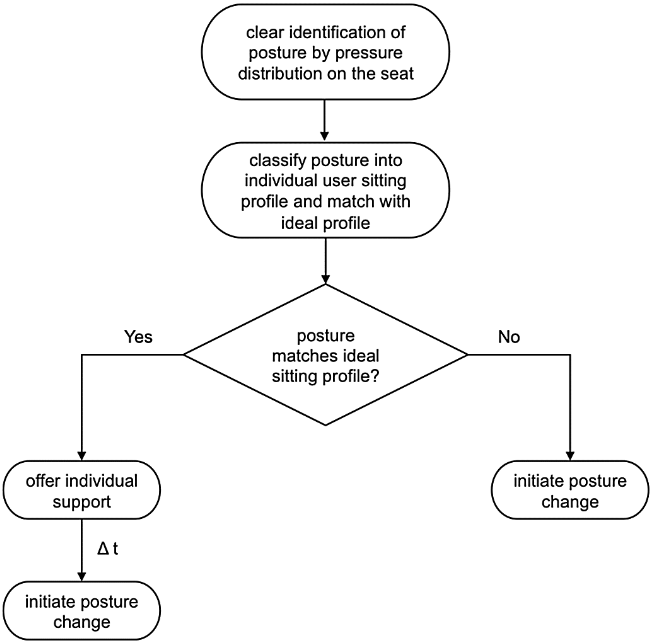

Fig. 4. Flow chart of working of the seating system concept

The individual support is carried out by comparison of actual posture and its duration with the theoretical ideal sitting profile. The identification of the actual posture happens by capturing the pressure distribution during sitting on the seat. When the actual posture is outside the ideal profile the seating system will initiate a posture change. The seating system will offer individual support by the backrest until an unaltered posture exceeds a critical duration. Only then a posture change is executed. Figure 4 shows the flow chart of the functionality of the designed seating system.

5 Conclusion

The design of a seating system for an ergonomic active sitting requires a holistic view of the seating behaviour with its consequences. A lot of people are not aware of the reciprocity between physically good sitting and well-being as well as effectiveness in work. The seating system can contribute to better awareness of body constitution and performance in connection to sitting postures.

To be accepted in terms of new work and from different users the system has to be intuitive in use. Seating modifications must not interrupt work and should act autonomously with imperceptive moves. Visualization and feedback to sitting postures and their consequences can be shown to the user via display graphics or external application in order to review personal seating preferences.

The approach of a generated theoretical ideal sitting profile considering common and new postures classified in load classes forms the basis for an expedient execution of posture changes to support effective dynamic sitting and promote health preservation.

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Human Factors Field Evaluation of a Blast Debris Protection Design Concept

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Abstract. In an effort to provide urogenital, perineal and femoral protection against blast debris, a novel personal protection device was developed. The prototype, a harness shaped device worn over trousers, was assessed by 15 Soldiers as they performed an assortment of simulated mission tasks. User ratings were generally positive for ease of use, mission performance, mobility and reduced restriction and interference. Participants felt the device allowed them good mobility, fit close to the body, had breathability and allowed access to the front pockets. Participants experienced some bunching in the crotch area, waste relief required the device be at least partially removed, and some restriction in the hip was noted.

Keywords: Human factors · Human-systems integration · Systems engineering · Urogenital · Body armor · Personal protective equipment · Groin · Blast debris protection

1 Introduction

The improvised explosive device (IED) is responsible for the majority of casualties and injuries sustained in Operation Iraqi Freedom [1] and casualties in Operation Enduring Freedom [2]. When an IED blast occurs, a variety of injuries frequently can occur, but frequently focus on the lower half of the body [1]. Although, injuries have been seen to extend all the way up to the bottom edge of the body armor vest, including the groin, buttocks, and pelvis, which are all highly susceptible to blast injury. Additionally, IED injuries frequently require amputations of the lower extremities, which have associated injuries to the perineum and genitals [3]. When an IED blast occurs, wounds are created that are contaminated with fragments of dirt and debris [4]. It was found that 4.7–10% of military trauma admissions had at least one urologic injury, and that of those 68% had external genitalia injuries [1].

During an IED explosion, fragments of dirt and debris can pepper an area of sensitive skin, such as the urogenital area. While these type of dirt and debris injuries are frequently not life threatening, the sexual and excretory capabilities, as well as the long-term effect on quality of life can be severely degraded. Potential outcomes from these events include genital destruction and disfigurement, destruction of reproductive capabilities, urinary tract damage, fecal stream diversions, and an unknown level of

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psychological impact [1]. Ballistic pelvic protection devices have been shown to decrease incidences of injury [5, 6].

The Blast Debris Protection effort investigated the trade-off space for urogenital, perineal and femoral protection against blast debris. The purpose was to define the materials, system design, and human performance trade space associated with providing blast debris protection to the lower abdomen, groin and upper legs of both male and female Warfighters. The team undertook an effort to help protect Soldiers, during an IED, from the effects of the dirt and debris that could potentially penetrate the urogenital, perineal, and femoral areas. The goal was to design, build, and evaluate novel concepts that help determine what works with the human shape, movement, and Soldier equipment. An additional goal was to push the boundaries of the acceptable concepts and look at novel designs, therefore a series of prototypes were developed to demonstrate those concepts within the “under trouser,” “within trouser” and “over trouser” trade space. As a capstone to this project, a field evaluation of these concepts was completed to evaluate mobility, compatibility and Soldier acceptance. As a result, one concept stood out, and this paper highlights those findings.

2 Methods

2.1 Test Item

In total, ten urogenital, perineal and femoral protection devices were assessed. Using these ten designs, a total of sixteen concepts were assessed. Participants in this study only wore eight of the concepts and only one of those concepts, the harness, will be discussed in this paper. The harness is a one-piece item, worn over the individual’s trouser and connected at the waist and side of the legs (see Fig. 1). The harness concept was designed to balance area of coverage, breathability, mobility, and access to pockets while still protecting the urogenital, perineal and femoral areas of the body.

In addition to the concept test item, participants also wore a duty uniform, a ballistic helmet, a body armor vest while carrying a mock weapon (either a M4 or AK-47) and a hydration pack or canteen. This additional gear was worn with the intent of assessing compatibility between the items and to simulate the way the harness would be worn in a training or combat environment.

2.2 Test Participants

Fifteen male National Guard Soldiers evaluated the harness concept; unfortunately, no female Soldiers were available to evaluate this item. Participants’ mean age was 30.3 years (ranging from 21 to 53 years old, SD = 8.2 years), and had a mean time in service of 7.4 years (minimum 1 year, maximum 17 years, SD = 5.6 years). Two of the test participants had served at least one combat tour. Ranks ranged from E3–E5, with the majority being E-4 (8 of 15). All of the participants wore either small or medium size trousers (in short, regular, or long lengths). Participant experience wearing groin protection was limited. A hot and humid test location was selected to simulate a “worst case” environmental condition to evaluate breathability.

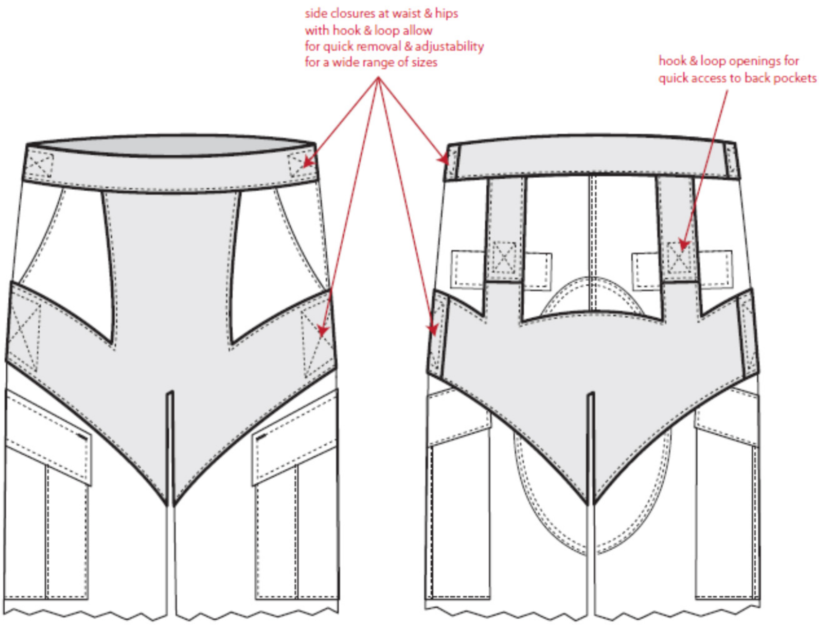

Fig. 1. Design sketch off the harness ballast debris protection device as worn over trousers; image on the left is of the front and image on the right is of the rear. (Patent 13/685,747, sketch courtesy of Natick Soldier Research Development and Engineering Center)

2.3 Test Procedures

This evaluation used a within-subjects design. Order of presentation of the test items was randomized. Each Soldier participated in an initial fit/size session followed by eight test sessions. Each test session lasted approximately four hours and consisted of executing a road march (~2 miles), an obstacle course, a vehicle compatibility task and a Military Operations Urban Terrain (MOUT) scenario. The test participants completed two test sessions per day, one in the morning and one in the afternoon. They wore a different concept for each test session, resulting in approximately four hours of wear time for each session.

At the conclusion of each activity, the test participants were asked to rate their ability to perform the mission/tasks as influenced by the test item they wore using a five-point scale, where 1 indicated very poor performance and 5 indicated very good performance. Testers also recorded any comments they offered. At the conclusion of each session of testing, the test participants were asked to complete a questionnaire, which addressed any further issues regarding Fit, Comfort, Restriction, and Compatibility with mission equipment. At the conclusion of all testing, the test participants were administered a final questionnaire which asked them to compare the various groin protection configurations. They also participated in a brief focus group.

The first language of most test subjects was not English. Efforts were made to overcome the language barrier by providing surveys written in and testers fluent in their native language. Even so, test participants' comments were somewhat limited and tended to be kept at a high level. It was often difficult to draw out some of the details regarding exactly what was causing discomfort and restriction. Despite the language barrier limitations, strong preferences were still evident from the data and test participants still commented and explained their feelings on all of the design concepts. The test participants all took their assignment to assess the different garments very seriously, and spent considerable time in answering the questions on the questionnaires. Additionally, testers followed up on the questionnaire responses if they found anything lacking or confusing with the test participants' ratings.

3 Results

Overall, the test participants had a very positive opinion of the harness concept (Fig. 2) after wearing it. When asked to give it an Overall Rating, all but one test participant stated that it was Very Good (5); that one test participant rated it as Good (4). Additionally, when rank ordered at the conclusion of the evaluation, test participants ranked this the harness concept first most often (7 times) and it had the best ranking score. The harness concept was also chosen as the preferred concepts for the following characteristics: Comfort, Weight, Ease of Use, Mobility, Access to Pockets, Bulk, Wound Care, Breathability, and Stability. Throughout the activities, test participants commented that they liked the concept, thought it felt lightweight, and was breathable. A few test participants had difficulty with bunching of the material in the crotch area and a few felt that access to their back pockets was limited, but overall opinions of the harness concept were positive.

Fig. 2. Images of test participants wearing the harness concept from the front and side.

3.1 Fit and Comfort

Mean ratings for fit of the harness concept were positive, with 11 test participants rating the fit as Very Good (5), and the other four rating it as Good (4). The harness concept had the second best mean rating for Fit of the concepts being compared. All but one of the test participants (who rated it as Good (4)) rated the Comfort as Very Good (5). Two test participants noted that they experienced discomfort on their Scrotum; one thought it was due to bunching of the test item and the other attributed it to chafing/rubbing. Both thought that heat buildup and area of coverage of test items were causes of the discomfort they experienced. Despite the fact that two test participants attributed the discomfort to heat buildup, the harness concept had the best mean rating for Thermal Comfort of any of the concepts. Eleven test participants rated the concept as Comfortable (3) and four rated it as Slightly Warm/Hot (4). The harness concept was also the only one of the sixteen concepts to not be rated warmer than Slightly Warm/Hot (4 on a 5-point scale).

3.2 Ease of Use

As can be seen in Table 1, test participants rated the harness concept very positively for Ease of Use. All test participants rated the harness concept as Very Easy (5) for Ease of Donning, Ease of Doffing, Ease of Quick Doffing, and Ease of Adjusting. While no test participants commented on it, testers noted that there was some confusion over which part of the concept was the front and which was the back. It was unclear if this was due to the design or because the labeling was on the front, whereas on other garments it was on the back. To aid test participants, testers notated the front and back onto the garment prototypes.

Table 1. Summary of ease of use responses.

Question	Mean	SD
Ease of donning test item	5.00	0.00
Ease of doffing test item	5.00	0.00
Ease of quick doffing test item	5.00	0.00
Ease of adjusting test item	5.00	0.00

3.3 Performance Metrics

Test participants also rated the performance characteristics of the harness concept highly, see Table 2. All variable except Ability of Soft Armor to Stay in Place (not bunch) received mean ratings approaching Very Good (5). The mean rating for Ability of Soft Armor to Stay in Place (not bunch) was still in the Good (4) range, although one person rated it as Poor (1). He noted that he experienced bunching in the crotch area which caused discomfort. All 15 test participants rated Weight of the test item as Very Good (5). The harness concept weighed approximately half a kilogram, and was the second lightest of the concepts worn by this group.

Table 2. Summary of performance characteristics of protection device.

Question	Mean	SD
Bulk of test item	4.93	0.26
Weight of test item	5.00	0.00
Breathability/ventilation of test item	4.87	0.35
Ability to prevent sand and dirt infiltration	4.60	0.63
Ability of soft armor to stay in place (not bunch)	4.42	1.00
Area of protection coverage	4.67	0.49

3.4 Mobility

Movement restriction/interference ratings (5-point scale, where 1 indicated the least restriction/interference and 5 indicated the most) for the harness concept were especially good (Table 3). The harness concept had the best Movement ratings (compared to the other concepts) for most of the movements. Taking a Knee, High Step, High/Low Crawl, Going Through a Doorway, Climb/Descend Stairs, Squat, Overhead Arm Reach, Aim a Weapon in the Kneeling Position, Aim a Weapon in the Prone Position, and Get Into Vehicle all received ratings of No Restriction/interference (1). Walk, Jog, Combat Roll, Climb Through a Window, and Ride in Vehicle received 14 ratings of No Restriction/interference (1), and one rating of Slight (2). Restriction/interference ratings for Waste Relief (both liquid and solid) were slightly poorer than ratings for the other movements because the harness concept had to be removed (at least partially) to perform this task.

Table 3. Movement restriction and interference ratings. Note that higher ratings indicate increased interference and restriction while lower scores indicate better performance.

Question	Mean	SD
Walk/brisk walk/march	1.07	0.26
Jog/run	1.07	0.26
Sit	1.13	0.52
Take a knee	1.00	0.00
High step	1.00	0.00
Combat roll	1.00	0.00
High/low crawl	1.00	0.00
Climb through window	1.07	0.26
Going through a doorway	1.00	0.00
Climb/descend stairs	1.00	0.00
Squat	1.00	0.00
Climb ladder	1.00	0.00
Overhead arm reach	1.00	0.00
Aim a weapon in the kneeling position	1.00	0.00
Aim a weapon in the prone position	1.00	0.00
Get into vehicle	1.00	0.00
Ride in vehicle	1.13	0.52
Waste relief (liquid)	1.31	0.48
Waste relief (solid)	1.33	0.49

3.5 Mission Activities

Similar results were seen in the mission activity ratings (5-point scale where 1 was Very Poor and 5 was Very Good), where the harness concept had the best mean ratings, and only the Road March received any ratings other than Very Good (5). For the variable Road March, two participants rated the harness concept's performance as Good (4), while all the other participants rated it as Very Good (5).

In the images in Fig. 3, test participants performed a variety of MOUT activities during the evaluations, and the reader is able to see how the harness concept stayed in place through those movements. There were instances where the bottom edges of the test item pulled away from the thigh, and there was some buckling at the sides (upper thigh); however, this was more prevalent on individuals who were on the small side. In general, the harness concept stayed close to the body and allowed the user to make the movements they required without compromising protection.

Fig. 3. Images of test participants wearing harness concept to perform mission activities.

3.6 Compatibility

Test participants were asked to state if they had any compatibility issues with their test items and the other clothing they wore and equipment they used. Test participants noted that the harness concept was worn over their belt, thereby not allowing access to attach or wear items on the belt, but in general, the was considered a minor inconvenience to most test participants. No other compatibility issues were noted for the harness concept.

4 Conclusion

In summary, the harness concept was the best performing concept. The primary driver was comfort and ability to move in the test items. The primary type of restriction encountered was when lifting the leg at the hip and some bunching in the crotch area. Participants also noted restrictions in their ability to access their back pockets. Based on these participant comments, modification should be made to the prototype and development should continue.

It should be noted that only user testing was performed and each concept was worn for a limited amount of time (less than four hours). Additional blast and thermal testing is recommended. It is recommended that additional user testing be conducted with extended wear times and a broader array of military tasks. The harness concept is a design that should also be considered in a full level of protection, similar to the current groin protector panel (small arms protection level).

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An Ergonomic Analysis of the Traditional Sorbetes Cart

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Abstract. Sorbetes, also known as 'dirty' ice cream, is one of the goods that have been sold on the streets of Metro Manila. Known for its colorful and unique cart design, people usually buy sorbetes because of its distinct taste and affordable price. Sorbetes vendors may be subjected to a huge amount of stress, causing them to experience pain on several parts of their body, because of the improper posture when using the cart. However, there is a lack of research on sorbetes peddling that could give basis to ensure that the cart design is ergonomic. Thus, this study aims to conduct an ergonomic analysis of the sorbetes cart and come up with solutions that may lessen the discomfort that vendors have grown accustomed to. Using Nordic Questionnaire, 15 sorbetes vendors were asked to identify which among their body parts are perceiving discomfort. Rapid Entire Body Assessment was conducted to assess their posture for each activity, and identify their risk for Musculoskeletal Disorders. This yielded a REBA score of 5 for all vendors when pushing/pulling the cart, and a range of 6–10 for scooping sorbetes – which entails medium and high risk, respectively. Moreover, it was identified that body parts with high prevalence of pain were more driven by poor posture in scooping, rather than pushing. In conclusion, few of the aspects of the cart (i.e. cart weight, handle design, canister's depth, handle distance) must be modified to reduce the vendors' REBA score and the discomfort that they experience.

Keywords: Ergonomics · Sorbetes cart · Ice cream

1 Background of the Study and Rationale

Street vending in the Philippines goes a long way back to the colonial era, wherein goods like milk, rice cakes, fruits, *binatog*, and *halo-halo* can be found alongside the streets of Manila [1]. As time passed by, the variety of goods being sold on the streets continuously increased, that an accurate list of goods that all the Filipino street vendors are selling today is nearly impossible to create.

Sorbetes, or what others refer to as 'dirty' ice cream, is one of the goods that have been sold on the streets for a long time now. Known for its colorful and unique cart design, people usually buy sorbetes because of its distinct taste and affordable price.

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Selling sorbetes along the streets all-day long is no easy task. Sorbetes vendors are usually subjected to a huge amount of stress, causing them to experience pain on several parts of their body. One of the causes of this stress is the pushing/pulling of the cart. As stated in the study of Reed [2], Garg and Moore [3] arrived at a conclusion that "Pushing and pulling activities account for nine to eighteen percent of all back strains and sprains". In addition, other factors that may cause these body discomforts such as the sorbetes vendors' posture and measurements (i.e. cart and relevant anthropometric measurements) are of importance to the analysis of the cart.

2 Problem Statement

The lack of previous research on sorbetes peddling gives no basis to ensure that the design of its cart is ergonomic. Due to this, sorbetes vendors may be subjected to risks driven by awkward posture and poor material handling, that may lead to work-related musculoskeletal disorders.

3 Review of Related Literature

With the lack of research in sorbetes peddling, researchers are limited to using past studies that are somehow similar with the nature of this study. In a research by Das, ergonomic analysis on the hospital meal cart was conducted [4]. Design considerations and recommendations for a hospital meal cart included maneuverability, handle height, handle placement, and ease of stopping. On the other hand, in terms of activity, some of the design considerations for pushing and pulling two-wheeled carts [5, 6], were wheel diameter, handle brake, handle height, and cart load.

To be able to analyze the body pain being experienced by sorbetes vendors, it is important to know which body part/s is/are perceiving discomfort. In order to do this, the Nordic Questionnaire [7] may be used. It is a tool in determining the symptoms of work-related musculoskeletal disorder (WMSD). Likewise, a Rapid Entire Body Assessment (REBA) may be conducted to determine the risk of sorbetes vendors to WMSD [8].

4 Methodology

To be able to conduct an ergonomic analysis on the sorbetes cart, 15 vendors around UP Diliman, Quezon Memorial Circle, and Maginhawa street, in the Philippines were interviewed with regards to the pain they were perceiving due to the usage of the cart. Although significant information on task performance, usability of the cart, and working posture were collected, other factors were also considered in order to accurately identify the source of discomfort.

The Nordic Questionnaire was used to gather data on the perceived body discomfort. Necessary sorbetes cart measurements were recorded. In addition, comments and suggestions of sorbetes vendors with regards to the sorbetes cart were gathered.

Pictures were taken while the sorbetes vendors were scooping ice cream and pushing/pulling the cart. The photos were used to conduct a Rapid Entire Body Assessment (REBA) on each sorbetes vendor, which served as a Postural Assessment Tool. Using this tool, risks on WMSD, and its corresponding action were identified. The gathered sorbetes cart measurements were compared with relevant Filipino anthropometric measurements, using the study of Del Prado-Lu as reference [9]. Specific recommendations on the sorbetes cart's design were formulated, with the goal of significantly decreasing the pain that the sorbetes vendors were experiencing.

5 Results and Discussion

5.1 Data Collection and Presentation

A total of 15 sorbetes vendors, with ages ranging from 16 to 55 years old, were interviewed. 87% of which are male, and 13% are female. The number of hours per day wherein sorbetes vendors work ranges from 6–17 h per day, and have been doing such work for 1–35 years.

The respondents were asked whether it was hard to push/pull, stop, and turn the cart. Seventy-three percent (73%) of the subjects have difficulty in moving the cart (i.e. pushing/pulling), 47% in stopping the cart, while none of them in steering the cart.

The sorbetes vendors were also asked regarding the most challenging part in sorbetes peddling, associated with the usage of the cart, 46.67% of the subjects stated that it was pushing/pulling the cart. According to the vendors, pushing/pulling the cart was actually easy - provided that you are walking on a flat road. However, when the road becomes uphill or downhill, that's where the challenge comes in. This is because they have to carry all the weight of the cart (if uphill), or they have to use all their strength to be able to prevent the cart from sliding down (if downhill).

5.2 Pain Discomfort Survey (Nordic Musculoskeletal Questionnaire)

Results of the interviews showed that within a year, sorbetes vendors experience pain mostly in their shoulders and lower back. Discomfort is also present in their hips/thighs, ankles/feet, and knees which are probably caused by prolonged time in standing and walking. The cart does not provide a seat for the vendor, and the nature of their job is to walk along the streets all-day long to seek out people who would possibly buy some ice cream. Lastly, pain is experienced in the neck and wrist/hands. The height of the peddlers is far bigger than the cart, they tend to bend and look down when serving ice cream – putting stress on their neck. Moreover, scooping ice cream involves a lot of movements in the wrist/hands area, causing it to feel the pain when done repetitively (Fig. 1).

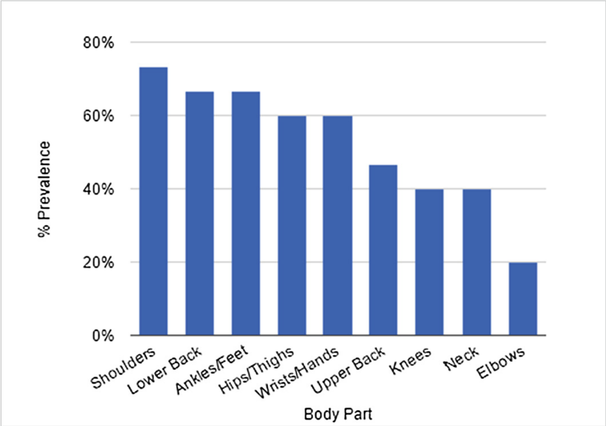

Fig. 1. Percentage prevalence of pain per body part in the last 12 months

5.3 Postural Assessment (REBA)

To determine the risk of the vendors to work-related musculoskeletal disorder (WMSD), their posture while pulling/pushing the cart and scooping ice cream were analyzed through Rapid Entire Body Assessment (REBA).

Pushing/Pulling of the Cart. While the sorbetes peddlers were pushing/pulling, their necks were tilted from 0° to 20°, their trunk formed no angle, and the weight of their body was concentrated on only one leg. The upper arm was forming an angle of 0° to 20°, 0° to 90° for the lower arm, while the wrists were twisted forming an angle of 0°–15° (see Fig. 2). The REBA score for all the vendors is 5, which indicated medium

Fig. 2. Posture of sorbetes vendor while pushing/pulling the sorbetes cart (left) and scooping ice cream (right)

risk for work-related musculoskeletal disorder (WMSD). Given this, further investigations should be done and change must be implemented soon.

Scooping Ice Cream. While scooping ice cream, the vendors' necks were tilted to greater than 20°, some of which were twisted. Standing on both of their legs, the vendors' trunks were forming an angle from 0° to 20°, with some having twisted trunks. In terms of their arms, the angle of their upper arm - which were abducted, and lower arm ranged from 0° to 45° and 0° to 60°, respectively. Moreover, some vendors had their shoulders raised and their wrists twisted to more than 15° (see Fig. 2). In total, the REBA score in scooping ice cream ranges from 6 to 10, with a mean of 8.14. This result indicates high risk work-related musculoskeletal disorder (WMSD) for the vendors. Investigation should be done and change must be implemented immediately.

5.4 Comparison Between the Results of REBA and Nordic Questionnaire

Results obtained from REBA are compared to the results of the Nordic Questionnaire in order to identify which posture mainly causes the pain experienced by sorbetes vendors. Percentage from the maximum possible score of each body part considered in REBA was calculated. A body part with a high percentage in REBA score means poorer posture; correspondingly, this body part should be indicated with presence of discomfort during the interview.

Analyzing the results of REBA for each activity, both pushing and scooping yielded the highest percentages for the wrist and lower arm. Using only the said data as the sole basis, one may infer that, indeed, it is in these body parts wherein vendors experience the most pain. However, the result from the Nordic Questionnaire showed that prevalence of pain for the wrists and elbows were 60% and 20% respectively, which is low in comparison to what its respective REBA score implies. Despite having awkward positions for these body parts, vendors may already accustomed to the pain, hence the low percentage in the Nordic Questionnaire (Tables 1 and 2).

Table 1. Mean REBA score and its percentage per body part (scooping) (The percentages were obtained by dividing the mean REBA score per body part with the maximum possible score.)

	Mean	Percentage
Wrist	3.00	100%
Lower arm	2.00	100%
Neck	2.13	53%
Activity	2.00	5.%
Upper arm	3.33	48%
Trunk	2.40	40%
Leg	1.00	25%
Coupling	1.00	25%
Force/load	0.00	0%
REBA score	8.13	54%

Table 2. Mean REBA score and its percentage per body part (pushing)

	Mean	Percentage[1]
Wrist	1.93	64%
Lower arm	1.27	63%
Force/load	2.00	50%
Leg	2.00	50%
Activity	1.00	25%
Coupling	1.00	25%
Neck	1.00	25%
Trunk	1.07	18%
Upper arm	1.07	15%
REBA score	5.0	33%

From the results of the Nordic Questionnaire, pain is most prevalent in the shoulders, lower back, and ankles/feet. The activity score in REBA is most likely associated to perceived pain in the shoulders since the shoulders are frequently used for both scooping and pushing. The percentage from the maximum REBA score of the Activity category for scooping concurs with the result from the Nordic. However, the percentage from the maximum REBA score of the Activity category for pushing deviates to the Nordic Questionnaire result. Same with the result for the lower back, maximum percentage from the maximum REBA score of trunks are low. Looking at the scores, a higher REBA percentage in the Trunk category was obtained for scooping compared to pushing, 40% and 18%, respectively. The vendors while scooping are in a stooping posture, unlike the upright posture when pushing the cart. Lastly, pain in the ankles/feet may be compared with the REBA percentage in the Leg category. Higher percentage

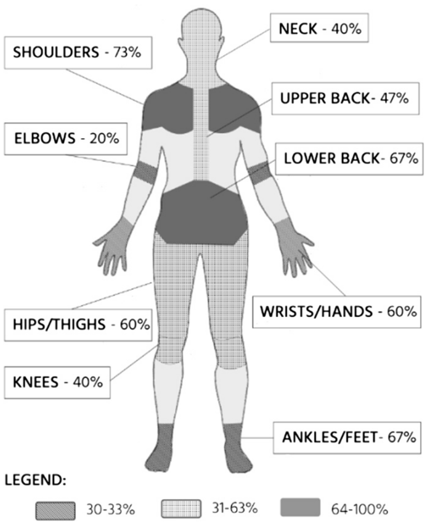

Fig. 3. Illustration of prevalence of pain per body part

was obtained for pushing, rather than scooping, which means that sorbetes vendors manifest a poor position of their legs while pushing the cart, thereby experiencing discomfort in their ankles/feet, given that they have to walk several miles a day (Fig. 3).

5.5 Cart Design

The measured mean length and width of a traditional sorbetes cart was 118.61-cm and 38.82-cm respectively. Upon evaluation, it has been identified that these measurements are within the recommended cart measurements [11] which are 121.92-cm for the length and 91.40-cm for the width (Fig. 4).

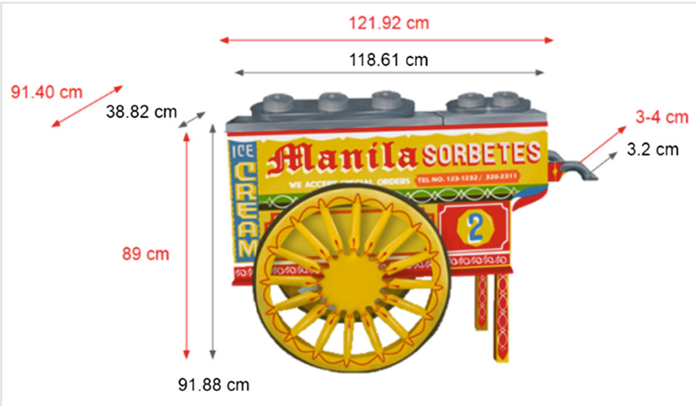

Fig. 4. Comparison between the actual (black two headed arrow) and recommended (red two headed arrow) cart measurements [10]

In addition, the current design's mean handle width of 3.2-cm complies with the recommended range of handle width or diameter for power grips which is 3 to 4-cm [12]. However, the handle orientation of the cart does not allow proper wrist posture; it requires vendors to twist their hands when gripping the handle. Likewise, the cornered shape of the handles is not suitable for gripping.

Since the distance between the two handles in the current design, 35.82-cm, do not comply with the 47-cm anthropometric measurement of the elbow breadth (based on the mean value of the 95th percentile male and female), it can be observed that the sorbetes vendors' arms were very strained.

Therefore, there is a need to change the design of the sorbetes cart accordingly. As it has been verified that the sorbetes vendors were experiencing body pains on several parts of their body from selling of sorbetes, their opinion on changing the design of the cart was asked. Although knowing that these changes may alleviate the pain that they were feeling, most of them were very hesitant with regards to change, not only because they were accustomed to the pain from peddling for many years, but most importantly because they had the notion that the appeal of the sorbetes cart to people might be affected, if ever its appearance will be changed.

6 Conclusion

The two main activities that sorbetes vendors undertake are pushing the cart and scooping the ice cream. Upon conducting REBA on their posture for each activity, it was identified that for pushing, sorbetes vendors are subjected to medium risk to work-related musculoskeletal disorder, while high risk for scooping.

On the other hand, comparison of the results of the percentage from the maximum possible REBA score to the Nordic Questionnaire showed that albeit the awkward posture that vendors manifest while peddling sorbetes, pain is not perceived. Possibly because sorbetes vendors have already grown accustomed to it or other risk factors are associated. However, higher REBA percentages were present for scooping rather than pushing.

Thus, focus must be directed towards minimizing the REBA score for scooping, since body parts which exhibit high prevalence of pain are driven by the awkward posture from the said activity.

Most importantly, there is a need to redesign some parts of the cart, since it has been proven to be unergonomic, as what the result of this study indicates. In this way, discomfort that sorbetes vendors are subjected to may be alleviated.

7 Recommendations

7.1 Pushing

Since pushing is the most difficult part in using the sorbetes cart, some parts of the body needed to perform the activity perceive pain. To alleviate the pain for the sorbetes vendors, REBA score should be minimized. For the posture of the vendors, neck angle should be kept within 0 to 20 and trunk must be straight. The upper arm must be kept within 0 to 20, while the lower arm must be kept within 60 to 100. The wrist of the vendor must be kept within 0 to 15 higher or lower. Bending and twisting should be avoided. Aside from posture, another factor which greatly contributes in the REBA score is the weight of the cart and thus, it must be decreased.

7.2 Scooping

To reduce the REBA score, it is recommended that the ice cream canisters' depth be reduced. Depth should be adjusted for the vendors to avoid:

1. tilting their neck with an angle greater than 20°;
2. bending their upper body; and
3. exceeding 20° for the upper arms, 60°–100° for the lower-arm and 15° for the wrist.

7.3 Cart Height

As a general rule, working height (for work which involves standing) should be based on elbow height [13]. With this, sorbetes cart height should be decreased from 91.88-cm to 89-cm, in order to accommodate the 5th percentile of female [9].

7.4 Handles

Rather than the four-sided handles that are used in the current design of the sorbetes cart [14], it would be better if the handles were cylindrical in shape. Likewise, its handle should be vertical with horizontal bar since it is a narrow two-wheeled cart that is less than 50-cm wide [11, 13], to cater to vendors of different heights and to improve the maneuverability of the cart. Lastly, the distance of the handles should be increased to 47-cm, which is based on the anthropometric measurement for elbow breadth, to be able to accommodate most vendors.

7.5 Brakes

Vendors have difficulty in stopping the cart, especially when going down the inclined surfaces. With this, it is recommended to install an emergency wheel brake for easy control in stopping the cart [12].

8 Areas for Further Studies

Further studies may be done by analyzing the design of the cart with the use of biomechanical analysis. In this way, the maximum acceptable force required in pushing the cart given its weight, and the likes may be determined. They may also study on the other occupational hazards that a sorbetes vendor experiences (i.e. environmental factors).

Moreover, the traditional two-wheeled sorbetes cart may be analyzed by comparing it to the other existing forms of sorbetes cart such as those with pedals and machine, and then evaluate which of these is the most ergonomic cart – given that the traditional appeal of the cart will not be affected.

Lastly, since one of the most problematic activities in sorbetes peddling is scooping, further studies may be done to determine how the method of ice cream scooping can be changed to alleviate the pain that it causes to sorbetes vendors.

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Adoption of Construction Ergonomic Interventions on Building Construction Sites in Nigeria

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Abstract. The construction industry is physical in nature and the incidence of work related musculoskeletal disorders is increasing, especially in a developing country such as Nigeria. Ergonomic hazards reduce the effectiveness of thousands of construction workers in the Nigerian construction industry. Work related musculoskeletal disorders (WMSDs) effectively marginalise construction productivity, which is a challenge in general in the industry. Furthermore, the industry is also affected by a shortage of skilled craftsmen. Then, observations and anecdotal evidence indicate that Nigerian construction workers have not adopted ergonomics principles. The research examines the level of adoption of ergonomics principles in preventing WMSDs on construction sites in Nigeria. It assesses the practice of ergonomics based on stretching and exercises, use of personal protective equipment, working methods, and material storage and movement. Site observations were used to assess ergonomic practices among one hundred and twenty workers on construction sites in Nigeria.

Keywords: Construction · Ergonomics · Productivity

1 Introduction

The construction industry has earned a reputation of being an extremely hazardous and dangerous industry because of the high incidence of accidents and fatalities that occur worldwide [1–5]. Statistics indicate that the construction industry is among the most hazardous industries. Data from the National Safety Council [6] of the United States 2003–2011 shows that, 8 993 people died in construction, which was the highest number of fatalities among all industries. The same trend was observed in other countries as well. Construction had the third highest occupational accidents in Egypt [7]. Mahmoudi et al. [8], Muiriri and Mulinge [9], and Olutuase [2] state that one in every six accidents occur on construction sites globally, and the situation is even worse in developing countries. In most developing countries, such as Nigeria, many accidents and ill health problems on construction site remain unreported and there is concern that the current situation is alarming because health and safety (H&S) management is poorly organised and is characterised by poor documentation [9–11]. Olutuase [2], and Smallwood and Haupt [1] assert that hundreds of construction workers are being injured

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and rendered permanently disabled. Construction is physically demanding [12]. The nature of construction work helps to explain why injuries, such as strains, sprains, and WMSDs, are so prevalent in the industry. Execution of tasks by construction workers requires lifting heavy loads, performing repetitive tasks, frequent bending and twisting of the body, working above shoulder height, working below knee level, manual handling of heavy and irregular-sized loads, adopting awkward work postures, working in confined spaces, holding the same position for long, forceful exertion and working under hot and cold temperatures/weather, which are inherent H&S risks and unfavourable ergonomic practices [1, 9, 13]. That is why it is being said that construction itself is a problem in ergonomics [14]. These factors can result in injuries or problems involving the tendons, muscles, or nerves which constitute WMSDs. According to Hsiao and Fosbroke [15], construction workers at 'increased risk' of injury include machine operators, plasterers, tile setters, carpet layers, structural steel workers, electricians, roofers, plumbers, carpenters, and general workers. WMSDs affect every aspect of a worker's life, people who work in pain are less productive and cannot produce quality. Buckley [16] posits that sprains, strains, and physical ailments have long been a drain to construction productivity and risk to construction workers' H&S.

The high prevalence of WMSDs and the growing need to improve H&S in construction have led to increasing focus on ergonomics. Ergonomics is one of the strategies in preventing WMSDs and improving H&S in construction [4, 17, 18].

The aim of the paper is to investigate the adoption of construction ergonomic interventions on building construction sites in Nigeria. The study investigates what is being done on Nigerian construction sites to prevent the incidence of WMSDs in the building industry. The objective is to assess the practice of ergonomics based on stretching and exercises, use of ergonomic personal protective equipment, working methods/practices, material movement, and the use of ergonomic designed hand tools.

2 Literature Review

2.1 Occupational Health and Safety

As a broad-based concept, occupational H&S encapsulates the mental, emotional and physical well-being of the worker in relation to the conduct of his work. Occupational H&S encompasses the anticipation, recognition, evaluation and control of danger, arising from workplaces that could affect negatively the health, wellbeing of employees considering the working environment. The basic premise of occupational H&S is to ensure a healthy and safe work environment, which would not have a negative impact on the health of workers.

2.2 Health and Safety in Construction

The high rate of injuries, illness, and fatalities has been a source of concern to stakeholders requiring them to provide a healthy and safe working environment for workers in the construction industry. According to Obiegu [19], most construction projects in Nigeria do not achieve H&S, and quality. Clients are not satisfied with contractors' poor task preparation, lack of worker protection and poor H&S culture, which results in accidents on construction sites. This has led to deliberations regarding ways of ensuring a healthy and safe working environment, especially for workers who are usually at the receiving end when these incidents occur [20]. That is why Mahmoudi et al. [8] posit that construction firms need to improve their conditions with respect to H&S. Workers in construction experience high rates of disabling WMSDs. The need to improve H&S, and reduce the incidence of WMSDs in construction has led to the implementation of ergonomics interventions.

2.3 Ergonomics in Construction

Construction craftsmen have an important role to play in the execution of projects, which is critical in terms of delivering quality buildings and structures. Ergonomics is a tool, which the construction industry can use to reduce injuries and work related injuries on construction sites.

Ergonomics basically considers how work affects a worker. The focus of ergonomics is always on designing equipment, tasks, tools, and the working environment for the individual employee, who brings unique characteristics with her or him to the job. Some of these characteristics, such as height and age, cannot be changed, while others, such as training and experience, can be changed.

2.4 Ergonomics Interventions

Administrative Improvements or Improvement. Administrative interventions include introducing work practices that reduce ergonomic hazards. It is known as administrative controls because they are interventions that are administrative and can only be implemented by management. The improvements include changes in the way work is prepared, job rotation, controlling the work schedule and work pace, muscle relaxation time, and implementing housekeeping and maintenance of work spaces, tools, and equipment.

Engineering Improvements. When the ergonomic hazard cannot be eliminated by administrative controls, engineering controls are the next preferred measure. Engineering controls involve rearranging, modifying, redesigning, or replacing tools, equipment, and work environment. These improvements reduce or eliminate the ergonomic risk factor. They include providing adjustable equipment, providing ergonomic designed tools, providing lifting and mechanical aids for movement of materials. Other engineering improvements include machine guards, backup alarms, guardrails, covers, slip resistant surfaces, and using machines to move heavy objects instead of carrying them [18].

Personal Protective Equipment. Ergonomic related personal protective equipment (PPE) are worn to protect a specific body part and should be always worn by employees to reduce the risk. PPE includes gloves, knee, shoulder and elbow pads, shock absorbing shoe inserts and other protective items. PPE is at the bottom of the hierarchy of prevention interventions, and should only be considered when other measures such as administrative and engineering interventions have been exhausted. The ergonomics intervention matrix is shown in Fig. 1.

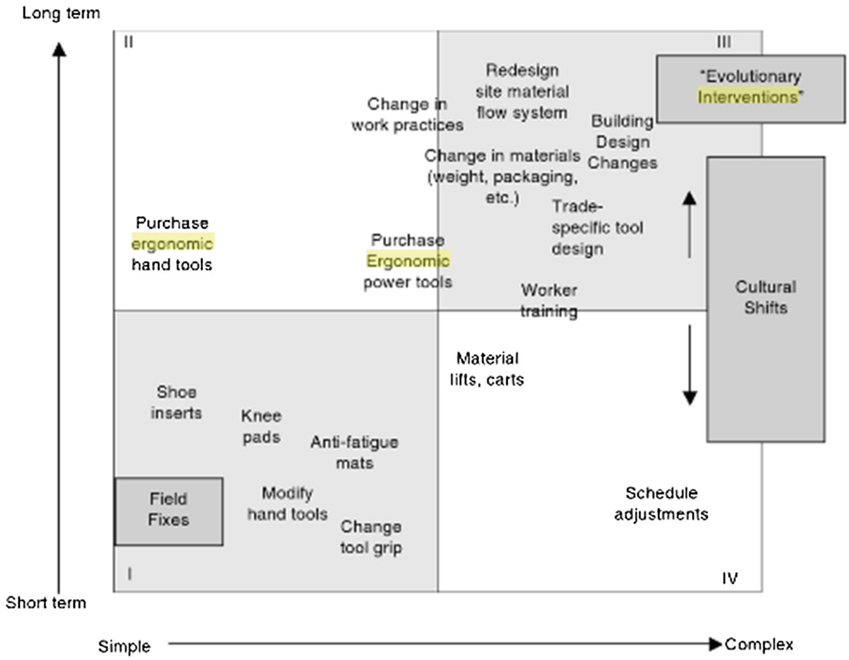

Fig. 1. Ergonomics intervention matrix [21]

3 Research Method

Quantitative and qualitative research methods were used for the study. Site observations and interviews were used for the study. Plumbers, carpenters, and floor tile layers were observed while working and interviews were used to complete the questionnaires. Convenience sampling was used to select 40 craftsmen in each category. The observations were focused on the practice of ergonomics in preventing WMSDs based on stretching and exercises, the use of PPE, working methods/practices, material movement, and the use of ergonomic designed hand tools. The artisans were interviewed with respect to ergonomics training, WMSD symptoms, and ergonomics in general.

4 Research Findings

It can be seen from Table 1 that the respondents were equally distributed (40 each) among carpenters, floor tile layers, and plumbers. 80% of Respondents have between 6 and 20 years' work experience, and can thus be deemed experienced. Most employees are employed on a temporary basis, as only 22% of respondents are permanent staff in the employ of their respective firms.

Table 1. Profile of respondents

S/N	Variable	Option	Frequency (Nr)	Percentage (%)
1	Trade	(a) Carpenters	40	33.3
		(b) Floor tile layers	40	33.3
		(c) Plumbers	40	33.3
		Total	120	100.0
2	Working experience	(a) 0–5 years	16	13.3
		(b) 6–10 yeras	37	30.8
		(c) 11–15 years	28	23.3
		(d) 16–20 years	32	26.7
		(e) 20 years and above	7	5.8
		Total	120	100.0
3	Employment	(a) Permanent	26	21.7
		(b) Temporary	94	78.3
		Total	120	100.0

The researcher chose to inform the workers regarding ergonomics and ergonomic injuries. This was done to help the respondents develop an understanding of the subject matter to be able to respond to other questions appropriately. During this process symptoms of WMSDs were listed and explained to the craftsmen. This was followed by a question as to whether they have experienced such signs and symptoms before.

Respondents were asked if they have experience any form of WMSD in the last 12 months. 61% of artisans indicated that they had, while 39% had not. This indicates that WMSDs are still a problem in construction. Artisans that have experienced WMSDs were asked to indicate the anatomic region affected. The back (34%) was the most affected while feet (8%) was the least affected. This also confirms the notion that WMSDs are prevalent in construction. The study also investigated training with respect to WMSD prevention - only 10.8% had received such training (Table 2).

Table 2. Experience of and training relative to WMSDs.

Aspect	Option	Frequency (Nr)	Percentage (%)
Experienced WMSD before	Yes	73	60.8
	No	47	39.2
	Total	120	100.0
Anatomic region	Neck	8	11.0
	Shoulder	11	15.1
	Hand	8	11.0
	Back	25	34.2
	Knee	15	20.5
	Foot	6	8.2
	Total	73	100.0
Training on WMSD prevention	Yes	13	10.8
	No	107	89.2
	Total	120	100

The research investigated whether respondents (artisans) stretch during their working day. As seen in Table 3, the majority (84%) of artisans do not stretch during their working day. There was no restriction on lifting of material by a single person and restriction on the maximum weight of 30 kg as per the International Labour Organisation, for lifting manually. There was no cap on the amount of weight to be lifted on all sites observed. It is also important to note that lifting aids were found on 68% of the sites visited, which would help reduce the amount of manual lifting.

Most of the respondents had not received manual lifting related training - only 13% had. The study investigated management policies/interventions such as job rotation in an endeavour to prevent WMSDs - most (93%) employees do not.

Table 3. Ergonomics interventions to mitigate WMSDs.

Intervention	Response	Frequency (Nr)	Percentage (%)
Stretches prior to work	Yes	19	15.8
	No	101	84.2
	Total	120	100.0
Restriction on single person lifting	Yes	0.0	0.0
	No	120	100.0
	Total	120	100.0
Training on manual lifting	Yes	16	13.3
	No	104	86.7
	Total	120	100.0
Restriction on lifting over 30 kg	Yes	0	0.0
	No	120	100.0
	Total	120	100.0

(*continued*)

Table 3. (*continued*)

Intervention	Response	Frequency (Nr)	Percentage (%)
Are dollies, cart and other lifting aids available for moving materials	Yes	52	43.3
	No	68	56.7
	Total	120	100.0
Do management implement job rotation	Yes	8	6.7
	No	112	93.3
	Total	120	100.0

Table 4 presents findings from observations of floor tile laying activities. It was observed that there was no use of PPE such as knee pads, and shock absorbing shoe inserts. Site observations that only 45% of floor tile layers use hand gloves while working.

No tile layer was found to use knelling creepers. Only 30% of tilers make use of tripod benches to mitigate cutting at ground level. It was observed that materials were stored near their place of use in 60% of cases. Most materials are stored on the floor as observed in 87% of the plumbing work cases. This contributes to the incidence of bending. It could have been stored at waist level to prevent frequent bending. The use of mechanical aids for movement of materials was found to be low. Wheel barrows were observed to be the most common aid used to move material.

Table 4. Floor tile laying ergonomic interventions

	Intervention	Yes	Percentage	No	Percentage
1	Shock absorbing shoe inserts	0	0.0	40	100.0
2	Knee pads	0	0.0	40	100.0
3	Kneeling creepers	0	0.0	40	100.0
4	Hand gloves	18	45.0	22	55.0
5	Providing tripod benches to reduce cutting at ground level	12	30.0	28	70.0
6	Materials stored near place of use	24	60.0	16	60.0
7	Materials stored above ground level	5	12.5	35	87.5
8	Mechanical aid for movement of materials	21	52.5	19	47.5

Carpenters do not use knee pads, leg wedges, and shock absorbing shoe inserts. 38% of Carpenters used hand gloves while working (Table 5).

In terms of material storage and management, materials were mostly stored on the ground as seen in the case of 70% of carpentry operations observed. It was also seen that materials were stored near their place of use in the case of 62% of carpentry operations observed.

It was observed that there was no use of adjustable saw horses. Fixed saw horses were found to be used. It was also observed that mechanical aids were rarely (23%) provided for movement of materials on site.

Table 5. Carpentry related ergonomic interventions and use of PPE

	Intervention/PPE	Yes	Percentage	No	Percentage
1	Knee pads	0	0.0	40	100
2	Leg wedge	0	0.0	40	100
3	Shock absorbing shoe inserts	0	0.0	40	100
4	Gloves	15	37.5	25	62.5
5	Materials stored near place of use	25	62.5	15	37.5
6	Materials stored above ground/waist level	17	42.5	23	57.5
7	Nail and screw gun	7	17.5	33	82.5
8	Adjustable saw horse	0	0.0	40	100.0
9	Mechanical aid for movement of materials	9	22.5	31	77.5

Table 6 presents findings from observing plumbers. The use of PPE was observed during plumbing and pipefitting operations. Plumbers were not seen to be using knee pads and shock absorbing shoe inserts. 48% of carpenters used hand gloves while working. It was observed that light weight PVC pipes were used on all sites visited. Benches were only used for cutting at waist level on 7% of sites. Mechanical lifts were only used - in 5% of plumbing operations observed.

Materials were stored on the ground in 85% of operations observed, as opposed to ground, or at waist level. Materials were stored near their place of use in 80% of plumbing and pipe fitting operations observed.

Table 6. Plumbing and pipe fitting ergonomic interventions.

		Yes	Percentage	No	Percentage
1	Shock absorbing shoe inserts	0	0.0	40	100
2	Knee pads	0	0.0	40	100
3	PVC(light weight) pipes	40	100.0	0	0.0
4	Hand gloves	23	57.5	17	42.5
5	Providing benches to reduce cutting at ground level	7	17.5	33	82.5
6	Materials stored near place of use	32	80.0	8	20.0
7	Materials stored above ground/waist level	6	15.0	34	85.0
8	Use of person lift/mechanical lift.	2	5.0	38	95.0

5 Conclusions and Recommendations

The study has limitations because of the small sample size, and the fact that only three trades were assessed, and therefore the result should not be considered representative of the construction population in Nigeria. A larger sample size is required to determine the degree of adoption of ergonomics in Nigeria.

The study has shown that construction workers face high rates of WMSDs. The study concludes that the adoption of ergonomics among carpenters, floor tile layers, and plumbers is low. The use of PPE is very low. Knee pads, shock absorbing shoe inserts, and leg wedges were not found to be used among the three trades. Because of the rate of kneeling while they work, a knee pad helps to reduce the pressure on the knee while the shock absorbing shoe insert helps give the cushion effect while they stand. Stretching and exercise was also found to be low among craftsmen. Craftsmen do not stretch before and during their working day. Even though the research did not address how much exercise and stretching they do outside the work environment.

In terms of material handling, no restriction was in place with respect to lifting of material by a single person and there was no cap on the amount of weight to be lifted on all sites observed. These are administrative interventions which help to reduce WMSDs through proper material handling and movement. This may be because most employees have not received any training on manual lifting as found in the study.

The use of ergonomic equipment such as kneeling creepers and tripod benches to reduce cutting at ground level for floor tile layers was low. The use of nail and screw guns and adjustable saw horses was among carpenters was also low. In the case of plumbers, the use of light weight (PVC) pipes instead of steel pipes was universal. This helps reduce the amount of load to be carried by plumbers. The use of person lifts to hoist a worker while working was also very low. In terms of ergonomic working methods, materials were usually stored near their place of use to reduce transportation of materials on site. Materials are mostly stored on the ground, rather than at waist level to prevent repeated bending and rising.

The study recommends training for craftsmen with respect to ergonomics and WMSD prevention to experienced craftsmen and inclusion into the syllabi of apprentices, and qualified craftsmen.

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The Impact of Ergonomics Interventions on Musculoskeletal Injuries Among Construction Workers

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Abstract. Most fatalities and injuries at construction sites can be traced to the worker not working in a safe position, using the wrong tool for the job, or using the right tool the wrong way. The aim of this research is to investigate into musculoskeletal injuries and ergonomic impact among construction workers. The objectives are to identify the types of musculoskeletal injuries; find the effect of musculoskeletal injuries among construction workers and to determine the impact of ergonomic interventions. Convenience and purposive sampling technique were used to select the sample size of 37 respondents. Questionnaires were used to take information from doctors and construction workers. Three medical doctors at the Cape Coast Central Regional Teaching Hospital revealed that strain and sprain were the major injuries recorded with means of 3.1 respectively. Loss of concentration, working not to specification and delay of work with respective means of 3.5; 3.3; and 3.2 were identified as the effects of musculoskeletal injuries on construction workers. It was found that some of the factors of musculoskeletal injuries among construction workers are awkward posture, repetition, vibration, force and extreme temperature. This was also confirmed by medical doctors' report that the most and frequent factor that caused musculoskeletal injuries is force, followed by awkward posture with respective means of 5 and 3.6. This clarifies the fact that construction workers attitude towards their health is poor.

Keywords: Ergonomics · Interventions · Musculoskeletal · Injuries · Construction

1 Introduction

The word "Ergonomics" comes from two Greek words "ergon", meaning work, and "nomos" meaning "laws" to denote the science of work [1]. The word ergonomics was created in 1857 by Wojciech Jastrzebowski in a philosophical narrative, "based upon the truths drawn from the Science of Nature" [1]. Eergonomics is a systems-oriented discipline, which now applies to all aspects of human activity.

The International Ergonomic Association [2] defines Ergonomics (or human factors) as "the scientific discipline concerned with the understanding of the interactions among humans and other elements of a system, and the profession that applies theoretical principles, data and methods to design in order to optimize human well-being and overall system". ErgoWeb Inc. defines ergonomics in a proactive sense: "Ergonomics removes

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barriers to quality, productivity, and safe human performance in human-machine systems by fitting products, equipment, tools, systems, tasks, jobs, and environments to people" [3]. A precise definition proposed by [4]. which leads to its very fundamental nature states that "Ergonomics is the design and engineering of human-machine systems for the purpose of enhancing human performance".

Ergonomics considers the physical and mental capabilities and limits of the worker as he or she interacts with tools, equipment, work methods, tasks, and the working environment [5].

[6] also said Ergonomics derives from two Greek words: *'ergon'*, meaning work, and *'nomos'*, meaning natural laws. Today, the word is used to describe the science of "designing the job to fit the worker, not forcing the worker to fit the job – thus, it is also the science of adapting work and working conditions to suit the worker".

Common examples of ergonomic risk factors are found in jobs requiring repetitive, forceful, or prolonged exertions of the hands or legs; frequent or heavy lifting, pushing, pulling, or carrying of heavy objects; and prolonged awkward postures. Vibration and excessive heat or cold may also add risk to these work conditions. The level of risk depends on the intensity, frequency, and duration of the exposure to these conditions [7].

2 Problem Statement

Construction, by its very nature, is a problem for ergonomists as it requires work above shoulder level and below knee height. Materials may also be heavy and/or inconveniently sized and shaped, thus presenting manual materials handling problems [7]. [8], stated that "by any epidemiological criteria, occupational musculoskeletal injures represent a pandemic problem in the United States with gigantic effects on the quality of millions of peoples' lives every year."

Numerous construction tasks pose significant risks to workers. To eliminate or mitigate the risks, it would be necessary to identify work risks in construction and assess the impact on workers, of even minimal ergonomics on the construction process [7].

Construction worker due pose in a certain posture in their everyday work and the response from them will either be waist pain, spinal cord pain or other musculo-skeletal disorders. This has made numerous construction worker to depend on drugs and other on unprescribe medication.

The outcome of this has affected their work output. That is; their ability to work effectively when they have taken drug and when they are not.

2.1 Aim of the Study

The aim is to investigate into musculoskeletal injuries and ergonomic impact among construction workers.

2.2 Objectives

The objectives of the study are:

1. to identify the types of musculoskeletal injuries
2. to find the effect of musculoskeletal injuries among construction workers
3. to determine the impact of ergonomic interventions

2.3 Ergonomics in Perspective

The goal of the science of ergonomics is to find the "best fit" between the worker and the job condition. Ergonomics tries to come up with solutions to make sure workers stay safe, comfortable, and productive [9].

Construction workers are exposed to a variety of ergonomic hazards, including awkward postures, heavy lifting, forceful exertions, vibrations, and repetitive motions [10]. They also experience an elevated risk of musculoskeletal disorders [11].

2.4 Types of Musculoskeletal Injury

The [12] has characterized "work-related" diseases as multi - factorial to indicate that a number of risk factors (e.g., physical, work organizational, psychosocial, individual, and socio-cultural) contribute to causing these diseases. The sum of these challenges affects the working capacity and decreases the satisfaction of the individual. Furthermore, it decreases the profit of the organizations. International commission on occupational health defines MSD as both disorders and diseases of musculoskeletal system that have a casual determinant that is work related.

[3] defines MSDs as injuries and disorders of the muscles, nerves, tendons, ligaments, cartilage and spinal discs which are directly and indirectly related to work or the work environment. Work related Musculoskeletal disorders (WMDs) are casually linked to physical loads resulting from occupational activities and believe to occur when mechanical workload is higher than physical capacity of human body. However, these relate to different body regions and occupational work.

The International Labour Organization (ILO) estimates that some 6000 worker dies each day worldwide and 337million people are victims of work related accidents and illness arising from occupational injuries [13].

Injuries to the musculoskeletal system can be classified according to the body structures that are damaged. Some injuries may involve more than one structure.

[14] suggested that there are four basic types of musculoskeletal injuries, and these are: Fracture; Dislocation; Sprain and Strain.

- *Fracture:* A break or disruption in bone tissue. This may be open or closed.
- *Dislocation*: A displacement or separation of a bone from its normal position at a joint.
- *Sprain:* A partial or complete tearing or stretching of ligaments and other tissues at a joint.
- *Strain:* A stretching and tearing of muscle or tendon fibers.

Alireza and Aref, 2013 attributes the effect of these types of musculoskeletal injury as Awkward posture; Repetition; Static posture; Vibration; Force and Extreme temperature.

Awkward Posture. Awkward posture is the position of the body outside of neutral that is a best location of each joint that can provide the strength and control. In the construction industry prolonged reaching, twisting, bending, kneeling, squatting, working overhead with your hands or arms, or holding fixed positions are as awkward posture. Work method or workplace dimension can contribute to create awkward posture. Therefore, awkward posture can associate to raising the rate of injury in the wrist, shoulder, neck, and low back and this can cause low output of workers [15].

Repetition. Performing the similar motion of the work in every few second for more than two hours without any rest and break time is mentioned as a repetition work. Repetition work can increase the rate of injury in the local tissue of the body [15].

Repetitive or sustained shoulder elevation during occupational tasks has been identified as a significant risk factor for shoulder tendonitis or non-specific shoulder pain [16].

Static Posture. Static postures or positions that a worker must hold for long periods of time, can restrict blood flow and damage muscles.

Same posture or position of the body is held throughout the exertion (no movement) or lack of movement reduces circulation and causes muscle tension which can contribute to injury [17].

Vibration. Vibration is defined as any movement of the body in one fix point while using power tools or equipment while driving which can put stress on the tissues of the fingers, hand and arms [15].

Many jobs in construction involve the use of hand-held power tools such as pneumatic breakers and disc grinders. The vibration from such equipment may cause carpal tunnel syndrome. The disease affects the fingers and hands. In the long run, permanent damages to the nerves will result in a loss of the sense of touch and dexterity [9].

Force. Forces vary with equipment type, design, and state of repair. Recognize that when applying force to an object, forces are transferred through your body. Forces transferred to your body are affected by not only the amount of force, but also the distance through which a force is applied. Choosing equipment that requires less force to activate and requires a shorter activation distance can reduce forces transferred to your body. Ensuring that equipment is in good working order helps reduce the overall forces to the body [18].

The amount of physical effort that is required by the workers to do the task or control and maintain the equipment and tools in a limited period is introduced as force. Utilizing the muscles much harder than normal by applying extreme pressure can cause stress on the muscles, tendons and joints [15].

Extreme Temperature. Extreme temperature is of the environmental features that can be divided to the extreme heat and extreme cold temperature. Extreme heat can reinforce fatigue and heat stress. On the other hand, extreme cold can narrow the blood vessels and decline sensitivity and harmonization of body part [15].

2.5 The Impact of Ergonomic Intervention

The construction industry is a dangerous place to work as its physical processes entail various ergonomic-related problems [19]. The construction industry faces many occupational injuries and fatality risks, making it both unique and challenging to study. Construction is always risky because of outdoor operations [20]. Construction industry is a complex industry that employs a large man power.

Comparisons have often been made between the construction industry and other industrial sectors and the chance of being disabled by injury or serious illness is much greater than for workers in most other industrial sectors.

As noted by [6]. developing countries encounter a number of ergonomic related problems as far as the construction industries are concerned. This can be attributed to the absence of the strong regulations and the weak implementation of the few existing once owing to the inadequate human and material resources to aid in the enforcement of these regulations [21, 22]. A number of these problems have their source in the nature of the work processes on site which happens to be more suboptimal as they are made worse by the use of manual approach in most developing countries, when a mechanical procedure would be very much suitable [6, 23].

3 Research Methodology

3.1 Research Design

The research is primarily quantitative in nature. The research strategy that was used to implement the comprehensive literature reviews on the above objectives was reviewed to see what other researchers have done, to gather the information on the types of musculoskeletal injuries, effect of musculoskeletal injuries among construction workers and the ergonomic interventions from previous researcher.

- *Research instruments.* Questionnaires, personal interviews and observation forms were the main data collecting instrument used in the study. Two set of questionnaires were design for this research, one set was for the artisans and another set for doctors.
- *Population.* The total population of workers at the Cape Coast stadium construction site and the Cape Coast Polytechnic Student Representative Council (SRC) hostel construction site was one hundred and fifty- five (155).
- *Sampling Technique.* Convenience and purposive sampling technique were used to select the sample size.
- *Data Analysis.* The data was analyzed using the descriptive statistics that comprises mean, tables and graphs.

4 Findings and Discussion

4.1 Section of Which Artisan Responding Belongs

It can be observed in Fig. 1 below that in an attempt of the researcher to find out about the section of artisans the various respondents belongs; it was found that 16 respondent indicated that they are steel benders while the remaining 21 which is the majority revealed that they are masons. Source:

4.2 Types of Musculoskeletal Injuries

The researcher as one of the objectives of the study sought to find out about the types of musculoskeletal injuries at the various construction sites. The results after the analysis of the data from the field survey are presented under the headings that follow.

4.3 Types of Musculoskeletal Injuries Encountered by Respondents

The information in the Table 1 makes it clear that fracture, dislocation, sprain and strain has been the types of musculoskeletal injuries usually encountered by construction workers. According to the field survey, both strain and sprain had the strongest mean of 3.1.

Table 1. Musculoskeletal injuries encountered by respondents

Type of injury	Strongly agree (5)	Agree (4)	Neither (3)	Disagree (2)	Strongly disagree (1)	Total	Mean
Fracture	2 (10)	9 (36)	4 (12)	18 (36)	4 (4)	98	2.6
Dislocation	1 (5)	10 (40)	4 (12)	15 (30)	7 (7)	94	2.5
Sprain	5 (25)	13 (52)	4 (12)	13 (26)	2 (2)	117	3.1
Strain	8 (40)	11 (44)	2 (6)	11 (22)	5 (5)	117	3.1

Source: Field Survey, 2015

4.4 The Factor of Musculoskeletal Injuries on the Activities of Construction Workers

In the daily activities of the workers, they are exposed to different factors. Respondents stated in the questionnaires the factors they are usually exposed. The Table 2 highlights the factors which they are exposed to; these including awkward posture, repetition, vibration and extreme body temperatures. As portrayed by Table 2, a greater number of the tradesmen agree and strongly agree to awkward posture and forces which were having a strong mean of 3.4 and 3.6 respectively.

Table 2. Factors of musculoskeletal injuries on the activities of construction workers

Factors	SA(5)	A(4)	N(3)	D(2)	SD(1)	Total	Mean
Awkward posture	9 (45)	12 (48)	5 (15)	7 (14)	4 (4)	126	3.4
Repetition	5 (25)	8 (32)	12 (36)	5 (10)	7 (7)	110	2.9
Static posture	6 (30)	8 (32)	5 (15)	9 (18)	6 (6)	101	2.7
Vibration	4 (20)	9 (36)	6 (18)	10 (20)	8 (8)	102	2.7
Force	13 (65)	10 (40)	6 (18)	5 (10)	3 (3)	136	3.6
Extreme temperature	2 (10)	12 (48)	1 (3)	9 (18)	13 (13)	92	2.4

Source: Field Survey, 2015

4.5 Nature of Respondents' Work

It was seen as shown in the Table 3 that carrying heavy loads; working on your knees and stretching to work overhead were the nature of work that affected most respondent with respective means of 4.4; 4.2; and 4.0. It can therefore be deduced from the data in the Table 3 most of the respondents indicated that they carry heavy loads; working on their knees and stretching to work overhead in their daily working activities.

Table 3. Nature of respondents' work

Nature of work	SA(5)	A(4)	N(3)	D(2)	SD(1)	Total	Mean
Carrying heavy loads	19 (95)	16 (88)	2 (6)	0 (0)	0 (0)	165	4.4
Working on your knees	12 (60)	22 (64)	2 (6)	1 (2)	0 (0)	156	4.2
Stretching to work overhead	12 (60)	18 (72)	4 (12)	3 (6)	0 (0)	150	4.0

Source: Field Survey, 2015

4.6 Effects of the Musculoskeletal Injuries on the Working Conditions of Respondents

As part of the injuries encountered, construction workers are affected in one or more ways. Loss of concentration; working not to specifications and delay of work were some of the critical effects as stated in Table 4, they had mean scores of 3.5; 3.3 and 3.2 respectively.

Table 4. Effects of the musculoskeletal injuries on the working conditions

Effects	Strongly agree(5)	Agree(4)	Neutral (3)	Disagree(2)	Strongly disagree(1)	Total	Mean
Lateness to work	4 (20)	9 (36)	7 (21)	12 (24)	5 (5)	106	2.8
Absenting yourself from work	6 (30)	12 (48)	3 (9)	11 (22)	5 (5)	114	3.0
Working to low standards	7 (20)	12 (48)	6 (18)	9 (18)	3 (3)	107	2.8
Working not to specifications	10 (50)	11 (44)	2 (6)	10 (20)	4 (4)	124	3.3
Delay of work	9 (45)	8 (32)	9 (27)	4 (8)	7 (7)	119	3.2
Shortage of money	5 (25)	13 (52)	7 (21)	6 (12)	6 (6)	116	3.1
Loss of concentration	12 (60)	10 (40)	5 (15)	6 (12)	4 (4)	131	3.5
Loss of contract	5 (25)	13 (52)	6 (18)	8 (16)	5 (5)	116	3.1

Source: Field Survey, 2015

4.7 Data Analysis from Medical Doctors at Cape Coast Teaching Hospital

In all, three doctors form the Cape Coast teaching hospital was interviewed, two from the emergency department and one from the physiological department. They were also given a set of questionnaires to give their report on musculoskeletal injuries prevailing to construction workers.

The three doctors who gave their responds asserted that they have work on musculoskeletal injuries of construction workers for quite a long time. The first doctor said she has worked for 3 years. Second and third doctor has work 3 and 5 years respectively.

As emphasized by the responds from the construction workers, all the three medical doctors also made it clear that, construction workers who mostly visit the hospital with cases of muscle injuries are mason.

The doctors ranked the types of the musculoskeletal injuries as how they frequently occur. Strain as a type were first ranked as most injury that occurs to the workers. Followed by sprain but fracture and dislocation were on the same level as they occur.

From the doctors respond, higher injuries takes 30 days and over before healing. Also, normal injuries take 20 to 25 days but for low injury, they take 15 to 17 days before healing.

5 Conclusion

The study depicted that musculoskeletal injuries occurs to construction worker. It was also found that injuries including fractures, dislocation sprain and strains occur at various construction sites and this affects the working abilities of the workers by making them loose concentration during work, do shoddy work, work not to standard and delays the duration of their work to a great extent. However, some construction sites appear to have tools which when used, reduces workers' exposure to these musculoskeletal injuries but greater number workers do not have any idea on them. This therefore appears to be increasing the number of workers who get exposed to musculoskeletal injuries at their job sites.

5.1 Recommendations

Based on the findings of the study, the researcher recommends the following:

1. There is the need for the offer of extensive education on workers' exposure to musculoskeletal injuries and the effects it has on their work performance. This will help reduce the number of injuries that occur at work sites as the workers will take much precaution in their operations.
2. Also, the introduction of musculoskeletal injuries reducing tools such as locally made pulleys to aid in lifting heavy load to heights at the various construction sites and that will go a long way to cut down the number of injuries at the sites. Workers must endeavor to make use of these tools in order to prevent injuries at the sites.
3. Moreover, there is the need to ensure that workers at the various construction sites, both masons and steel benders should have adequate knowledge and training on the tools they use.
4. In addition, the government and other NGOs in the country can offer their help through the provision of funds to provide good and required tools and equipment for construction workers and also offer support for workers displaced through musculoskeletal injuries.
5. Efforts must be made by the manager's or leaders of construction workers at the various construction sites to ensure strict adherence to safety measures at the sites.
6. There should be a requirement by law for all involving in any construction work before the onset, to obtain the service of a qualified and licensed safety and health practitioner to be in charge of health and safety practice on the building site.
7. Lastly, construction workers must make it a habit to visit the hospital from time to time to enable them know their health standard and also try to treat any level of musculoskeletal injuries at the hospital.

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Assessment in Office Work and Productivity

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Abstract. It is necessary to adopt specific positions to perform a work activity for long periods of time; as sitting posture. This condition increases the risk of developing musculoskeletal pathologies such as lumbago. The aim of this paper was to analyze the factors that originate this pathology using a literature review about office work and low back pain, the impact on productivity and describe the association of office work and productivity. This review aims at obtaining relevant articles, which show the relationship between office work in prolonged sitting posture and its effect on work productivity. The review found specific methodologies for each type of office activities and the considerations to take into account for this evaluation shown the necessity to pursue studies that analyses the office activity to find the influence of agents that affect the perception of lumbago, and its incidence on the efficiency of office work activities.

Keywords: Office work · Tasks · Lumbar pain · Productive time

1 Introduction

Low back pain (LBP) is the musculoskeletal disorder with the highest prevalence in office work, and The World Health Organization (WHO) defines it, as a major cause of disability. This affects work performances, well-being, activity limitation and work absence throughout the world and it causes an enormous economic burden on individuals, families, communities, industries and governments [1]. WHO in the United Kingdom and United States, found the LBP is the most frequently cause of disability affecting young adults; evidenced around 100 and 149 millions of working days lost per year, with an estimated cost of 100 and 200 millions of dollars per year, which have interfered with the quality of life and work performance.

In the Colombian context, VIII National Pain Survey [2] reports the LBP as the second pathology with the highest prevalence in workers with a 23.6% of the total sample. This LBP interferes in their work activities and at the same time in work performance [3]. The report makes clear that the 67.5% of people with back pain has been sick in the workplace. As a specific case, in the office work this musculoskeletal disorder has a multifactorial origin for the sitting and static posture, where it has considered as biomechanical risk factor [4]. In this posture is common that the lumbar area takes a kyphotic curvature or low back flexed due to discomfort presence [5]. This situation increases 35% of the biomechanical load on the ischial tuberosities support in

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contrast with the standing posture [6]. A decrease of lumbar muscles activation is also observed, that at the same time lead the load to ligaments and intervertebral discs [7].

That is why the aim of the present paper is to analyze a literature review focus on the Universidad Industrial de Santander is data bases, ISI Web of Science and Science Direct specifically, to address the review question: In what way does the office work in seated posture have impact on lumbar pain and workers' productivity? In this order of ideas, topics will has covered such as the association between office work and LBP, the factors that originate this pathology, the impact on productivity and describe the association of office work and productivity.

2 Materials and Methods

2.1 Reference Words

First of all, research words were identified in accordance with the principal review question: In what way does the office work in seated posture have an impact on lumbar pain and workers' productivity? This was done with Thesaurus assistance to standardize the different relation ways, indicated in Table 1 and categorized according to 4 variables to the review´s question.

Table 1. Reference words

A/related with the seated posture	B/related with office work	C/related with BP and their risk factors	D/related with productivity and work performance
Sedentary	Read	Hip flexion	Production
Sitting	Write manually	Lumbar pain	Productiveness
lumbopelvic movements	Answer the phone	Lordosis	
Sitting posture	Meet visitors	Intradiscal force	Efficiency
Prolonged sitting posture	Organize meetings	Lumbopelvic movements	Human factors
Discomfort	Correspondence	Head flexion	Depress*
Static posture	Financial managements	Discomfort perception	Stress*
Macro repositioning	Typing	Pressure on the body	Concentration
Seat angle	Office work	Back pain	Time
Repositioning frequency	Read text	Force	Design furniture
Desk	Read from the computer	Repetition	Workday
Desk bound	Navigate in the internet	Back effort	Perform*
Seated	Using software	Stress	
Annoyance	Lecture	Anxiety	
Displeasure	Talk	Exigency	
Stall	Desk work		
	Filing		

2.2 Search Sub-themes

Sub-themes were identified as a guide to approach the review equations. These equations were established with the relation of the table´s columns and the paper focus in this way:

- LBP associated with seated posture in office work.
- LBP associated with work environment.
- LBP and workstation.
- Office tasks in seated posture.
- Office work and productivity.

Because the study topic was always related with the lumbar pain and work activity, it was necessary to conduct a sub-themes review "office tasks in seated posture" and "LBP and workstations" as a random review, since this search consolidates the context but fails to advance in the knowledge of the review question.

It was not limited or established restrictive parameters, but a few inclusion and exclusion criteria were established. These factors are explained below.

2.3 Search Equations

Through the references words in Table 1, four search equations were raised.

The databases used, are property of the Universidad Industrial de Santander. Each of the search questions was used in each of the previously named databases in that order. On the other hand, because all the equations must relate with the same requirement, the same inclusion and exclusion criteria were determined during the search.

Inclusion criteria: seated posture, office furniture, administrative work, secretaries, office work, lumbar pain, lumbago, low back pain, stress, office task repetition, woman and man, productivity labour, efficacy, production chain, teamwork

Exclusion criteria: studies involving with babies, children, preadolescents and adolescents, elderly, work outside the office, standing work, work with load lifting.

The literature review was done from September 29 to October 13 of 2015.

3 Results

The publication of research works that included the reference words related sitting posture, office work and LBP and their risk factors shown growth in these topics during the past 14 years (2001–2015) and have initiated after 2001, observing a total of 1298 publications.

United States had the greatest number of publications with 337 followed by England, Australia and Canada, with 103, 93 and 70 publications respectively. In this order of ideas, between 2002 and 2009 was the period of time that has occurred the most cited scientific productivity. On this period of time, the research with the highest number of citations (193 citations) was the Marcus et al. research conducted on 2002 [8]. Productivity between the 2001 and 2015, in terms of the author's research frequency with the highest number of citations, was about 458 researches. With co-author production, frequency showed 551 publications over the same period.

In 10 journals have published the 15, 33% of the last 14 years scientific production, which corresponds to the highest percentage in this period of time. These journals were: Work, Applied Ergonomics, International journal of Industrial Ergonomics, Ergonomics, BMC Public Health, Journal of Electromyography and Kinesiology, Spine, Plos One and Optometry and Vision Science.

For the other hand, were included the references words related office work, LBP and their risk factors, productivity and work performance. The behavior in this scientific production was stable because the research development numbers were the same. The total of publications was 1136. As in previous results, United States had the greatest number of publications but China and Germany occupied the second and third place.

Applied ergonomics and industrial ergonomics were the topics with highest number of publications. Productivity measured by author production frequency evidenced that in this case, all authors have been published the same number of research works.

In a global context, it is possible to observe that United States had the greatest number of research, followed by China and Germany. In the case of United States, 53, 2% of their researches have been carried out by Educational Institutes and local companies. In contrast, 46, 8% remaining were conducted in partnership with Netherlands, China, Malaysia, Colombia, South Korea, Serbia and Brazil. In Latin America, Brazil and Mexico were the country leaders in scientific production in this knowledge area with a cooperative work involving Portugal and Spain.

Furthermore, engineering, public environmental occupational health, and psychology have been the principal areas of research, with 45.64, 37.43, 31.28% respectively of the whole publications (N = 2434). For previous areas of research, the visual display units (VDU) assessment had a stronger presence complemented with analyses in the office ergonomics interventions, psychosocial risk factors, musculoskeletal disorders, occupational health problems, pressure measurements and non-computer work time.

Therefore, a better knowledge of musculoskeletal disorders, office ergonomics interventions and VDU assessments was acquired, because unquestionably different authors have attributed the office work with VDU as the principal cause to develop musculoskeletal disorders, principally by the posture, inactivity and the persistence posture in 75% all time during the work time [9, 10]. In this way, has ensured the association between persistence posture and discomfort as a possible source of weak labour productivity performance [9–11].

3.1 Ergonomic Assessment and Intervention in Office Work Activities

First of all, due to the influence of the posture in the musculoskeletal disorders, the authors focused more specifically to analyses and evaluation of office work. This analysis was performed by assessments factors, interventions in office workstations and preventions methods, focused in the tasks with high risks.

In the context of interventions in office workstations, a sitting and static posture promotes an extreme kyphotic curving in the lumbar area, which associated with discomfort [5] which increase a 35% of the biomechanical load that ischial tuberosities supports, in comparison with standing position [12]. Additionally, as the lumbar muscles low activation that transmitting the load to the ligaments and intervertebral disks [7]. Thus, from an efficacy of work, it can lead to a reduction of the automatic actions speed, and therefore, to a lower work execution. For these reasons, Mörl and Bradl [7] consider the torso hip flexion may be the motives of the lumbar muscles activity benefits decreasing discomfort in the lumbar area and improving work conditions. In this way, the formal characteristics chairs that are used currently have backrest inclination, increasing the pressure on the backrest. This situation has an effect on the reduction of load in ischial tuberosities [13]. On basis of the results obtained about the benefits of the muscle activity when the torso hip flexes, is considered that 5° of inclination forward and backward (in this specific case, seat tilt motion), the discal compression was reduced, as evidenced by studies on car driving activities through digital simulations [14]. However, it is necessary to verify whether this principle is the same in the office work.

For the other hand, identification of the risk tasks that affect workers' health is the principal step to initiate a study [15]. Principal ways to define these tasks were surveys that ask workers the physic demands activities [16], hearth rhythm monitoring [17] and observational method OWAS [18]. In the office work case, clerks, administrative workers, students and college professors [19], taken persistence postures in prolonged time due to the office task as to read, type, write and surf the internet [20].

Thus, it has been proposed some characteristics for a research work that consider the relationship between the seat, to encourage the office work health and impact in the productive time. Based on these, different authors have proposed methodologies in each of these variables.

3.2 Typing on a Computer Keyboard

The assessments were done in a specific text with participant's native languages and providing general context themes, without technicalities and used simple verbal commands and the continuous form [21].

A person that have experience in office work tasks can type a text directly from the memory at a rate of 40 words per minute (wpm), with medium experience at 35 wpm and without experience at 23 wpm. On average, people with medium experience in typing directly from a printed text at rate of 23 wpm [22]. On that basis, it was suggested a text with an average 600 words for executing the task in 20 min.

Is necessary to give each participant a printed black text to reduce the familiarization whit the material [23], with Arial font of 10 lb size (medium-sized), to establish a minimum cognitive demand [24] in a white A4/letter size page.

During the test, participant can place the text on the left or right size of the screen, according to their preference [25–27] to perform the test in a natural way.

- Read

An average adult reads 180 wpm [28]. Thus, the read test was suggested with 3600 words in text to, as previous one, be executed in 20 min. Each participant should read the text aloud, file in PDF version because it is the most technically complex that print text [29]. At the same time, have the Arial font of 10 lb size (medium-sized). The current zoom level must be 100% but it can be change for convenience. Typography color is black with a white background to give it maximum contrast value [30].

- Handwrite

A person in the stage of secondary education, writing 80 wpm [31] thus established 1600 words in the text in a digital file. The materials to be used are letter-size bond paper, without strip, or checkered, completely white, and pen with a black ink for a higher contrast [32].

- Surf the internet

It is necessary that the contents are hierarchical, have a search system, navigation options are clear, good relation figure-background and have a suitable typography. They also found that the studies are evaluation related to the graphic characteristics of the web pages, but not of a specific task to perform in this one.

In these cases, the pages of government, NGOs and online shopping have been the most studied due to the high flow of navigation; shopping pages have been thoroughly studied with usability tests (e-commerce), since it is necessary to take a series of steps (fill out forms) to make a purchase. In the same case, the e-mail pages have exposed it too, since a series of preliminary steps must be carried out, in order to finally use the main platform.

Because of this, this paper proposes to consider, the analysis the task of surf the Internet with each of the steps to be performed. Those ones that has established with 140 clicks to execute the task, the concentration of information in the same spaces, the task of creating an email and a shopping cart, and the theoretical execution time of 20 min.

4 Conclusion

The office work related with the musculoskeletal disorders is a recent research topic, with a continuing transformation of work. This is reflected on the attention that had have countries as United States, England, Australia, Canada, China and Germany, develop case studies with different analyses focus, primarily such as the VDU assessments, ergonomic interventions in office work, psychosocial risk factors and non-computer work time.

As a consequence, there is a possibility to study in local context, the office work with the literature guidelines and ergonomics workstation interventions to find evidence about possible improvements for the benefit of office workers. Thus, it is proposed four office tasks with higher repetition and worker´s risk to be assessment with a seat tilt motion to find new ways to prevent the lumbar pain, this being the principal musculoskeletal disorder in the workers.

Finally, this paper raises the general framework for the protocol to assess the seat variable with productive time in office work, considering physiological and biomechanical factors.

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Evaluation of Bodily Discomfort of Employees in a Slaughterhouse

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Abstract. Brazil is the fourth leading producer and exporter of pork meat in the world. This study aimed to evaluate the bodily discomfort of employees in a pig slaughterhouse. The participants were 72 workers, 34 females and 38 males. A human body map, an interview regarding organizational issues, the OCRA method, descriptive statistics and Chi-square test ($p \leq 0.05$) were used. The results indicated that 80.6% of workers performed repetitive tasks, all workers took rest breaks, 41.7% performed job rotations and 62.5% used tools. Cold was felt by 44.4% of workers, with the most complaints for the feet (68.8%) and hands (28.1%). Most workers felt bodily discomfort in at least one region (83.3%) and the bodily regions most affected were shoulders (47.2%) and arms (25.0%). Their symptoms were pain (56.7%) and fatigue (45.0%), and 50% were taking medications. There was no association between bodily discomfort and the variables analyzed in this study.

Keywords: Bodily discomfort · Slaughterhouse · Ergonomics

1 Introduction

In the annual report released by the Brazilian Association of Animal Protein, Brazil was rated the fourth leading producer and exporter of pork meat in the world [1]. The Occupational Safety and Health Administration (OSHA) [2] identified some of the risk factors for musculoskeletal disorders (MSDs) in meatpacking plants as repetitive and/or prolonged activities, forceful exertion, awkward and static postures, continued physical contact with work surfaces (edges), excessive vibration from power tools, cold temperatures and inadequate hand tools.

Discomfort is seen as an unpleasant state of the human body in reaction to its physical environment [3] and feelings of pain, soreness, numbness, fatigue, auditory and thermal discomfort and anxiety [4]. Upper limbs work-related musculoskeletal disorders (UL-WMSDs) involve significant pain and in many cases, diagnosis of a disorder is based on the nature and extent of the pain reported by the person [5].

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There are few studies regarding pig slaughterhouse workers, bodily discomfort [6], and the occurrence of lacerations of these workers [7, 8]. Tirloni et al. [9] analyzed the perception of bodily discomfort in poultry slaughterhouse workers revealing that the majority of them felt discomfort (67.2%).

Pig slaughterhouse employees are exposed to ergonomic risk related to the physical environment and physical load, and presented high incidences of perceived pain in the wrist, shoulder and lower back [6].

Kyeremateng-Amoah et al. [7] cite that workers in pork meatpacking industries have high rates of acute injuries and chronic disease. Cummings [10] found that the majority (63%) of injury reports from a pork processing plant occurred in a cold work-site, and the main source of injury was the tasks that required the use of handheld tools. Lander et al. [8] verified that recent tool sharpening and equipment malfunction were associated with the highest rate of laceration injury. High-velocity and high-force manual work is a risk factor for musculoskeletal injuries in pig slaughterhouses [11]. The study of Moore and Garg [12] provide additional epidemiological evidence that upper extremity musculotendinous disorders may be causally associated with work in pig slaughterhouses. The disorders included epicondylitis, nonspecific hand/wrist pain, carpal tunnel syndrome (CTS), trigger finger, trigger thumb, and De-Quervain's tenosynovitis.

Therefore, the purpose of this study was to evaluate the perception of the bodily discomfort of employees in a pig slaughterhouse and its associations with the individual's sex, length of time working in the company, task characteristics (repetitive and non-repetitive), the classification of distribution of rest breaks during the workday, job rotation, use of tools and perception of cold.

2 Methods

The Federal University of Santa Catarina Ethics Committee approved the procedures of this study, and written consent was obtained from the subjects. This study was conducted in a pig slaughterhouse in the South of Brazil, with approximately 2,000 workers employed, distributed in two shifts, where 4500 pigs were slaughtered every day.

The daily work schedule was 8 h and 48 min, with 45 min for lunch or dinner, 16 min for physiological needs and 25 min for snacks (coffee).

2.1 Participants

The company provided a list of all the names of the workers to be randomly selected for data collection. The workers were invited to participate in the study, and were interviewed in a private room.

A total of 72 workers, 34 females and 38 males participated in the study. The mean age for female participants was 34.2 years (19 to 60 years) and 33.6 years for males (18 to 50 years). They were employed for 10.2 ± 9.0 years, at least three months and at the most 33 years, with the majority being right-handed (94.4%).

Regarding the workstations, 62 workers performed their activities in an artificially cold environment (temperature ranged from 8 to 12 °C), while 10 worked in areas without air conditioning.

2.2 Instruments

The perception of discomfort was assessed utilizing a human body map [13], adapted by the authors in order to include the following bodily regions: elbows, wrists, hands, knees and feet/ankles. In addition, questions regarding to the participants (sex and age), work organization (performed of job rotations, rest breaks and use of tools), and perception of cold were included. The length of time working in the pig slaughterhouse was calculated based on an employee list provided by the company. The tools used by the workers were classified into two ways: knife/knife-sharpener and other tools: bowl, stamp and pen, fork, bucket, steel spatula, keys, scissors, thermometer, hammer and vacuum cleaner.

In order to analyze the repetitiveness, the OCRA method [14] was utilized. The workers were videotaped for five minutes while performing their activities. Repetitive tasks were characterized as cycles (regardless of the duration) with upper limb movements, or repetition of the same work gesture for the majority of the time (over half of the total time) [15]. The OCRA criteria considers as poorly distributed breaks during the workday the breaks that could not be performed before the main meal, and in the last hour of the workday, maintaining a ratio of 5:1 between working time and recovery time [14].

2.3 Statistical Analysis

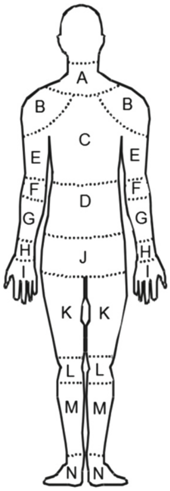
Descriptive statistics was utilized in order to verify the relationship between variables, as well as the Chi-square test, with a significance level of $p \leq 0.05$.

3 Results

Regarding bodily discomfort, 83.3% of the workers reported perception of discomfort in at least one body region among the 14 regions mentioned. The discomfort occurred mostly in the right side of the body ($p < 0.001$). Generally, the body regions most frequently cited were: shoulders (47.2%), arms (25.0%), lower back (18.1%), hands (18.1%), neck (16.7%), wrists (16.7%) and legs (12.5%) (Fig. 1).

From the 60 workers who reported discomfort, 33.3% classified it as mild/very mild, 51.7% as moderate and 15.0% as strong/very strong. The three symptoms most often reported were pain (56.7%), fatigue (45.0%) and tingling (10.0%). The majority of the workers felt discomfort for a period equal to or longer than six months (93.3%), noticed increased discomfort during work (73.3%), and attributed to the workplace (96.7%).

The workers could select more than one alternative to justify the perception of reduction in discomfort: 93.3% perceived reduction in discomfort due to the rest breaks, 51.7% during weekends, 43.3% at night, 6.7% during task rotation and/or breaks, and



	Bodily discomfort (%)					
	Regions	**Right**	**Left**	♂	♀	**Total**
A	Neck	15.3	11.1	13.2	20.6	16.7
B	Shoulders	41.7	29.2	47.4	44.1	47.2
C	Upper back	4.2	1.4	5.3	2.9	4.2
D	Lower back	18.1	11.1	18.4	17.6	18.1
E	Arms	25.0	15.3	26.3	23.5	25.0
F	Elbows	1.4	2.8	2.6	2.9	2.8
G	Forearms	2.8	2.8	0.0	5.9	2.8
H	Wrists	9.7	9.7	15.8	17.6	16.7
I	Hands	12.5	9.7	18.4	17.6	18.1
J	Hips	0.0	0.0	0.0	0.0	0.0
K	Thighs	0.0	0.0	0.0	0.0	0.0
L	Knees	1.4	0.0	2.6	0.0	1.4
M	Legs	12.5	12.5	7.9	17.6	12.5
N	Feet/ankles	1.4	1.4	0.0	2.9	1.4
	Total	73.6	58.3	84.2	82.4	83.3

Fig. 1. Human body map with regions of discomfort reported by workers. Values equivalent to percentages according to sex (♂ = 38, ♀ = 34), and side of the body. Source: The authors

6.7% of workers mentioned that the discomfort did not diminish in any of the surveyed situations.

Half of the workers (50.0%) were taking medications in order to be able to work, where 53.7% were self-medicated and only 10.0% reported having received a medical prescription by the company's physician. Analgesics were the most widely used (60.0%), after anti-inflammatory drugs (30.0%).

Regarding the length of time working in the company, 44.7% of males worked in the company for more than 10 years and 55.9% of the females worked for less than 5 years (Table 1). However, there was no association between length of time working in the company and individual's sex ($p = 0.067$).

Table 1. Length of time working in the company of the males and females [n (%)]

Length of time working in the company	Males	Females	Total
<5 years	11 (29.0)	19 (55.9)	30 (41.7)
5.1 to 10 years	10 (26.3)	05 (14.7)	16 (20.8)
>10 years	17 (44.7)	10 (29.4)	26 (37.5)
Total	38 (100.0)	34 (100.0)	72 (100.0)

The majority of the workers performed systematically repetitive work (85.9%), and 86.2% that felt discomfort performed repetitive work. All of the workers took rest breaks (excluding meal breaks) lasting 08 min, with a frequency of 1–4 times per day, where 50.0% took two daily breaks. Additionally, 65.3% took at least one poorly distributed rest break during the workday.

Job rotation performed by 41.7%, consisted of 2–4 tasks, and most of the workers (43.3%) completed three tasks during the workday. In this study, the contents of the tasks performed by each employee were not explored. The majority of the workers interviewed (62.5%) used hand tools, and 51.4% of them felt bodily discomfort, where 71.1% of those used knife and knife-sharpener frequently.

In relation to the perception of environmental conditions, nearly half of the workers felt cold during the workday (44.4%), where 93.8% worked in sectors with artificially cold room temperatures. Conversely, 47.9% of the workers felt heat (sometimes and frequently), where 79.4% of them worked in sectors with natural room temperatures.

The body regions in which the workers felt the coldest were feet (68.8%), hands (28.1%), back (9.4%), legs (6.3%), trunk (3.1%), and some felt it in the whole body (12.5%).

In this study, it was not possible to carry out the tests of association between bodily discomfort and classification of distribution of rest breaks during the workday, the length of time working in the company, the use of tools, and the characteristics of the tasks (repetitive and non-repetitive), due to the low frequency of cases of some of the variables. For the other variables, the presence of bodily discomfort of these workers was not associated with the individual's sex ($p = 0.833$), job rotation ($p = 0.521$) and perception of cold ($p = 0.138$).

4 Discussion

The findings of the present study are similar to Tirloni et al. [9], developed with 290 poultry slaughterhouse workers, in which the majority of the workers reported perception of body discomfort (67.2%), with higher incidence for the right side of the body ($p < 0.01$). Reis et al. [16] investigated the risk of developing UL-WMSDs in poultry slaughterhouse workers, using the OCRA method, and found that the risk in the reported activities was higher for the right side of the body as well.

No studies have analyzed the risks of UL-WMSDs in pig slaughterhouse workers, using the OCRA method, and the perception of bodily discomfort felt by the workers was not studied in detail.

Vergara and Pansera [6] confirmed high incidence of perception of pain in the wrists, shoulders and lower back in pig slaughterhouse workers, nevertheless, the region of the body that had the highest incidence was not mentioned. The shoulders region was the most affected in the present study (47.2%) as well as in Tirloni et al. [9] and Reis et al. [16] (62.6 and 45%, respectively). The studies cited previously [9, 16] reported the neck region as the second most affected with discomfort, unlike the present study, which identified the arms as the second most affected. According to Van der Wind et al. [17], the prevalence of musculoskeletal pain in the shoulders, arms, and hands is high among slaughterhouse workers, due to the high workload intensities and cyclic repetitive muscle actions throughout the workday.

The three most frequently reported symptoms in Tirloni et al. [9] were pain (84.6%), fatigue (51.3%), and tingling (19.0%). The present study had identical classifications; however, the values were lower. In this study, the majority of the pig slaughterhouse workers felt discomfort in a moderate intensity (51.7%), unlike in Tirloni et al. [9], where less than half of the poultry slaughterhouse workers felt moderate discomfort (41.5%).

Nevertheless, strong/very strong discomfort intensity (35.4%), mild/very mild (21%) presented higher values, in addition to the 2.1% that did not answer.

Among the slaughterhouse workers who felt discomfort, most of them reported feeling discomfort for a period equal to or greater than six months (93.3%). Tirloni et al. [9] also reported a high percentage (88.7%) of discomfort for the same period. Both studies presented similar results regarding the perception of increased discomfort during work, with 73.3% for the present study, and 90.3% for Tirloni et al. [9]. More than half (96.7 and 96.4%, respectively) associated the discomfort to the workplace. Nonetheless, in Tirloni et al. [9], the majority of the workers were not taking any medications (24.6%), while the present study revealed that half of the individuals (50%) were taking medications in order to manage the pain.

WMSD's are particularly prevalent in the meatpacking industry [2]. According to Theorell et al. [18], workers with chronically high levels of job demands have a high pain tolerance and may ignore its warning signals. Moreover, the authors point out that the workers may also be more likely to develop chronic musculoskeletal disorders.

Regarding the length of time working in the company, it is noteworthy that nearly half of the pig slaughterhouse workers worked less than 5 years. Nevertheless, Tirloni et al. [9] found that the majority of the poultry slaughterhouse employees worked in the company from 5 to 10 years (55.9%); though, there was no association between time in the company and perception of body discomfort. Culp et al. [19], affirms that employees with the least experience were at the highest risk of injury in a pork meatpacking plant.

Despite the results of the present study, slaughterhouses are usually installed in the countryside of Brazil where the job market is limited. Before a company is established in a city/state, it is necessary to analyze the availability of resources and workforce [20]. The factors determining the installation of production plants are the cost of labor, tax benefits, and trade unionism in the region, spatial saturation, specific location advantages and proximity to the market [21].

According to Perez et al. [22], the workforce in slaughterhouses is considered to be low-skilled, with a large resource, but with rare exceptions, turnover is high and absenteeism is low. In a pork processing plant in the Midwest of the United States, Culp et al. [19] revealed that the employee turnover was 65.7% per year. There were not studies that reported the rate of absenteeism in slaughterhouses and the causes of their occurrences. However, for Vilanova, Dengo and Fumagalli [23] the improvement in working conditions, with emphasis on ergonomics, reduces absenteeism in poultry slaughterhouses. Nevertheless, OSHA [2] recommends maintaining sufficient number of employees in the production lines as well as to cover absenteeism, in order to reduce occupational diseases.

In the present study, females have fewer years working for the company than males, although there was no significant difference between length of time working in the company and the individual's sex. This can be justified by the fact that in pig slaughterhouses, workers manipulate larger pieces of meat, consequently, heavier loads; and females have smaller and more fragile body structures than man, in addition to other risk factors that are present in slaughterhouses. In Culp et al. [19], women had higher injury risk than men in a pork meatpacking plant. Women were self-selecting out of the more hazardous work sections as evidenced by their representation of sections: support section (49%), cut (37.8%), harvest (26.9%), and production section (24.2%).

Corroborating with the present study, Tirloni et al. [9] cite that the majority of interviewed workers performed repetitive tasks (87.6%), and used tools (61%). On the other hand, the same authors revealed that the majority of poultry slaughterhouse workers performed job rotation (1–7 tasks) (82.8%) and 86.2% took rest breaks. While in our study nearly half of workers performed job rotation and 2–4 tasks per day, and all of the workers took rest breaks and half took two daily breaks.

After an ergonomics analysis of the task of boning the pig shoulder, Vergara and Pansera [6] suggested actions to reduce complaints of pain and occupational diseases. These actions are related to the effectiveness of rotation of activities that show postural ergonomic risks; training of the movement patterns performed during boning, and other movements that make up the rotation; implementing breaks in situations of high repetitiveness of movements or static positioning of the body.

Studies in pig slaughterhouses are scarce, despite OSHA [2] position on overall risk factors for meatpacking plants: repetitive activities and/or prolonged and vigorous exertion, uncomfortable and static postures, cold temperatures and inadequate hand tools. Moreover, several studies developed in poultry slaughterhouses revealed that the tasks performed presented high risk, contributing to the development of UL-WMSDs [15, 24–26].

Regarding the tools, Brazilian Regulate Norm [27] cites that the tools should be specific and appropriate for each type of activity, light and efficient. Thus, the NR-36 recommends sharpening and suitability of tools and equipment; training and orientation of workers, on admission and periodically; as well as the existence of a regular maintenance schedule [27].

OSHA [2] considers inadequate hand tools, poor grips and handles as WMSD risk factors for slaughterhouse workers. Therefore, it is recommend that tool and handle designs are well-designed to reduce the risk of WMSD and eliminate or minimize chronic muscle contraction or steady force, extreme or awkward finger/hand/arm positions, repetitive forceful motions, tool vibration and excessive gripping, pinching, and pressing with the hands and fingers.

Conversely, a study performed with 10 companies [7] showed that the average annual total of injury rates were 6.4 per 100 workers in poultry plants and 13.2 per 100 workers in pork slaughterhouses. The authors cite that sharp tools and animal products were most frequently reported sources for lacerations. Lander et al. [8] verified that recent tool sharpening and equipment malfunctions were associated with the highest rate for laceration injuries.

A review study found that there is inconsistent evidence for recommending job rotation as a strategy for preventing musculoskeletal complaints [28]. Nevertheless, the NR-36 indicates that between tasks with cadence set by machines, treadmills, overhead conveyors and other tasks where the workers can freely determine their pace of work; in activities where workers' hands are completely wet and it is not possible to use gloves, due to the probability of generating additional risks, rotation to other tasks is advised [27]. OSHA [2] recommends using job rotation as a preventive measure, to alleviate physical fatigue and stress to a particular set of muscles and tendons. In Padula et al. [29]

study, job rotation did not appear to reduce the exposure of physical risk factors; yet, there are positive correlations between job rotation and higher job satisfaction.

All workers who participated in this study performed rest breaks. However, for a break to be efficient, it could not be performed before the main meal and in the last hour of the work, maintaining the proportion of 5:1 between working time and recovery time [14]. It is suggested that rest pauses to relieve fatigued muscle-tendon groups, as well as, the length of time needed depends on the task's overall effort and total cycle time [2].

The NR-36 [27] advises that in the production process in the activities performed at meat processing industries sites, which requires repetitiveness and/or static or dynamic neck muscles overload, shoulders, back and upper and lower limbs, distributed psycho-physiological breaks should be provided.

In relation to the perception of environmental conditions, Tirloni et al. [9] found that approximately half of the workers felt cold during the workday (41.4%), as well as in the present to this study. Nevertheless, 54.1% of those who worked in artificially cold environments felt cold, opposing the results of this study (93.8%). In Tirloni et al. [9] the following regions where the most affect with cold: hands (35%), feet (31.7%), trunk (11.7%), upper limbs (6.7%), lower limbs (2.5%) head (2.5%) and whole body (25%). In the present study the feet was the most affected region (68.8%).

Ramos et al. [30] found that 78% of poultry slaughterhouse workers reported feeling cold in the hand. Moreover, when analyzing the temperature of the hands using an infrared camera, the results showed that there were no differences between the left and right hand's temperatures of the workers who did not use a knife, however, the workers that use the knife had lower temperatures for the hand handling the refrigerated products.

In promoting thermal comfort of workers, slaughterhouses should have accessible system for heating hands near the toilets or rest break areas. In addition, personal protective equipment (clean and sanitized socks) should be provided. Rest breaks (20 continuous minutes) after an hour and forty minutes of continuous work, and rotation of activity in order to change environmental exposure (noise, humidity, heat, cold) is needed. Lastly, it is important to obey the hygienic and sanitary aspects [27].

Regarding the association between body discomfort and occupational variables, it was not possible to perform the statistic test with four variables, due to low frequency of participants. In the previously mentioned study with n = 290 [9], there was association only between the body discomfort and perception of cold ($p = 0.035$), which did not occur in the present study.

5 Conclusion

The majority of the workers felt bodily discomfort, the right side of the body was the most affected, the regions with the biggest complaints were the shoulders and arms and the symptoms most often cited by workers were pain, fatigue and tingling. Half of the workers who felt bodily discomfort were taking medication on their own, and the analgesic was the most commonly used medication.

All of the workers reported taking rest breaks; the majority of workers performed systematically repetitive work and used hand tools; and nearly half of the males worked in the company for more than 10 years, while most females worked less than 5 years. The minority performed job rotation and felt cold, and the body regions in which most workers felt cold were first the feet and then the hands.

The application of the statistical test was only possible for three variables. There was no association of body discomfort with the individual' sex, the job rotation performance and the perception of cold by the workers. Thus, further research on pig slaughterhouse workers, using larger samples sizes, are needed to expand on this subject. In addition to, analyzes of the contents of the tasks of the rotations, monitoring the workers during a day of work, to ensure that the breaks were taken, and verify the reason why workers did not feel cold.

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Physical Ergonomics

Use of Soft Tissue Properties for Ergonomic Product Design

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Abstract. In order to achieve better comfort and fit for designed products it is important to understand the product and user interface and to analyze the interaction at the region of contact. Study of biomechanical properties of soft tissue can provide a good insight of this interface between user and the product. Biomechanical properties can help the designers in material selection which can improve the comfort and fit and help in serving the purpose of the designed product. A sample study of soft tissue thickness of human head and face was conducted using an ultrasound indentation device at selected locations. Results showed the variation in soft tissue thickness levels, which was further used to discuss the role of soft tissue properties in the field of ergonomic product design.

Keywords: Biomechanical properties · Soft tissue thickness · Comfort · Fit · Ergonomic product design

1 Introduction

Traditional anthropometric measurements acquired from tapes [1, 2], scales, calipers [3, 4] have been used by the product designers in past for designing products. However, due to the complex contour and surface geometry of the body surfaces it is very difficult to acquire accurate anthropometric measurements using traditional techniques [5]. Also, measurements acquired from these conventional techniques are less reliable and have human errors involved in them [6, 7]. With the advancement of 3D scanning and 3D modelling techniques it has been possible to acquire highly accurate and precise 3D anthropometric data [8] which can be used for designing of products. Many researchers have used 3D models developed from multiple images [9, 10], medical imaging data like Computerized Tomography (CT) [11] and Magnetic Resonance Imaging (MRI) [12] or by using various 3D scanning techniques for acquiring 3D anthropometric data [13, 14]. These 3D models have been further studied to understand the shape variance [15, 16] of the surface morphology of the region of interest in order to develop products and to understand their sizing for a wider range of target population.

However, this 3D anthropometric data can only provide the surface dimensions for the designing of product but it fails to provide any valuable information regarding the

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actual interface between the product and the related body surface, which can be influential factor in understanding user comfort and fit.

2 Soft Tissues Properties and Product Design

Soft tissue properties vary depending on various parameters like the location of the tissue, age of the person and existence of any pathophysiological condition. In past many researchers have used this data in studying different medical conditions like edema [17], cancerous tissue [18], ulcers [19] muscle thickness changes [20] and corneal data [21].

Safety devices, wearable devices, medical devices and textile products are designed to carry out functions like protection, information transmission and for improving the aesthetics appearance. Some of these products cover the related body part partially or completely and in order for its proper functioning, they need to have a close fit, which leads to certain amount of pressure to the body. If the pressure is too high, it can lead to discomfort or pain. Also, if the device is supposed to be worn for a continuous period for a long duration, even a small amount of pressure can lead to discomfort. Researchers have shown that continuous application of force in a specific region can lead to occurrence of marks on the skin, rashes, skin irritation or ulcers [22].

Research studies have also been conducted to evaluate the impact of designed products like seats of wheelchairs [23] and bras [24] on the soft tissue of the contact region. At the same time researchers tried to use this data for optimizing and designing better comfort based products like prosthetics [25], undergarments [26] and footwear [27]. But still the application of soft tissue data in the field of ergonomic product designing has not widely been seen and there is a need of more exploration in this field of research. Xiong et al. [28] studied the effect of pressure on soft tissues and deduced a range of Pressure Discomfort Threshold and Pressure Pain Threshold for human foot. The pressure sensitivity map developed from such research can provide a wide range of useful information for ergonomic product design.

User experiences like comfort and fit are considered to be the most important factors while buying products [29]. There is a need of studying the biomechanical properties of soft tissues in relation with the product interface. This paper tries to explore how these biomechanical properties of soft tissues can help in improving comfort and fit and lead to designing of better ergonomic products.

3 Experimental Study

In order to study the soft tissue thickness and understand how it varies in different regions, an experimental study was performed to collect soft tissue thickness data of head and face.

3.1 Participant

Ten Chinese adults (three males and seven females) participated in the study. They were provided information and explained the experimental protocol. Written consents were obtained from them before starting the experiment. Participants with no facial deformities or abnormalities were selected for the study.

3.2 Equipment

Artec Eva 3D scanner was used to capture 3D surface shape of head and face of the participants. Twelve landmarks were selected on head and face corresponding to areas in contact with products related to head and face for the soft tissue study as shown in Fig. 1. An ultrasound indentation system as shown in Fig. 2 was used to measure soft tissue thickness at the selected landmarks. Ultrasound gel was used as the coupling medium.

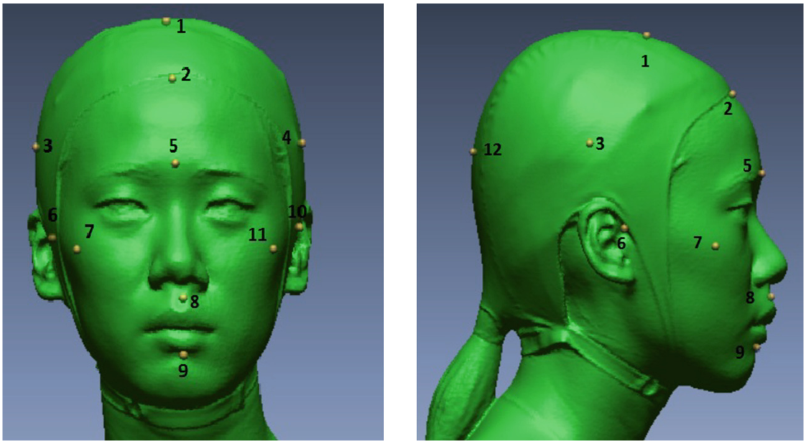

Fig. 1. Position of landmarks selected for the study in (a) front view and (b) side view

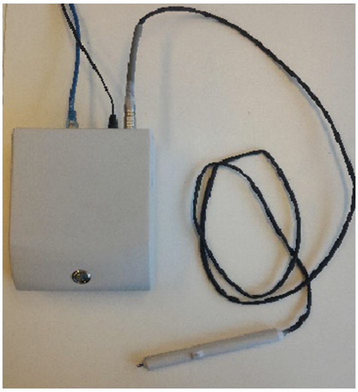

Fig. 2. Ultrasound indentation device

3.3 Procedure

3D scanning was performed first. The participants were made to wear a cap for 3D scanning in order to compress the hair and get head data. The cap used while scanning was removed during the experiment for measuring soft tissue thickness. The participants were informed about the experimental protocol and then trained to understand the ultrasound indentation device for 5 min. Ultrasound echo signals were recorded at all the individual landmarks in order to evaluate the soft tissue thickness.

3.4 Results

The ultrasound data acquired during the study was post processed using the software developed in Microsoft C++ for the ultrasound indentation device. The time of flight of the ultrasound wave was used to measure soft tissue thickness at selected landmarks. The mean values of soft tissue thickness for all the 10 participants are shown in Table 1.

Table 1. Mean values of soft tissue thickness at the selected landmarks

Landmark	Mean soft tissue thickness (mm)
1	5.76
2	4.66
3	5.04
4	5.18
5	4.64
6	2.75
7	6.24
8	7.03
9	5.30
10	2.81
11	6.31
12	5.98

4 Conclusion and Discussion

Current techniques used for product design tend to focus on using 3D anthropometric data which provides valuable information about the anatomical contour and surface measurements. However, the point of interaction of the product and the user, which can be influential in understanding the user comfort and fit parameters is not explored. With the use of soft tissue thickness data, further biomechanical properties can be analyzed which can help in understanding this relation more prominently and can help in designing of better ergonomic product.

The results acquired in the experiment help us understand the variation in the soft tissue thickness in different areas of head and face. The skull region (landmarks 1, 2, 3, 4, 12) and the area near the ears (landmark 6 and 10) have a thinner soft tissue layer. At the facial region (landmarks 7 and 11) the thickness is higher as compared to areas near the skull region. The philtrum region (landmark 8) is the thickest region compared to all the other selected landmarks. The area with thinner soft tissue thickness like the skull or region near the ears would be less deformable as compared to facial region. Designer can hence use this soft tissue thickness values to evaluate the potential product material, size and weight and the amount of force it should create on the soft tissue surface so that the deformation is not too large and does not lead to discomfort or pain.

Products with better effectiveness and efficiency can be designed using the above collected soft tissue thickness data. Further calculation of soft tissue deformation limits and Young's modulus can help in deciding the material requirement for different regions in order to make sure the corresponding regions are compensated while designing of protective devices. Soft tissue deformation data can help in understanding of fit, which is very important for designing of wearable devices, garment manufacturing and also for designing of products used for protection purpose which need a close fit.

This study provides a good insight of how the soft tissue thickness varies on the head and face in order to help the designers to design ergonomic products with better comfort and good fit. A better understanding of the role of biomechanical properties of soft tissue like Young's Modulus and maximum deformation at areas of interest is needed in further studies.

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Assessment of Human Balance Due to Recoil Destabilization Using Smart Clothing

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Abstract. Several studies focused on the importance of postural balance as a key for success of shooting performance and training. The most destabilizing factor is recoil that is the reaction effect produced on humans by a shooting task. To assess the postural control during a shooting task, stabilometry (posturo graphy) is the golden standard technique. Force and pressure plate are the main traditional instruments. Today, smart clothing provides a method to monitor in real time mechanical, environmental, and physiological parameters in an ecolo gical and in non-intrusive approach. Smart clothing (t-shirt) based on body-worn accelerometers (trunk accelerometers) was compared with posturographical by a pressure plate obtained during each shooting trial. The smart t-shirt revealed to be an innovative tool to assess human balance due to recoil destabilization.

Keywords: Smart clothing · Trunk sway measures · Accelerometer · Balance control · Human factors

1 Introduction

Recoil is the effect produced on humans by a shooting task provoking an external perturbation of the postural control system that can induce the resultant ground reaction forces ("center of pressure") to exit from the base of support with the risk of falling.

Balance is a generic term describing the dynamics of body posture to prevent falling [1].

In upright quiet standing, humans are never in equilibrium but they are stable. Their body returns to its mean position when it is pushed aside from the base of support [2]. The erect posture is regulated by control systems that organize the balance dynamically and depend on three actors: the sensory system, the central nervous system and the muscular and osteoarticular actuators.

The human body is mechanically unstable since its center of mass is located above its center of pressure on the ground. As soon as the resultant of the forces of gravity is

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no longer aligned with the resultant of the reaction forces on the ground, a torque is created which tends to accelerate the fall of the body.

The stabilization of this mechanically unstable body therefore requires a feedback control system whose inputs can detect any deviation from the “equilibrium position” to control the appropriate reactions to return to this “equilibrium” [3].

The output of a perturbation or input impulse is modulated by the state of excitation or attention of the individual [4, 5].

The amount of attention is positively correlated with the regularity of the movement of the center of pressure (COP) [6] and during standing [7].

The postural stabilization is a synergy of different subcomponents [7–19]: sensory organization (visual, vestibular and proprioception), perception, motor coordination, biomechanics of the muscle-skeletal system and adaptation to the environment.

Shooting tasks require an alignment of the eyes (gaze effect) to the target adopting a shooting posture that require a lateral bend on the shooting hand trying to prevent the recoil destabilization distributing the load forward during the aiming.

Normal balance requires control of both gravitational forces, to maintain posture, and acceleration forces to maintain equilibrium [20].

In quite standing the multisegment chain that describes the biomechanics of the body can be simplified in a physiological condition, in a reverse pendulum simply hinged at the ankle with a single degree of freedom on the sagittal plane [1]. This model allows us to analyse the dynamics of balance taking into consideration two variables: the center of pressure (COP) and the center of mass (COM). The COM is the centre of the elements of mass that compose the body (body segments). Its position determines the lever of arm of the reaction force in comparison to the articulations and the sign of the corresponding moment of destabilization. The COP is the centre of pressures applied by every point of the surface of the foot in contact with the base of support. It deals with the point of application of the resultant of the strengths exchanged between foot and ground (strength of reaction to the ground). The position determines the arm of lever of the external strength of reaction (F) in comparison to the articulations and the sign of the correspondent reactive moment.

The COM, influences the real movements of the body segments and the COP, reflects the action of the muscular active strengths and is the key in the analysis of the postural control.

The postural control system also employs open-loop control schemes and strategies [21], the output of which may take the form of descending commands to different postural muscles.

A right-handed rifle shooter must have enough extensibility of the hip flexors, the left iliotibial band, right high adductors, spinal musculature, and wrist flexibility to assume a stable position requiring a little amount of muscular activation [22]. Maintaining of upright posture during a perturbation, like recoil, depends on a synergy of several muscle contractions to maintain the centre of mass inside the base of support [23].

In particular, at the moment of aiming the load is transferred on the right hip and it is supported by the upper body. Each knee and ankle transfers the occurred load to the hip [24]. As well, balance training can influence shooter’s performance.

Braune et al. [25] was the first that evaluated the position of the centre of gravity on human balance and in shooting.

Elite shooters have higher stability than untrained control subjects [26] and non-elite shooters [27, 28]. Shooters can improve their stability in the last few seconds preceding the shot [28, 29].

Experimental data proved that shooters adopt a mechanically unstable posture as consequence of the interactions among body segments [30].

Higher balance of an athlete is obtained by training [31–34] also on an effort to pay attention to proprioceptive and visual cues [35].

Performers focusing on their body movements, or an effect that occurs in close proximity of the body, maintain a more stable posture than performers focusing on a more distant effect [36].

Motor training can improve performances asking a cognitive reorganization of motor cortex [37].

The central nervous system is perfectly capable of predicting the trajectory of a movement that it controls and sees over a few tens of milliseconds. Recoil destabilization affects soldier performance. Motor learning plays an important role and therefore training and experience can influence the soldier performance significantly [38, 39].

Mononen et al. [40] found that postural balance is related to shooting accuracy both directly and indirectly by shooting through rifle stability.

Skilled shooters employed smoother and more efficient rifle movement while aiming than less-skilled shooters [41].

The shooter organizes to predict the moment of the shot by observing the vertical movements of his line of sight, predicting the trajectory of this unique movement, since the body is practically immobile in this plane [42].

The possibility of simultaneously following during firing, the shooter's center of gravity oscillation and line of sight, explains this inability. This shows the independence between the weapon and body movements.

But when the movement of the weapon is not correlated with the movement of the body, then he needs to predict two different trajectories, which he monitors by two distinct mechanisms: one visual and conscious (the movements of the weapon), the other blind and unconscious (the fore-and-aft movements of his body) [43].

The movement required to pull the trigger is independent of body sway but can cause the movement of the weapon influencing the performances [44].

Posturography (stabilometry) [45] is the science that studies the mechanism in postural control alteration due to a perturbation to obtain balance and stability.

Force plate and pressure plate, are the common instruments for measuring postural sway in clinical setting.

Researchers already used force plates to evaluate postural stability in shooting measuring displacements of the Center of Pressure (COP) [46–49].

Innovative technology, body-worn accelerometers have been proposed as a portable alternative and inexpensive wearable health systems (WHS) for sway measurements [50–54] but not yet for recoil destabilization analysis.

Moreover, the evolution of "the wearable era" brings the introduction of "intelligent textile" where the technology is embedded in the cloths in a non-intrusive and ecological approach [55, 56]. The estimation of human trunk movement using smart clothing is already done [57, 58].

Recently our group, designed a smart cloth t-shirt for monitoring Belgian soldiers based on anthropometric approach measurement on 1615 soldiers [59]. The smart t-shirt is capable of monitoring in real time the heart rate (ECG) and the 3D body accelerations of the trunk.

Starting from this assumption, the paper presents a new assessment for human balance evaluation due to recoil destabilization based on trunk accelerometry measurements collected on the smart t-shirt and posturographical measurements by a force plate.

2 Materials and Methods

2.1 Subjects and Protocol

Four volunteer soldier at Belgian Royal Military Academy participated in the research study aged between (21–30). The characteristic of the individuals who participated in the study are described in Table 1.

Table 1. Main anthropometric properties of the individual that participated in the study

	Height (cm)	Body mass (kg)	Shoes size	BMI (kg/m^2)
1	182	89.5	44	27.03
2	180	78.0	45	24.07
3	178	70.0	43	22.15
4	197	95.0	45	24.48

Subjects were asked to perform four trials of one single shot pointing at the target at 7 m distance, standing in a shooting position on a pressure plate, wearing the smart t-shirt. At the beginning of the session, each volunteer was asked to wear and test the smart t-shirt standing on a force plate in aiming position. A high-speed camera was also placed perpendicular to the sagittal plane of the shooter (Fig. 1).

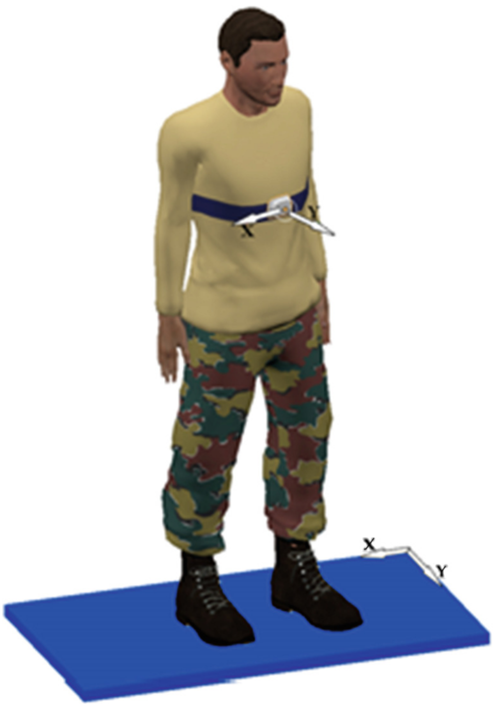

Fig. 1. Set-up illustrating the alignment of measured axis

2.2 Instruments

Shooting balance was measured with a 1 m footscan system (RSscan, Belgium) pressure plate with 8192 active sensors at 100 Hz.

The plate was triggered automatically by foot contact. Data export in Excel of the center of pressure (COP) was obtained by the footscan balance software.

Trunk accelerometry was collected by a 3D chest-worn accelerometer (MMA7361L, Freescale) of the smart t-shirt [59]. Data can be stored in the garment and can be connected by Bluetooth with an app for real time acquisition.

2.3 Data Analysis

Two custom MATLAB (MathWorks, Natick, MA) scripts were built to acquire, store and analyze different components of posturographical data by the pressure plate and the 3D trunk accelerations.

A first program was used to calculate the posturographical data of the moment of the shot collected by the COP measurements of the force plate exported as Excel file.

Manually, we were able to extrapolate the COP data at the moment of the shot (Fig. 2).

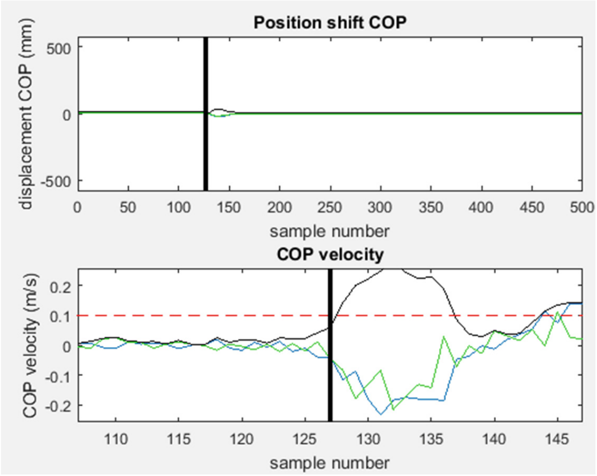

Fig. 2. Shot event extrapolation by the force plate in Matlab

According to Schubert et al. [45], we calculated time domain posturographical data starting from 1-dimensional COP anterior-posterior (COPap.) and COP medio-lateral (COPml.) as can be seen in the Table 2.

Table 2. Posturographical parameters calculated from the force plate (all data in mm)

Measures	Description	Matlab script formula
COP distance	Mean distance from the center COP (mm)	mean(sqrt(COPap.^2 + COPml.^2));
COP length	Total length of COP trajectory (mm)	sum(sqrt(diff(COPap).^2 + diff(COPml).^2));
RMSap. and RMSml.	Root mean square of COP time series (mm)	sqrt(sum(COPap.^2)/length(COPap)); sqrt(sum(COPml.^2)/length(COPml));
Rangeap. and Rangeml.	Range COP (mm)	range(COPap); range(COPml);

From the COPap. and COPml. we are also able to calculate the statokinesiogramm (Fig. 3). and the stabilogram for each shot.

A second Matlab program was used to create an algorithm for extrapolating the peak corresponding to the shot by the trunk accelerometric data (Fig. 4).

Starting from the peak of the shot we identified the total signal of the shot calculating.

3DACC(x,y,z) before and after the peak of a total half second as is marked in Fig. 4.

The 3DACC(x,y) components at the shot were computed for calculating the time domain measure of the trunk posturographical data [45] as described in Table 3.

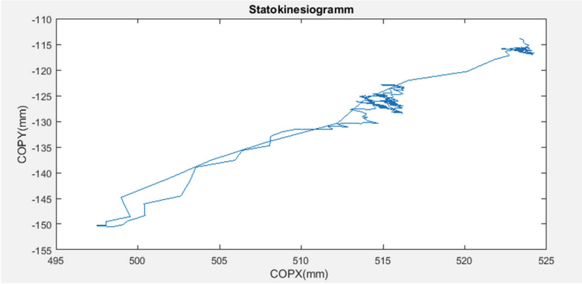

Fig. 3. Sway path (statokinesiogramm) at the shot event

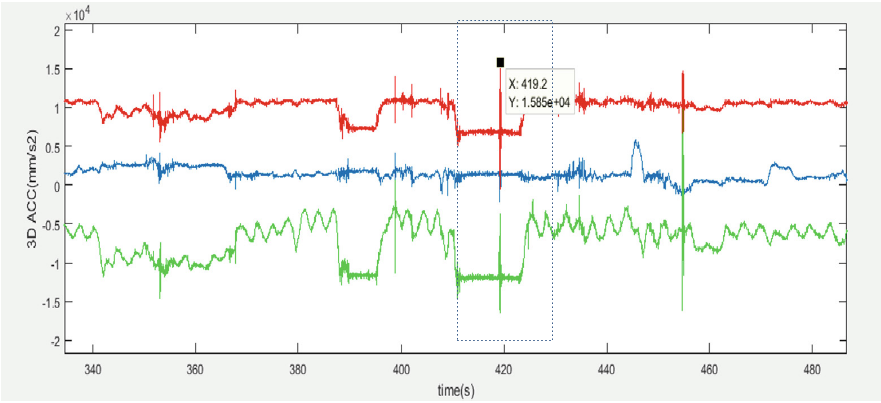

Fig. 4. Shot event solution based on 3D accelerometric data

Table 3. Posturographical parameters calculated from the body-worn accelerometer (all data in mm/s^2) and the relate script Matlab formula. Sway path (statokinesiogramm) by trunk ACC in the moment of the shot were also plotted (Fig. 5).

Measures	Description	Matlab script formula
COP distance	Mean distance from the centerCOP(ACC)	mean(sqrt(COPap.^2 + COPml.^2));
COP length	Total length of COP(ACC) trajectory (mm)	sum(sqrt(diff(COPap).^2 + diff(COPml).^2));
RMSap.; RMSml.	Root mean square of COP(ACC) time series (mm)	sqrt(sum(COPap.^2)/length(COPap)); sqrt(sum(COPml.^2)/length(COPml));
Rangeap.; Rangeml.	Range COP(ACC)	range(COPap); range(COPml);

Mean ACC-based measures of sway were compared with the mean posturographical measures obtained by the pressure plate through linear regression using COP distance, COP length, RMSap–RMSml, Rangeap–Rangeml values calculated with both devices for the 16 shots. All statistical analyses were conducted using

Minitab statistical software and are described in Table 4. Correlation between COP and ACC measures are also reported.

Table 4. Correlation of COP and ACC-based measures

Trajectory measures	Mean-COP (mm)	Mean-ACC(mm/s^2)	r	p-values
DIST	12.55	8853.41	0.109	0.689
RMSap.	13.15	107.42	**0.466**	**0.069**
RMSml.	13.41	276.92	**0.568**	**0.022**
Rangeap.	52.93	12066	0.198	0.463
Rangeml.	41.72	12036.19	0.076	0.781
Sway path	310.13	89481.43	0.108	0.691

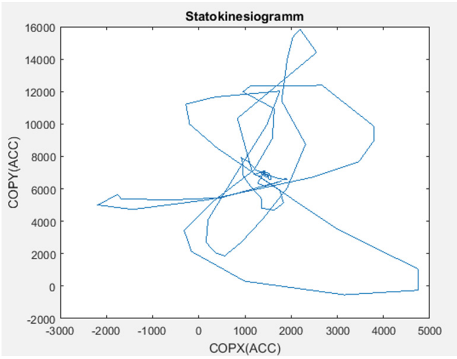

Fig. 5. Sway path (statokinesiogramm) by trunk 3DACC(x,y) at the shot event

Mean RMSap(ACC) and Mean RMSml(ACC) were found to be significantly associated with the Mean RMSap. and Mean RMSml. predicted by the force plate.

Anthropometrical data (height, body mass and shoes size) were also significant by correlated ($p < 0.05$) with the Mean RMSml as are described in Table 5.

Table 5. Correlation of ACC-based measures RMSap and mean anthropometrical measures

Mean	Body mass (kg)	Height (mm)	Shoes size	BMI (kg/m^2)
RMSap. (ACC)	**–0.752**	**–0.686**	**–0.661**	**–0.451**
[mm/s^2]	**0.001**	**0.003**	**0.005**	**0.079**
Sway path [mm]	**–0.794**	**–0.770**	**–0.732**	**–0.620**
	0.001	**0.001**	**0.001**	**0.010**

3 Discussion

The chest worn accelerometer on the smart cloth reveals a good capacity to discriminate posturographical accelerometer based measures.

The correlation between the two devices was significant considering the RMS measure in the anterior–posterior and in the medio-lateral direction (Table 4).

A higher value was found more in RMSml due to the fact that at the moment of the shot the subject ('right handed') transfers the load to the right hip (hip strategy) and is supported by the upper body. Question arises if also anthropometrical variables at the shot moment can influence the RMSap. (ACC).

High negative correlation with ($p < 0.05$) was found between RMSap. and height, shoes size and body weight respectively (Table 5).

During the shot the body mass index of the subject was an important factor for recoil impact force attenuation expressed by a correlation of $r = -0.620$ with ($p < 0.01$).

As while, if the body is represented by an inverted pendulum height and the shoes size (base of support) have a negative correlation with RMSap. (ACC). The sway path is related to ankle strategy that is affected by body mass, height and ankle stiffness with high correlation as demonstrated in Table 5.

4 Conclusion

The use of smart clothing based on chest worn accelerometer showed a good capacity to discriminate posturographical measurements for human recoil balance destabilization compared with the force plate.

Smart clothing reveals to be a non-intrusive garment for recoil destabilization that can adopted in different environment in an ecological approach. The added value to use it is also the capacity to adding a physiological evaluation of heart rate variability by the two electrocardiographical (ECG) textrodes embedded into the cloths.

Future perspective will address to the evaluation of heart rate variability measures with the same protocol to have a more complete assessment for monitoring recoil destabilization.

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Systems Anthropometry of Digital Human Models for Seat Design

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Abstract. Traditional vehicle package engineering assumes that driver anthropometry and the location of vehicle controls determine driver posture, and thus seat parameters. Due failure of this approach to provide comfortable seating conditions, ERL combines a systems anthropometry model with a force deflection model of the seat and soft tissue digital human model (DHM) to design seat specifications for the driving package. With the systems anthropometry model, we optimize seat design for calculated driver positions and postures. We derive comfort scores from measurements of the interface between the DHM, seat and controls. Analysis of 13 passenger cars and 10 utility vehicles shows that drivers adapt to vehicle interiors with different postures that are inconsistently associated with vehicle type. In conclusion, the seat affects how and where we sit. Thus, DHMs are needed for both seat and package design at the very beginning of vehicle development.

Keywords: Seat comfort · Human–systems integration · Automotive package engineering

1 Introduction

Sitting is required to drive a car. Sitting positions reflect body size and adaptations made to drive the vehicle. Traditional anthropometry describes variation in body size with the effects of posture removed in a standardized posture. Moreover, systems anthropometry defines landmark positions with respect to anatomical frames of reference so that body size and posture are both represented in the data. While linear dimensions such as stature, sitting height, or arm reach define body size, posture has been defined primarily by joint angles in the limbs [1]; sitting posture however also includes the spinal configuration of the back. Recently, landmarks have been used to estimate driver back posture [2]. Systems anthropometry of human subjects includes the position of limb joint centers and spinal landmarks that are needed to define digital human body models (DHM) for the study of tasks, and the design of products supporting tasks [3].

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DHMs for automotive package design must incorporate vision, reach and comfort to define a driver's position when operating a vehicle [4]. Drivers adjust seat, steering wheel and sometimes pedal positions to find comfortable reach to controls, good vision and postural comfort in the vehicle. While body size defines the range of these adjustments [5] in populations, back posture defines positions of these adjustments within the range for comfort, safety and operability. Since the seat interacts with the driver, forces acting on the seat should be part of the design environment. Thus, a systems anthropometry definition of comparable landmarks among drivers that transmit loads to the seat cushion and back provides a scientific basis for designing seats in support of vehicle package requirements. In today's automotive design environment, only very few positions of landmarks in drivers, defined in SAE-J 826 [5] are considered an element of design.

Comfort is considered a package [6] and a seat design [3, 7, 8] parameter, but there is no standardized tool to measure comfort. Dama et al. [9] found 10 objective evaluations of seat comfort and 4 subjective evaluations. Yet, comfort is a subjective response to an environment.

Safety on the other hand has a well-defined domain in government regulations, and it is tied to ergonomic design with the SAE H-point machine (i.e. SAE J826 or SAE 4002) [5]. Eleven Federal Motor Vehicle Safety Standards (FMVSS) reference this tool for regulations of controls and displays (#101), mirrors (#111), safety (#201, 202/a, 203, 204, 208, 209, 210, and 214) and seating (#207).

Package engineering uses the Seating Reference Point (SgRP) for defining a vehicle layout, including seat adjustments, steering wheel adjustments, pedal adjustments, and vision models. Seat design begins with the H-point machine, and compliance of the seat with the package is verified with a test that measures if the H-point machine sits in the vehicle seat within ±12.5 mm of a SgRP. The fit of the seated driver in the total vehicle design to reach controls, see the road and instrument panel, and achieve a comfortable posture is typically evaluated at the end of vehicle development [10, 11].

In the 1980s, RAMSIS, JACK, SAMMIE, and SAFEWORK (now DELMIA) were developed to evaluate vehicle interiors for the driver without a seat [8, 10, 11]. These DHMs are positioned in the vehicle within comfortable joint angle ranges to reach controls if their "hip joints" lie within H-point travel. Tools developed to evaluate pressure distribution in seat design, such as Pam Comfort [12] or Casimir [13], use finite element models without considering back posture or driver position to operate the vehicle.

The present investigation uses an optimization model to calculate how seated drivers [14, 15] with different back postures adapt positions of the seat and steering wheel to operate cars and Utility Vehicles (UVs). This analysis uses small female, medium male and large male DHMs sitting in three back postures. Each DHM is constrained by the same criteria to reach controls (steering wheel and accelerator) with good vision of mirror, instrument panel and the road. The data are summarized to describe back posture effect on driving positions. Comfort, packaging, and seat design are queried for their linear and non-linear interactions to provide a systematic description of seat design effects on driver's comfort, safety and operability in cars and UVs.

2 Methods and Materials

Twenty-three vehicles that have an adjustable 6-way seat, and steering wheel rake (telescope) and tilt were investigated as competitive benchmarks in the US automotive industry (Table 1). Thirteen cars and ten utility vehicles (UVs) were measured.

Table 1. List of cars and UVs measured for study of the seated driver.

Year	Car	UV	Model
2001	Lexus		LS430
2003	Audi		A6
		BMW	X5
		Volvo	XC90
2004	Volvo		S80
	Nissan		Maxima
	Saab		9-3
		Lexus	RX330
		Toyota	4Runner
		Toyota	Sienna
2005	Chrysler		300
		Toyota	Sienna
2006	Saab		9-5
	Cadillac		DTS
		Chevrolet	Equinox
		Pontiac	Torrent
2007	BMW		530Xi
	BMW		328i
		BMW	X3
	Toyota		Camry XLE
	Audi		A4
2008		Ford	Edge

Each vehicle was measured with a 3-dimensional Coordinate Measuring Machine (CMM) to define positions and range of adjustments of vehicle controls and seat. Seating surfaces were laser scanned, and the cushions and seat backs were measured with a force displacement machine. All data from CMM to force displacement measurements were input into software that calculates the seated positions of DHMs in the vehicle.

Every driver seat of vehicles listed in Table 1 was measured with a force displacement machine that loaded the seat cushion and back to a maximum of 540 N in the cushion and 200 N in the back. A force deflection curve was generated to calculate input for the seat model. These force deflection curves are defined by three parameters:

1. An initial displacement (mm) of the trim and pad under load (“toe”),
2. A regression line of the force per displacement (N/mm) for the foam (“linear”), and
3. The total change of foam displacement (mm) under a 20-min peak load (“creep”).

Each seat was scanned to define the trimmed seating surface (Fig. 1). The scanned seat surface was input as a seat back and cushion assembly into the CAD software with the centerline, seat insert and seat wings defined at sites of anatomical landmarks. The eight patches are delimited by a line segment on the centerline, widths of the seat insert from the centerline, and a rise and width of the inboard and outboard seat wings.

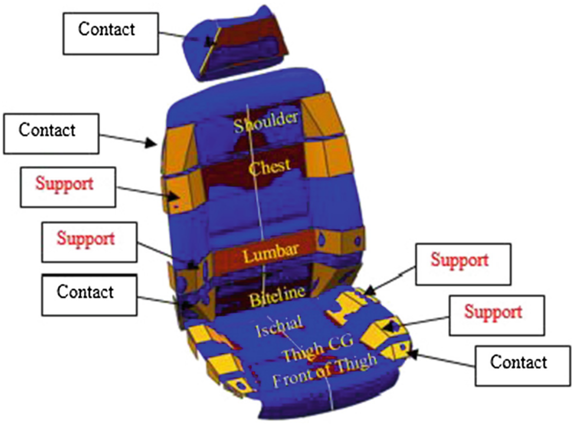

Fig. 1. Scanned surface of a seat with ERL patches defining the locations of support and contact with the seat made by each DHM in the software model.

Centerline shape is defined by continuity and orientation between patches. Continuity, or smoothness between patches, is defined by the angle Θ_A. Orientation is defined by the angle Θ_B. Seat cushion angles are calculated from the rear of the cushion at the ischial patch to the front of the patch in successive pairs of patches. Seat back angles are calculated from the bottom of the bite line patch to the next successive patch. Angles of each patch were calculated relative to track angle with the seat in rearmost, downmost position. The seat back frame was aligned perpendicular to the seat track. The contour of the seat is defined by the orientation between patches. DHM maintain a constant relationship with support patches. Thus, penetration of the contact patches defines the fit of the seat for each driver to operate the vehicle.

The seat supports body weight at support patches on the seat back and cushion. A biomechanical model calculates the distribution of body weight at the chest, lumbar, pelvis and thigh center of gravity. Once the forces are known, deflection of the seat can be calculated using the stiffness of the seat as described above. Support patches identified in Fig. 1 are defined by positions of the spinous process of the 8th thoracic vertebra (chest patch), spinous process of the 4th lumbar vertebra (lumbar patch), ischial tuberosity (ischial patch), and thigh center of gravity (thigh patch). The force supported by the seat in each of the patches is calculated to be acting at these four landmarks.

Contact patches are not supposed to be penetrated by the landmark representing the body's relationship to the seat at the head restraint, shoulder and bite line in the seat back and front of thigh in the cushion. Contact patches identified in Fig. 1 are defined by positions of the spinous process of the 4th thoracic vertebra (shoulder patch), hip joint (bite line patch), and front of thigh landmark that is 75% of the distance from the thigh center of gravity to the back of the calf with a knee flexion of 90°. The head restraint is a contact patch, with its relationship to the back of head defined in FMVSS 202a. The small female is not considered in the head restraint definition because her head is often at the height of the shoulder patch. Each of these four landmarks has a boundary condition that defines the distance between the landmark and the patch.

The computer algorithm uses nine DHMs plus SAE J826 ("Oscar"). Each DHM body size has three back postures [14, 16] with user control of joint angle limits in the limbs, including neck, torso and hip angles, to optimize comfort and fit. Size and posture are based on 3D measurements of spinal [16] and pelvic [17] landmarks essential for locating the position of loads on the seat (Fig. 2). These skeletal landmarks form the basis of a systems anthropometry description of the seated driver.

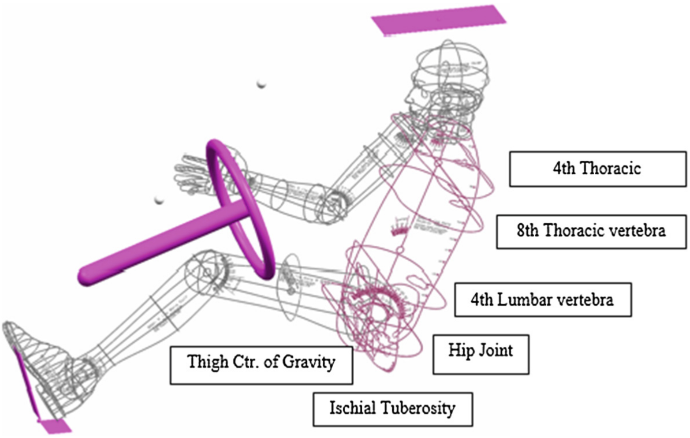

Fig. 2. Wireframe image of medium male, with a neutral posture of the spinal column showing landmarks used for loads and seat contact in all nine DHMs.

Stature, body weight and sitting height are reported in Table 2. Leg length is the standing trochanterion height defined in the US Army ANSUR data [18]. Arm length represents the length from acromion at the shoulder joint to stylion at the wrist joint. These dimensions create a systematic body representation of a small woman, medium size man and large man. The comparative anthropometric data from Germany, Italy, Japan and the United States [19] shows that the dimensions of stature, body weight, sitting height, leg length and arm length are representative of drivers in the world.

Arm length is the sum of acromion-radiale length and radiale-stylion length. Trochanterion height was used as an independent variable to estimate link lengths in both arms and legs [20]. German Arm Length [19] was measured from acromion to wrist crease. The spinal shapes, landmarks and soft tissue shape at these landmarks are based on investigations conducted in the Ergonomics Research Laboratory [16, 21]. Shape of the seated driver is given by the deflection of soft tissues from the seating surfaces [21]. The deflected shapes of soft tissues at landmarks of load application were measured to create a model of the deflected body shapes.

Table 2. ERL anthropometric dimensions.

ERL stature	With shoes	Large male			Medium male			Small female		
		Slumped	Neutral	Erect	Slumped	Neutral	Erect	Slumped	Neutral	Erect
		1865	1881	1914	1741	1758	1785	1492	1502	1518
	Percentiles		95th %tile	99th %tile		50th %tile		1st%ile	5th %tile	
	ANSUR (88)		1867	1909		1755		1483	1528	
	Germany		1865	1910		1758		1486	1529	
	Italy (South)		1804	1848		1701		1429	1471	
	Japan		1781	1820		1687		1439	1474	
	NHANES '03–'06		1887			1763			1507	
ERL weight (kg)		100	100	100	77	77	77	50	50	50
	NHANES '03–'06		122.6			85.6			50.5	
	ANSUR (88)		98.1			77.7			49.6	
ERL sitting height		923	938	971	873	891	918	777	786	802
	ANSUR (88)		972	991		914		775	795	
	Germany		977	1000		921		785	807	
	Italy (South)		925	948		869		734	759	
	Japan		970	995		913		771	793	
ERL leg length		1009	1009	1009	927	927	927	789	789	789
	ANSUR (88)		1009	1040		927		761	789	
	Germany		998	1031		917		728	759	
	Italy (South)		NA	NA		NA		NA	NA	
	Japan		912	940		846		687	711	
ERL arm length		656	656	656	609	609	609	513	513	513
	ANSUR (88)		656			609			513	
	Germany		648	668		601		492	510	

Positions of each seated DHM in the vehicle are optimized to grip the steering wheel, contact the accelerator pedal and sit in the seat with each DHM's eye within boundaries required for good vision as defined by horizontal, upward (rear view mirror) and downward (center of speedometer) lines of sight. A biomechanical model [14, 15] calculates the distribution of body weight in static equilibrium for each DHM in the seat. Seats support body weight between four points on the seat and heel on the floor. When a point is unloaded so that the force of body weight equals zero, the displaced point lies on the undeflected seating surface. The model positions the body, seat and steering wheel to find a solution that places this zero-load point within ± 2 mm of the seating surface.

Data from mass distribution studies of living subjects were used [22, 23] to establish segmental weights and center of gravities.

Reach to the steering wheel is controlled by joints at the shoulder (3DOF), elbow (1DOF) and wrist (3DOF) for the hand to grip the steering wheel along a palm axis.

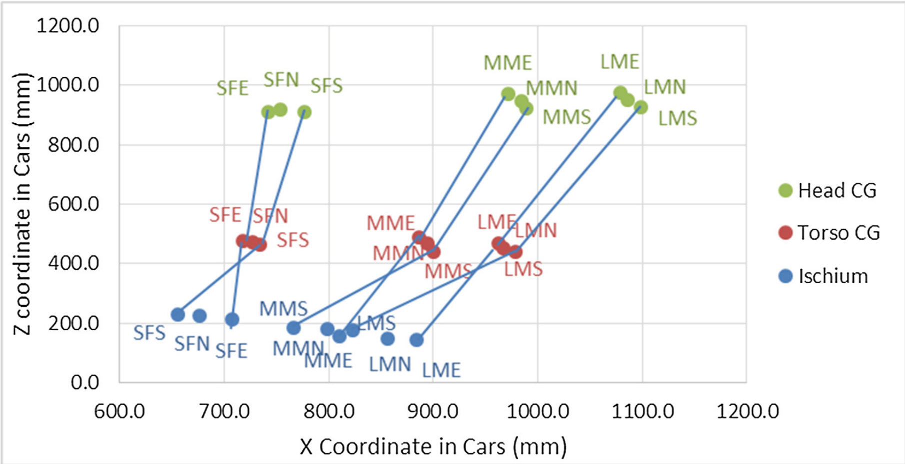

Fig. 3. Seated posture by head CG location, torso CG location and ischial tuberosity (IT) location for all DHMs relative to the accelerator heel point (AHP) in cars.

Reach to the accelerator is controlled by joints at the hip (3DOF), knee (1DOF) and ankle (3DOF) for the foot to contact the accelerator and the heel to rest on the compressed floor carpet. The heel had to be within ±0.1 mm of the compressed floor carpet height.

A reliable comfort model reported and validated in Reynolds and Wehrle [14] was used for the study, with a correlation factor of 0.78 between the model score and subjective driver scores from 2-h drives in seven vehicles.

3 Results

In Fig. 3, the effect of posture on seated body landmarks is shown for small females, medium males and large males (from left to right). The positions of the center of gravity of the head and torso and the position of the ischial tuberosity (IT) with respect to the Accelerator Heel Point (AHPx and AHPz) show how each DHM sits in cars. These data only show relative landmark positions. The IT in the erect posture is more rearward than in the neutral and slumped postures, while the inverse is seen in head centers of gravity.

Figure 4 depicts the force deflection at the IT of each DHM, with a regression coefficient of R^2 = 0.9992 for cars and 0.9996 for UVs for the different body sizes. In all three body sizes, whether in cars or UVs, the erect posture generates the highest force and deflection, followed in sequence by the neutral and slumped postures.

Figure 5 shows the relationship between the penetration of the front of thigh patch and deflection under the IT. The front of thigh on the DHM marks a point 75% of the distance from thigh center of gravity to the knee joint. The IT on the pelvis transmit body weight into the seat cushion. A parabolic quadratic equation best fits the data with R^2 values of 0.964 and 0.976 for cars and UVs respectively. The same impact of back postures as in Fig. 4 is seen in Fig. 5 for the front of thigh penetration in cars and UVs for the three body sizes.

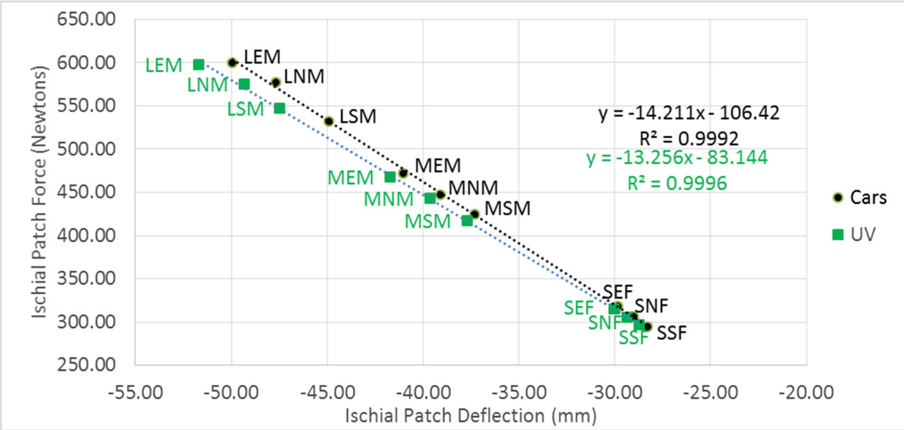

Fig. 4. Ischial force/deflection (N/mm) for all DHMs in cars and UVs.

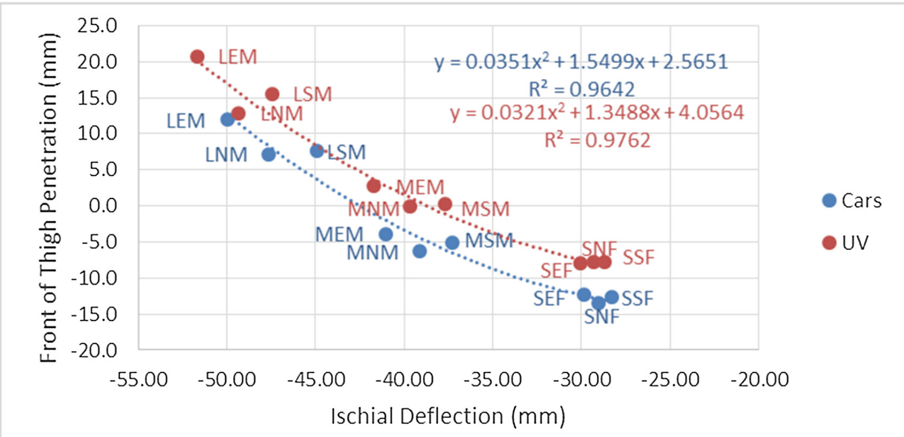

Fig. 5. Front of thigh penetration per ischial deflection for all DHMs in cars and UVs.

Given the phenomenological background, the front of thigh penetration per thigh flexion is highly correlated. R^2 values of 0.9414 and 0.9900 in cars and UVs respectively (Fig. 6) represent the fit of the quadratic correlation. Large males in erect posture sit with no thigh contact, erect sitting small females sit with high penetration. This difference represents the effect of both joint angles and seat design. The medium male achieves an optimum level of contact with the front of cushion.

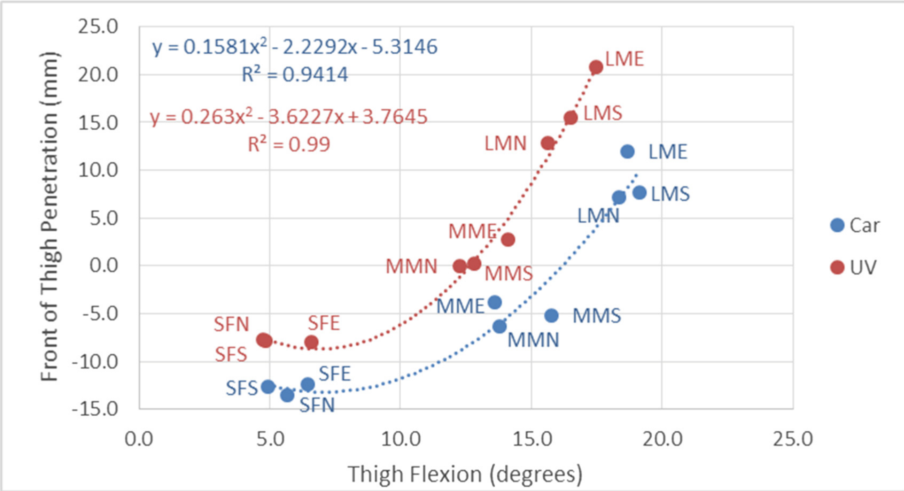

Fig. 6. Average front of thigh penetration per thigh flexion in all DHMs in cars and UVs.

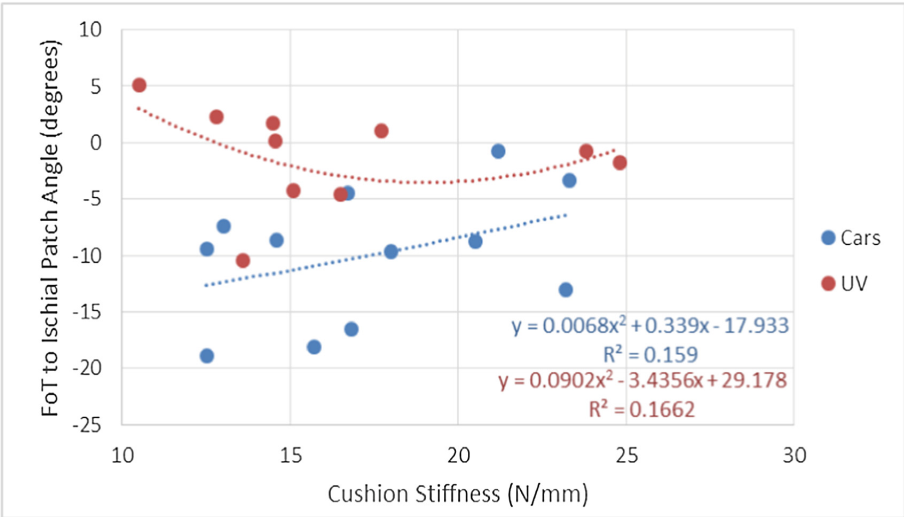

Fig. 7. Relative front of thigh to ischial patch angle per car and UV cushion stiffness.

The relationship of the angle between the front of thigh patch to the ischial patch, and cushion stiffness (Fig. 7) was found to be insignificant at R^2 values of 0.1590 and 0.1662 for cars and UVs respectively.

4 Discussion

Although motor vehicles are mostly designed and built in Japan, the United States or Germany, drivers from countries around the world may drive them. Thus, vehicles are designed using anthropometric databases, which underlie digital human model tools. Since driving is a seated task, the design however needs to consider relations between the seat, driver anthropometry and driver posture, which also affects driver dimensions.

To understand the effect of back posture on seat position, it is necessary to recognize the change in relative positions of a driver's head, chest and pelvis. As seen in Fig. 3, a small female driver has the centers of gravity (CG) of head and torso only slightly behind the ischial tuberosity. In a slumped posture however, the CG of her torso and head lie behind the pelvic ischium, thereby creating a moment arm applying a rearward tilt to the pelvis, further exacerbating the slumped posture. In contrast, medium and large male drivers have their positions of torso and head CG clearly behind the IT, independent of back posture. Therefore, these drivers will typically react to the rearward momentum with muscular effort to achieve a more erect posture. Medium and large drivers will however most likely sit with a neutral to slumped back posture. Ironically, this neutral-to-slumped posture was measured by Geoffrey in 1959 [5] when he defined the H-point and shape of the back subsequently used in the original H-point machine (SAE J826).

In contrast to the postures in Fig. 3, the force displacement curve in Fig. 4 shows a postural effect in both cars and UVs. An erect posture applies the greatest force and deflection to the seat cushion ischial patch for each body size, followed by neutral and slumped postures. The postural logic associated with this relationship should be seen throughout the data, but in subsequent figures, it is unpredictable despite the logic defined from Figs. 3 and 4. This inconsistency arises from the lack of a design standard for seating, where seat shape is highly variable as measured by patch angle coefficient of variation.

Styling appearance needs to follow functional shape to support drivers in position to operate the vehicle. There is no evidence that back postures are associated with any vehicle type and the data in this paper reports that neither cars nor UVs accommodate this postural logic. In fact, comfort data shows that seat design and controls packaging does not equally accommodate small women, or short drivers, and medium men. Likewise, large men are not as well accommodated as medium males, although their discomfort levels are normally smaller than in small woman.

The use of different back postures by drivers can be logically assigned to either a need or a preference. Small drivers need to sit as upright as possible for good vision. Tall drivers need to slump to lower head and eye height for fit in the vehicle. Most drivers have a seated back posture preference that fits their anatomy and/or the driving conditions. Since torso angle changes with back posture, so does reach to controls by moving the shoulder and the hip joints in opposite directions. As revealed in the analysis of ischial positions in drivers, an erect posture requires less horizontal sitting space than a slumped posture. To accommodate the variation in back posture and its effect on driver packaging, seats must be incorporated into very early vehicle design, so that track travel, track orientation, seat height adjustments, and seat cushion tilt adjustments are correctly designed.

Seat design on the other hand cannot be based solely on pressure distribution or accommodating a seating reference point. As seen in Fig. 4, the position of the ischium, which is the position of greatest seat cushion pressure, changes with back posture. Moreover, the penetration of the front of thigh as seen in Fig. 5 shows that the contour of the seat has to be designed to accommodate changes in thigh orientation associated with the change in ischium position. The net effect of these changes from an erect to slumped posture is a reduction in thigh angle relative to horizontal, associated with a greater reach to the accelerator and an increase in knee angle.

In conclusion, the results of this analysis demonstrate a consistency that seems to focus on average body size despite the adjustments of seat and steering wheel in the vehicles. Given these findings and the capability of an optimization algorithm to be used in either evaluation of benchmark vehicles or the design of new vehicles, it would seem appropriate to begin considering a change in how vehicles are developed at the beginning of design. Very simply, the initial layout of any motorized vehicle should be considering the range of seated postures rather than simply reach in a sitting position of a digital human body model of a driver. Seat shape and foam indentation should also be taken into account. Driver back posture and seat design affect where and how the driver sits, and this information is needed to optimize the vehicle for driver comfort, safety and operability.

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The Veronesi Method - Judicial Expertise for Physical Therapists

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Abstract. The Veronesi method follows scientific criteria, applicable law, regulations and recommendations on the subject to a path in a structured completion and grounded to assist the court in decisions. The goal is to bring to society the knowledge of the technical and scientific aspects of the method. From TST guidelines, the method analyzes the nexus, conducts research in the workplace, where you use regulations such as ISO 11226 to assess posture and motion analysis software to quantify them, ISO 11228 for survey analysis the lifting and transport of weigth and repetitive activities. Using criteria established by the Instruction of the INSS for the link. It was a retrospective, cross-sectional, which randomly chose 100 cases by Method. It analyzed the number of affected segments (diagnosed diseases) that sought if there was a causal nexus, concausa nexus and no nexus. Randomly selected 10 first and second instance decisions in order to correlate the findings with the method. Found 159 diseases diagnosed being 49 showed 1 affected segment, 43 had 2 segments 7 with 3 segments, and 1 case with 4 diseased segments. They showed causal nexus in 71 cases, 50 nexus concausa and 38 no nexus. All judgments of first and second instance, the Veronesi method was accepted, giving sustainability to justice fulfill their craft. The study method was shown to be an important scientific technical tool to be used by experts for reports with informed and fundamentas conclusions, thus helping the judgment in fairer decisions.

Keywords: Veronesi Method · Judicial expertise · Causal nexus

1 Introduction

The meaning of the word Method comes from the Greek, "Methodos" meaning pathway, route, in other words, the means used to reach an end. Therefore, "Methodos" is the way of the best scientific techniques in the search for a problem's solution. In science, the problem is the object of research, it's what drives the search for answers in order to bring the philosophy of science, that is generating answers to reflect on new doubts. According to Popper (1985), the task of epistemology or the philosophy of science is to rationally reconstruct *the later proofs by which it was discovered that inspiration was a discovery or came to be recognized as knowledge* [1].

The practice of judicial expertise by the physical therapist professional in Brazil initiated in 1999 by physiotherapist José Ronaldo Veronesi Junior, when this

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professional made a Physiotherapeutic report for a patient following the ABNT standards in an article format and this document sent by the lawyer to court.

The method of analysis and expert formatting has been studied for years. The first book on the subject was published in 2004, reissued in the years 2008 and 2013 [2]. Also in 2004, at the request of the Federal Council of Physical Therapy and Occupational Therapy, Dr. Veronesi launched the professional enhancement course in Judicial Expertise by Method, where many students have been trained these years.

In 2011, the Method's author, Dr. Veronesi, concluded his PhD thesis validating an evaluation and quantification protocol regarding functional capacity for judicial expertise. This work resulted in publications at the World Conference on Ergonomics, United States, 2014 [3], and in a scientific journal of law in the same year [4]. To evaluate the functional capacity within the Veronesi Method's protocol, the author published, in 2012, the Book of Orthopedic Functional Tests [5].

Seeking for continuous improvement in the judicial expertise area, and in need of a more complete instrument for analysis of the expertise process, Dr. Veronesi launched the "Veronesi Ergonomic Risk Index for Repetitive Activity of Upper Limbs" (IVRE-ARMS). The "6th International Conference on Applied Human Factors and Ergonomics" validated this work in 2015 and it was also published in Procedia Manufacturing journal in the same year [6]. The IVRE-ARMS tool allows an analysis of the labor activity in a broader way and from the perspective of the physical, cognitive and organizational aspects, bringing a greater systematization inside the expert inspection.

The Veronesi Method provides continuous training for Physiotherapists professionals interested in working in the judicial expertise area, following the precept of the Code of Civil Procedure (CPC), Art. 156 [7].

In 2014, the physiotherapeutic expertise was recognized by the Superior Labor Court (TST), in its publication on guidelines of the expert evidence in labor accident and occupational diseases [8]. Chapter 1, regarding the expert, in art. 1 says: "In matter of occupational accidents and diseases, judicial expert should be appointed to meet the legal and ethical-professional standards for analysis of the object of proof, such as physicians, psychologists, *physiotherapists*, among others, without loss to the appointment of more than one professional, even if it is not a complex skill, in the mold of art. 431-B of the Code of Civil Procedure."

2 Objective

Bring to society in general, the knowledge of technical and scientific aspects adopted in the Veronesi Method of Judicial Expertise for Physical Therapists.

3 Applied Methods

Methods used in this work were divided into: method procedures and work performed.

3.1 Procedures of the Veronesi Method for Judicial Expertise

The legal and judicial expertise of the Veronesi Method follows the scientific criteria, a current law, recommendations, and norms on a thematic.

The Veronesi Method works with three main fields of analysis: Establishment or not of the legal nexus, to evaluate and to quantify the functional capacity and analysis of the labor regulating norms fulfillment.

In labor judicial expertise, the Method starts the analysis following the recommended by Art. 5 of the TST Guidelines on Actions in Occupational Accidents and Occupational Diseases [8]: "The expert must find the correlation between the health condition and the functional incapacity, and observe if it is related to the Technical Epidemiological Social Security Nexus". From this presumption of nexus, the investigative process begins.

The Veronesi Method, in its protocol, strictly follows Article 473's second paragraph of the CPC [7]: "The expert is forbidden to exceed the limits of his designation, as well as to issue personal opinions that exceed the technical or scientific examination of the object. Therefore, the object of the skill is given according the court's designation where the entire expert's work concerns the object." Both the documentary analysis of the procedural records and the expert inspections, and on-site (in case of labor expertise), are made based on the object designated by the court.

It is important to emphasize that the Article 473' second paragraph of the CPC [7] brings a special and differential condition to the Physiotherapeutic Expertise, because by law, the physiotherapy professional cannot diagnose diseases, meaning he cannot discover injuries. Therefore, the expert analysis by the Veronesi Method analyzes only the object demanded by the court, thus contemplating, with all property, the CPC and collaborating for the judicial process to be more agile and just.

Still following the CPC's Art. 473 [7], the Veronesi Method uses in its expert inspection an analysis according to the demanded object, searching for the best tools and scientific instruments for such.

In order to make the analysis of the legal nexus (causal or concomitant cause), judicial expert reports, for labor justice, use as recommended by Art. 7 of the TST Guidelines on expert evidence, which initially performs on-site expert inspection in the company, analyzing the organization of the work [8].

For work organization analysis and legal nexus, the INSS's Normative Instruction 98/2003, which is the regulatory labor standards, is used as base for orientation and guidance [8]. In particular, NR 17 and its application manual, as directed in Art. 4 of the TST guidelines on expert evidence, which analyze the following criteria [8]: Nature of exposure, ergonomic risk of work activity, time and intensity of daily exposure, time and intensity of total exposure, physiomorphopathological characteristics of the disease, preventive methods adopted and incidence of the disease at the analyzed spot.

Complementing the legal norms for work organization analysis, the Veronesi Method also uses as reference: NBRs ISO 11226 [9], which deals with static posture and brings references about acceptable and non-acceptable angulations, NBR ISO 11228-1 [10], about lifting loads, ABNT ISO 11228-2 [11], which contains load bearing references with safety and ABNT ISO11228-3 [12] which guides the analysis of repetitive activity.

For the ergonomic risk analysis of the work activities developed by the individual, the Veronesi Method applies the following scientific tools [13]:

– The IVRE-ARMS: Veronesi Ergonomic Risk Index for Repetitive Activity of Upper Limbs, which analyzes ergonomic risk separately, within the organizational, cognitive, biomechanical aspects of the shoulder, elbow and wrist (Fig. 1).

Fig. 1. IVRE-ARMS tool.

– The Ocra Index, which according to ANBT ISO 11228-3 is an instrument whose final index brings a risk classification and prediction of illness for repetitive activities of upper limbs [14].
– The NIOSH tool, oriented and recommended by ABNT ISO 11228-1 [10], establishes the recommended weight in the analyzed activity and compares it with the actual weight manipulated, thus providing a final index with a prediction of illness due to the task (Fig. 2).

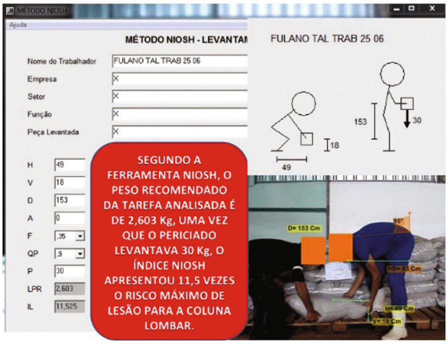

Fig. 2. NIOSH tool.

The HARSIM, (Humanoid Articulation Reaction Simulation) model consists of a humanoid computer representation with 38 segments, a full spine with 24 vertebrae, and upper and lower limbs with 8 and 6 segments, respectively. The developed model has

100 degrees of freedom, 72 for the spine, 12 for the lower limbs and 16 for the upper limbs. HARSIM can do the following functions Simulation of posture sand movements: the model allows the simulation of the main postures in an interaction with a product or workplace situation. Calculation of forces, strain and stress in each articulation joint [15], (Fig. 3).

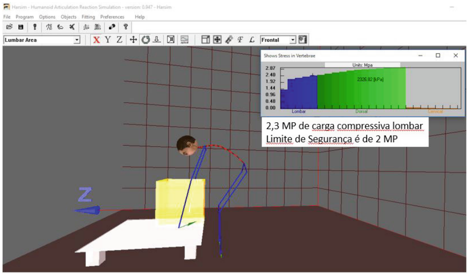

Fig. 3. HARSIM - humanoid articulation reaction simulation.

– The RULA, REBA and Strain Index (developed by Moore and Garg) tools, all recommended by NBR ISO 11228-3 [12], for upper limbs biomechanical risk analysis.
– The OWAS tool, also recommended by NBR ISO 11228-3 [12], for lumbar spine biomechanical risk analysis.
– For cargo transport analysis, is recommended by NBR ISO 11228-2 [11] the table developed by SNOOK AND CIRIELO (Fig. 4).

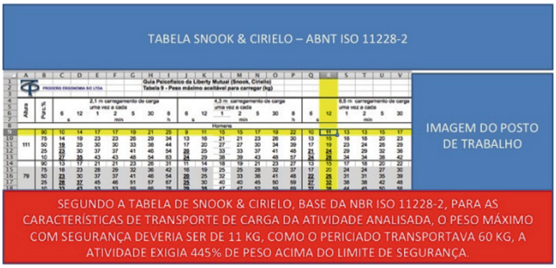

Fig. 4. Reference table on safe weight for loading.

For movement and work posture analysis, following the ABNT ISO 11226 [9] guidelines in detail, the Veronesi Method uses a photogrammetry resource, which using human movement analysis, through angular measurements, a computer program (Kinóvea) [16] creates a video analysis of the activity at different speeds. At specific moments in the analysis (guided by the Normative Instruction 98/2003 of INSS) the video is paused and the postures angulations required by the work are analyzed (Fig. 5).

Fig. 5. Kinóvea software illustration.

According to the first paragraph of Article 473 [7], “In the report, the expert must present his reasoning in simple language and with logical coherence, indicating how he reached his conclusions. The Veronesi Method uses a technical language of simple understanding with objectivity within each phase of the protocol, and has a textual logic leading all reasoning with coherence on report’s conclusion”.

In the event of a traffic accident, both for Civil Expertise and for DPVAT (Mandatory traffic insurance in Brazil), the Veronesi Method uses the SUSEP [17] (Superintendence of Private Insurance in Brazil) table. However, in labor investigations involving diseases, the method follows the third paragraph of Art. First, Circular number 029, December 20, 1991, about SUSEP table, that says: “SUSEP table must not be used in case of diseases included to the professionals because they are not included in the concept of personal accident”. Therefore, it’s applied the Veronesi Method’s Functional Capacity Assessment Protocol for functional capacity evaluation and quantification.

According the TST Guidelines, article 12, on expert evidence, referring to the conclusion of functional capacity, “In the incapacity evaluation, the International Classification of Diseases (ICD-10) and other documents, national or international standards of recognized competence and technical scientific qualification may be used in conjunction, for this purpose, and the expert shall determine whether the disability is partial or total, permanent or provisional [8].”

The Protocol for the evaluation of functional capacity for judicial expertise, which was the doctoral thesis of Veronesi Method’s author, contemplates what article 12 says, and was published in a World Congress of Ergonomics and at the Scientific Interface Magazine [4].

The protocol for functional capacity evaluation for judicial expertise was based on fundamental aspects to evaluate the functional capacity of the work within a philosophy of thought that concerns the worker’s functionality, based on two instruments: the ICF - International Classification of Functionality and the Functionality Classification of Baremo. In addition to these two instruments, other data were used to analyze the functional capacity such as age, schooling, injured structures, diseases prognosis and functional tests, because they have to be applied for functional capacity analysis.

A protocol was made for upper limbs analysis and another for the lower limbs and spine, because the ICF variables were specific for each segment. The same was created in a computerized system for better applicability and data management. It has 3 lists of analyzes: documentary list, practice list (these two lists are common for both protocols), and activity and participation list, which is specific for each protocol and has specific functionality elements for each segment of analysis related and oriented by the ICF.

The Veronesi Method, within its expert analysis, can verify whether the individual is simulating or not during the expert inspection, because it applies kinematics analysis elements associated to kinesiopathogeny knowledge, knowing the coherence of the facts. Here, by expert secrecy it is not possible to do more detail. For Veronesi (2014), convincing elements of the expert are test responses and observations made by the expert to analyze the reliability process of the movement's functional behavior, which would indicate a possible simulation condition created by the investigated individual [4].

3.2 Work Performed

The present research was carried out through a retrospective and cross - sectional study, where a hundred judicial trials were randomly selected by the Veronesi Method, already performed by the Electronic Judicial Process (PJE) system from 2014 to 2016.

It was analyzed the number of affected segments (diagnosed diseases) that sought to establish or not a nexus and, from these, how many were causal nexus, concomitant cause nexus and non-existence of nexus. Among these 100 skills analyzed, the 10 first and second instance decisions were randomly chosen to analyze the conclusions and relate them to the Method.

4 Results

All first and second court judgments based on the Veronesi Method were analyzed in the processes investigated here. In all cases, the judge of the first instance took a decision based on the expert's report. Regarding the cases that were appealed and went to the second instance, the labor courts, of the regional labor court, that analyzed the facts unanimously maintained and, in some cases, even praised the expert's report.

Of all the analyzed processes, when added the affected segments, 159 segments were found, or diseases diagnosed for the nexus establishment. Among these, 49 cases presented only 1 segment affected, 43 cases presented 2 segments, 7 cases with 3 segments, and 1 case with 4 segments affected with diseases.

Was found causal nexus in 71 cases (44.6%), 50 had concomitant cause nexus (31.4%) and 38 (24%) had no nexus. The average disability was 30%, and the highest disability was found in 3 cases of the 100 studied, representing 80%, of which 2 were of permanent disability and 1 of temporary disability.

In three of studied cases, the analyzed individual presented capacity preserved, which means 100% functional capacity, even if there was a causal or concomitant cause relationship.

In four cases where the individual had three diseases, we had three different conclusions: a causal nexus, a concomitant cause nexus, and a lack of nexus.

In three cases, it was concluded that there was no nexus between diseases and work, where the defendant was not guilty in the process. The other findings of non-existence of nexus were in cases where the individual had more than one segment, in one of the cases that had three affected segments, two had no nexus, and one had concomitant cause nexus.

When the court judgments were analyzed, in one of them the defendant contested the Veronesi Method with the following argument: "The SUSEP table was not designed to measure incapacity due to illnesses but accidents instead." However, the Judge in his decision pronounced the following: "In addition, the TST has admitted the appointment of Physiotherapist for the accomplishment of expertise in matter of work accident and occupational diseases, being worth the expert of using the international classification of diseases and other documents National and international standards of recognized suitability and technical-scientific qualification for the collimated purposes. In this case, the expert made an analysis of the functional capacity based on the doctoral thesis itself, of recognized scientific value. In this process, the scientific recognition of the Veronesi Method in the quantification of functional capacity is evident".

In the verdict, in one of the expert cases conducted by the Veronesi Method, the judge concluded: "Thus, in view of the fundaments and findings reported by the expert, the judgment understands to accept them completely concerning the causal nexus characterization." The defendant filed an appeal and the Judgment of this case concluded: "I accept the expert opinion, because it was prepared by a qualified professional and trusted by the Court."

In another case, the Judgment says: "The expert appointed, in a detailed report, in which no defect is found, acknowledged that the claimant has injuries on the upper limbs … The assumptions for civil liability of the employer are therefore present (Articles 186 and 927 of the Civil Code) [7]".

Contrary to the expert's conclusion, the defendant filed an appeal in the second instance, and the Judgment pronounced "Irresigned, it adds the defendant, in summary, that the expert's report is a partial and personal manifestation of the expert. In addition, the technical expertise of the social security authority did not recognize the causal nexus between pathologies and business activities, and that the expert report should be considered null and void, removing the causality nexus. But the T.R.T. concluded that the expert report presents high technical quality, it is meticulous and elucidative, and the defendant does not present the qualified element capable of belittling and failing the conclusions drawn by the expert."

In another case, the Judgment says: "The expert report analyzed in depth the working conditions in light of the regulatory norms issued by the Ministry of Labor and Employment. The expert report was conclusive in the sense that the claimant has permanent functional impairment in the order of 60% due to spinal problems."

In another case in which he went to the second instance, the Judgment says: "The investigation was conclusive in pointing out the existing relation of concomitant cause between the pathology that affects the worker and the activity performed at the claimed one and the intrinsic factors of the own victim. The expert testified that the functional disability is temporary and partial, in a mild degree, corresponding to 30%. The expert's report is clear, and there is no element in the file that demerits or contradicts the conclusions made by the expert. Sufficiently proven the damage and the causal nexus with the activity performed".

The judgment of another case, states: "In a court of appeal, the defendant maintains that it is wrong to quantify the applicant's limitations by 80%, since it is impossible to apply the International Classification of Functions used by the expert, fighting for reduction of 30%, depending on the Susep /DPVAT table". The conclusion of the Regional Labor Court. Was: "The quantification of the limitations contained in the expert's report, based on the ICF, is not worth repairing. Currently the ICF is one of the instruments adopted by the World Health Organization as a reference for states of health, capacity and disability, alongside ICD-10. Therefore, no inconsistency is found in the application of the abovementioned technical-scientific criteria by the expert. Once again the court recognizes the technical-scientific criteria of the Veronesi Method for the evaluation and quantification of the functional capacity of the evaluated individual."

The judge in a trial pronounced the following decision: "I take the expert opinion, because it was produced by a qualified and trustworthy professional of the Judge, as well as because there is no evidence in the files capable of invalidating it." The defendant appealed and the Judgment concluded: "In these terms, I maintain the judgment that acknowledged the civil liability of the defendant for the occupational disease acquired by the claimant."

In another case, the judge in his sentence said: "Therefore, I accept the expert opinion regarding *non-existence of causality nexus*, since it is prepared by a qualified professional and trusted by the Court, as well as because there is no evidence in the records capable to inflict it. In this context, I *dismiss* the request for a declaration of the occurrence of occupational disease and the lawsuits for payment of compensation for moral and material damages."

In a judgment presented in a trial, where the defendant contested the amounts of the expert's fees, the decision was: "The defendant is incensed in the face of the sentence that fixed the value of the expert fees in R$ 1,980.00. He maintains, in synthesis, that the accomplishment of the skill required simple equipment and little time of preparation, thus, it required its reduction to R$ 800,00". Under analysis by the class of the regional labor court, the conclusion was the following: "The expertise was performed by specialized physical therapist. Considering the complexity and quality of the work presented by the expert, as well as the time required for its realization, I consider the value of the expert fees fixed at the origin as appropriate."

As evidenced in the first and second instance judicial decisions, the Veronesi Method brings a great technical-scientific consistency, giving support for the justice to fulfill its calling.

5 Discussion

When there is injury or damage to the individual, and this is the object of the grounds for claiming compensation as a consequence of the accident or labor disease, a technical investigation called judicial expertise is required [2]. The Veronesi Method seeks to adapt the established in the precepts of the Code of Civil Procedure's Articles for a technical and scientific investigation providing more results that are concrete.

After determining the existence of the disease in question, the main objectives in the exclusive investigations of LER/DORT are to clarify if the disease presented by the claimant (plaintiff) has nexus with the activities performed by him at the claimed (defendant in the action), that is, the establishment of the causal nexus and also the quantification of the residual functional capacity of the claimant [18].

According to the Aristotelian philosophical system, in the theory of causes, there are material cause, final cause, formal cause and efficient cause [19]. In cases of judicial expertise, the efficient cause is applied, where the cause or concomitant cause nexus can only be removed when the expert concludes that the work activity in no way stops the onset and/or anticipation of the health problem [20]. As illustrated in the present research, the establishment of the nexus separately with disease is important because it establishes an efficient cause between cause and damage separately in each segment. Where the same person can have three diseases in different segments, and for one segment has a cause nexus (the one claimed has total guilt), another has a concomitant cause nexus (the fault is partial) and for the other there is no nexus, no guilt, as occurred in 3 cases analyzed in this work.

Fernandes (2005), in his work already showed the importance of the functional capacity results for the judicial conclusion, since it refers to financial amounts [21]. In the study with the Veronesi Method of Functional Capacity Assessment, the control group, which evaluated the functional capacity in a conventional way, observationally and subjectively, presented a great variability in the results of the same expert cases done by different professionals (CVQ 33%). Meanwhile, the group studied, practically did not present this variability (CVQ 6%), showing that the protocol developed in this work is more solid and consistent in its results. The present study evidenced that the functional capacity average of the studied cases was 30%, following a scientific analysis criterion.

This makes possible the applicability of the impartiality and justice principle, currently recommended in Article 173 [7], second paragraph. It brings light on the applicability of civil liability to the employer when established the nexus, but in an impartial and fair way, where only in the segments that in fact the work had direct or indirect cause will be inferred the responsibility.

6 Final Considerations

The Veronesi Method uses analysis elements of the active simulation process, which, through kinematics, identifies when the individual is simulating or even exaggerating reactions when compared to characteristics of the disease he is carrying, a fundamental condition for the legal analysis process.

The professional improvement offered by the Veronesi Method has a philosophy of continuous and evolutionary learning process, where the students are trained to search for knowledge based on ethics and technical scientific foundation.

Taking into account what is stated in Code of Civil Procedure, Article 173 [7], which clearly recommends that the expert must indicate the method used for the technical and scientific analysis of the object of the expertise demanded by justice, with a simple language and logical coherence.

The Veronesi Method of Judicial Expertise has clearly demonstrated its adequacy to the Code of Civil Procedure Articles, associated with modern scientific analysis techniques, recommended by NBR ISO, NR 17 [22] and its application manual, TST guidelines on expert evidence, Normative Instruction 98 of 2003 of INSS [8] and a protocol of functional capacity evaluation scientifically valid [3, 4], thus demonstrating itself as an instrument of great scientific rigor to assist justice in the decision process and to be more just.

Thereby, the Veronesi Method is an important technical scientific instrument to be used by judicial experts for an expert report with solid and grounded conclusions, thus assisting the judgment in a more just and reasoned decision with great structuring considering contestation cases where judge's decision, when based on the expert's report, has more chance of recognition by the second instance. This can be inferred considering that, in all cases where the Veronesi Method was applied, the first instance judge decided based on the expert report. As for the appealed cases that went to second instance, the regional labor court classes that analyzed the facts, unanimously maintained and, in some of them, praised the expert report, as illustrated in the results of this research.

To conclude, a reflection by Marinoni (2000), the search should always be for fairness, effective justice, not forgetting that there is no risk-free effectiveness, and that "the judge who omits himself is as harmful as the judge who misjudge [23]."

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Total Force of Pinch and Grasp by Hand Postures

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Abstract. The aim of this study was to measure the total force of pinch and grasp by various hand postures of pinching with two fingers (2P), three fingers (3P), four fingers (4P), and five fingers (5P), and power grip (5G). Male graduate and undergraduate students participated in the experiment. The pinch and grasp forces were measured using a pressure measurement system with a pad. The pad of the body pressure measurement system was attached to the object using double-sided tape. The participants picked up the objects using the hand posture required by the experimenter. The participants were asked to lift the object to approximately shoulder height and maintain the posture for 3 s. The results of ANOVA applied to the total forces on the thumb, index, middle, ring, and little finger, which indicated that the main effects of the hand posture ($p < 0.0001$). The total force on the thumb increased as the number of fingers used increased. However, the total force on the index finger decreased as the number of fingers used increased, except for the 5G hand posture. In conclusion, the hand posture difference was also evident in the distribution of the individual finger force.

Keywords: Total force · External force · Pinch and grasp · Hand postures

1 Introduction

The human hand is one of the most flexible organs of the other body parts. Thus, human hand is the most useful in various tasks. These various tasks are used for purposes such as manipulating devices, picking up objects, pointing, climbing, playing musical instrument, drawing, and sculpting. Since the human hand is highly utilized, the physical load is increased in various fields. The physical load on the hand has typically been evaluated using biomechanical methodology. Biomechanical analysis of the human hand can be divided into kinematics, kinetics, anthropometry, and electromyography (EMG). Previous studies of biomechanical aspects reported that the hand postures [1].

In kinetics methods, to measure the grip force is very commonly and simply used in physical load. Force data (external force) is used for hand biomechanics models development. Thus, many researchers in various fields are attempting to assess the physical loads and develop the hand model of various hand postures. The most common method for measuring the grip force involves the use of bars separated by force gauge, such as a dynamometer and custom made measurement devices [2–4]. In addition, the grip force

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is measured in various methods. However, in previous studies are not measures the grip force of the various hand postures.

Thus, the aim of this study was to measure the total force of pinch and grasp by various hand postures of pinching with two fingers (2P), three fingers (3P), four fingers (4P), and five fingers (5P), and power grip (5G).

2 Methods

2.1 Participants

Ten male students participated in the experiment. All the participants were right-handed and had no history of illnesses or injuries in their extremities in the last 1 year. 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 average (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. Table 1 shows their basic anthropometric information.

Table 1. Basic anthropometric data of participants

Participant	Age (year)	Height (cm)	Weight (kg)	Hand length (cm)	Hand circumference (cm)	Hand breadth (cm)
1	20	167.0	56.0	17.4	17.7	9.6
2	20	170.0	98.0	18.2	18.8	9.6
3	26	167.0	65.0	15.4	19.5	9.3
4	21	175.0	61.0	18.5	15.3	7.8
5	20	171.	62.3	17.4	19.1	10.0
6	32	180.0	85.0	19.7	19.9	8.3
7	20	178.0	100.0	18.8	19.5	10.2
8	33	180.0	100.0	19.9	20.6	10.1
9	21	170.0	65.0	18.0	17.6	8.8
10	20	175.0	70.1	20.0	19.7	10.4

2.2 Apparatus

The pinch and grasp forces were measured using a body pressure measurement system (Novel.de Inc., Germany) with a pad (No. S2085, Elasticsens ES-256-108/432-135). The pad was 108×432 mm^2 in area and had a total of 256 (8×32) sensors. The typical pressure was measured in the range of 5~600 kPa, with a sampling rate of 50 Hz. All the data were acquired on a laptop computer with a 16-bit analog-to-digital converter. Each sensor was divided using colored tape and numbered tape to confirm the contact area during grasping (Fig. 1).

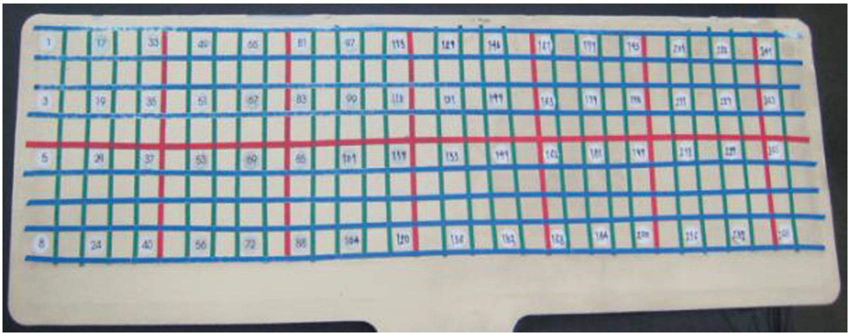

Fig. 1. Pressure pad

A table made of wood and aluminum framing material was used. The table height followed the recommended standing work surface height for light assembly work tasks. The objects used were four cylinders and rectangles made of acrylic panels with sizes of 6 cm.

2.3 Procedures

The participant stood in front of the table. The participant's initial position was standing naturally at attention at the table. The objects were placed in the center of the table in line with the participant's sagittal plane; the participant's midline was aligned with the center of the object. The participants picked up the objects using the hand posture required by the experimenter. The participants were asked to lift the object to approximately shoulder height and maintain this posture for 3 s. Each participant performed only one trial for each experimental condition.

2.4 Data Collection and Experiment Design

All the experimental conditions were recorded using four video cameras to confirm the contact area in the pressure pad during grasping and pinching. The total forces on individual fingers were obtained after checking the cell number (contact area) from the recorded films. For the total force data, only the data from the middle 1 s of the entire measurement time (3 s) were used.

For the pinch hand postures, only the fingertip forces of individual fingers were collected. For the grasp hand posture, fifteen contact forces were collected: the fingertip force; contact force of the distal phalanges; contact force of the middle phalanges; contact force of the proximal phalanges for the index, middle, ring, and little fingers; the contact force of the proximal phalange; contact force of the metacarpal; and the contact force of the CMC (carpal metacarpal) for the thumb.

SAS 9.1 (SAS Institute Inc.) was used to perform analyses of variance (ANOVA) followed by Tukey's studentized range test at a significance level of 0.05 for each dependent variable.

3 Results

The main effects of the hand posture ($p < 0.0001$) on the total forces on all the fingers were statistically significant. For all the participants, the total external forces by hand posture ranged from 11.87 N to 25.02 N. The highest external force appeared when participants held objects using the 5G hand posture (24.93%), followed by 5P (16.92%), 4P (15.24%), 3P (12.99%), and 2P (11.87%). The external force on the thumb increased as the number of fingers used increased. However, the external force on the index finger decreased as the number of fingers used increased, except for the 5G hand posture (Table 2).

Table 2. Pinch and grasp force on each finger and total force by hand posture

Finger	2P	3P	4P	5P	5G
Thumb	6.05	5.58	6.53	6.42	4.85
Index finger	5.82	3.70	3.05	3.13	5.44
Middle finger	–	3.71	3.25	3.14	5.59
Ring finger	–	–	2.41	2.54	4.79
Little finger	–	–	–	1.69	4.35
Total	11.87^{A}	12.99^{B}	15.24^{C}	16.92^{D}	25.02^{E}

*Alphabetic letters represent statistically significant groupings

The participants showed high external forces on the thumb for the 4P and 5P hand posture followed by 2P and 3P. The external forces decreased as the number of fingers used increased. The 2P hand posture showed the highest external force, followed by 3P, 4P and 5P. The external force on the middle finger was largest when participants held the object using the 3P hand posture followed by 4P and 5P. Overall, the external force on the middle finger decrease as the number of fingers used increased. For all the participants, the external force on the ring finger for the 4P, 5P and 5G hand postures range from 1.38 to 2.54 N. The external force on the little finger was largest when participants held the object using the 5G hand posture.

Table 3 represents the contribution of individual fingers to the hand posture. The thumb made the largest contribution when participants held objects in all the hand posture, followed by the middle, index, ring, and little finger.

Table 3. Pinch and grasp force on each finger and total force by hand posture

Finger	2P	3P	4P	5P	5G
Thumb	50.97	42.96	42.85	37.94	19.38
Index finger	49.03	28.48	20.01	18.50	21.74
Middle finger		28.56	21.33	18.56	22.34
Ring finger			15.81	15.01	19.14
Little finger				9.99	17.39
Total	100	100	100	100	100

4 Discussion

The hand postures were more important for the external forces on the thumb and fingers. The participants produced force evenly in all the fingers when they held objects using the 5G hand posture. Because the 5G hand posture yields a larger contact area with the object surface, the larger contact area therefore may facilitate a more precise force control capacity [5].

The thumb made the largest contribution when participants held objects in all the hand postures, followed by the middle, index, ring, and little fingers. The thumb produces the equilibrating forces on the opposite side of the object. In addition, the force produced by individual fingers decreased as the number of fingers used increased. In addition, the force produced by individual fingers decreased as the number of fingers used increased. In conclusion, the hand posture difference was also evident in the distribution of the individual finger force. That is, when an object was held without the little finger, the little finger's proportion of the force was distributed among the other finger.

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Investigation of Musculoskeletal Symptoms and Associated Risk Factors in the HORECA Sector

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Abstract. This cross-sectional study aimed to identify the prevalence of musculoskeletal symptoms and quantify the associated risk of MSDs development among workers in two sections of a Portuguese enterprise integrated in the HORECA sector. Rapid Upper Limb Assessment (RULA) was the method used to quantify the risk associated to MSDs development. The Chi-square test and Cramer's V coefficient were used to assess associations between variables (demographic/work-related characteristics) and the prevalence of complaints (in each body region assessed) or the pain level of the working situation. Considering the RULA results, the risk for the development of MSDs is present in all tasks and in both assessed sections suggesting that investigation and adjustments in the work situation are relevant. In general, there were no statistically significant associations between variables (demographic/work-related characteristics) and the prevalence of complains (in each body region assessed) or the pain level of the working situation.

Keywords: Risk assessment · Musculoskeletal Disorders (MSDs) · RULA · HORECA sector

1 Introduction

The hotel, restaurant and catering (HORECA) sector is a major part of the European economy. It is an important job creator both in the service sector in many EU Member States [1, 2]. According with the same sources, the HORECA sector, in 2004 provided jobs for nearly 7.8 million people, which represent 4% of the total employment in the EU-25. These numbers highlight the importance of the sector in the economy as a whole, considering that the employment growth rate in 2003/04 was 3.4% higher than in the overall EU economy [1].

Workers in the HORECA sector may experience fatigue and discomfort when performing highly repetitive tasks, working in repeated or sustained awkward postures, performing heavy physical work, and using forceful exertion. Continued work under

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these conditions may result in chronic injuries to muscles, tendons, ligaments, nerves, and blood vessels, which are known as work-related Musculoskeletal Disorders (WMSDs) [3]. In other words, WMSDs are pain disorders of muscles, bones, nerves, tendons and other soft tissues due to workplace activity. WMSDs are responsible for morbidity in many working populations and are known to cause significant occupational problems with increasing compensation and health costs, reduced productivity, and lower quality of life [4].

Nowadays, WMSDs are a major occupational health issue in both industrialized and industrially developing countries and present a considerable socio-economic impact (as a result of the high cost to the injured worker, his or her family, employers, and society to a large extent) causing suffer, and often leading to permanent disability [5, 6]. Already considered the main occupational disease, WMSDs are affecting over 1/3 of the workers in Europe, which represent millions of people and consequently cost employers billions of euros [7]. Although the number of WMSDs is lower than in the rest of the economy sector (14.7 against 23.9 cases per 100 000 workers) in 2003; they represent 50% of the diseases in HORECA sector [1].

WMSDs are considered to be multifactorial and due to interactions between various risk factors, which result in conditions that vary across different occupations [7–9]. In the HORECA sector, WMSDs are associated with physical as well as psychosocial/organizational risk factors.

Considering the 3rd European Working Conditions Survey (EWCS), the physical workload is high: almost 55% of the EU-15 workers reported that their job involved pain or tiring positions, compared to 45% across all sectors; 43% said their job involved carrying or moving heavy loads (compared to 36% in total) and 64% reported repetitive hand or arm movements (compared to 56% overall) [10].

Consequently, MSDs are widespread in the HORECA sector [11]: ≈33% of the EU-15 workers report being affected by backache; around 20.3% report muscular pain in the neck, ≈11.5% in upper limbs and 17.6% in lower limbs. The same source reports that in the accession and candidate countries, 34% of HORECA workers report backache and the muscular pain in lower limbs is more common in the HORECA sector than elsewhere.

The high risk to develop WMSDs among HORECA workers could be explained by:

- prolonged standing and working in awkward postures;
- the work is physically demanding, stressful and involves long working hours.

Therefore, there are a number of risk factors that may contribute to the development of WMSDs. The most important physical ones are concerned with the postures adopted, the force levels exerted, the rates of repetition required and working for long periods without a break. As known, WMSDs may occur if any of these risk factors, either alone or in combination, overload the musculoskeletal system.

This cross-sectional study was conducted in two sections of a Portuguese enterprise integrated in the HORECA sector. The aim of this cross section study was:

- To determine Musculoskeletal Disorders (MSDs) prevalence among workers using a modified version of the Nordic Musculoskeletal Questionnaire (NMQ);

- To assess the level of ergonomic workplace risk factors by using the Rapid Upper Limb Assessment (RULA);
- To investigate the relationship between MSDs (in terms of the presence of complains, such as symptoms of pain or discomfort) and socio-demographic characteristics, job characteristics, and the pain level of the working situation.

2 Materials and Methods

2.1 Stages of the Study

This study comprised three fundamental stages, which are related with the 3 objectives of the study: Characterization of the Work Situations with focus in the prevalence of complaints (annoyance, discomfort and pain); MSDs risk characterization and Investigation of the relationship between MSDs and the risk factors assessed.

Characterization of Work Situations included characterization of both the operators and the two sections of a Portuguese enterprise integrated in the HORECA sector and task analysis, e.g., task identification and characterization. At the end, the prevalence of complains in terms of annoyance, discomfort and pain was assessed based in a self-reported symptoms questionnaire organized by body regions.

MSDs risk characterization included the application of Rapid Upper Limb Assessment (RULA) to find if the risk for the development of MSDs was present in the tasks or Sections assessed.

Investigation of the association between MSDs and the others variables assessed tried to find if they could be related.

2.2 Work Situation

This cross-sectional study was conducted in two section (Section I and Section II) of a Portuguese enterprise, which was located in Grand Lisbon area.

Section I is placed in COPA, the name used in Portugal to the dishwashing zone. It included the cleaning of the thick crockery (pots and pans,…) and the fine crockery (cutlery, plates,…).

Section II is placed in the Bistro Zone - the term used to described a restaurant/pub with small dimensions. It included customer service, replenishment of products on line and fast-food preparation.

A total of 51 employees work in these two sections, where 60% of the workers are females. In terms of age, these workers had an average of 33 years old (20–57 years) in section I and 26 years old (18–34 years) in section II, which is in accordance with the main characteristics' of the population in this economic sector. Considering the seniority, the average is 5 and 3 years old, respectively. In terms of work organization, these two sections work between 10:00 and 24:00 (Section I) and between 8:30 and 24:00 (section II) and the workers could have a work contract with 16/20/25/40 h per week. We identified a total of 10 sub-tasks in Section I and 14 sub-tasks in sections II to apply the RULA method. At the end, the results obtained were integrated as global Section results (by each section, respectively).

The work tasks performed within these two sections involve, as is usual in the HORECA Sector, prolonged standing and working in awkward postures, physical work demands, which involve stressful and sometimes long working hours. When the work environment was evaluated, awkward workstation design was sometimes observed, which could be responsible for the postures adopted.

2.3 Participants

Only 28 out of the 51 workers accepted to collaborate in the study. Out of these workers 57% (N = 16) integrate section I, 42% (N = 12) integrate section II and 70% (N = 20) were females. However, in section I there were much more females (81%) than males (17%) while in section II the proportion was more balanced (58% - female, 42% - male). Only three workers (who work in section I) had more than 35 years, which means that the population is young as is usual in this economic sector.

2.4 Data Collection

In this study, the data were obtained by direct and retrospective observation and with a questionnaire specifically developed for this purpose. For dimensional characterization of the workstations, several dimensions of the work surface and of the equipment were collected resorting to a measuring tape. Image and video recording of working postures resorted to a digital video recorder camera with 4 megapixel and 1920 × 1080 HD resolution - Sony HD ACHO Full HD1080 handycam 4.0.

The questionnaire was based on the Nordic Musculoskeletal Questionnaire and integrate the adaptation made by Serranheira et al. [9] and information provided by the company. The questionnaire was applied to identify key parameters for the workers' characterization, evaluate their perception of the real working conditions, as well as to identify self-reported symptoms of annoyance, discomfort and physical pain. The questionnaire has five sections. On the first section were integrated items to better characterize workers' gender, age, anthropometric data (height, weight, body mass index (BMI) …) dominant upper limb, and data that characterize the relationship with the organization (number of work hours worked per day/week, schedule type, practice of work breaks and second job,…). On the second section were integrated items to better characterize the workers' health, sport and physical activities, smoking habits, and presence of chronic illnesses. On the third section were integrated items to assess the workers' perception related to the task/subtask accomplished. For this purpose a Likert scale with 4 levels (where 1 means very low discomfort and 4 means unbearable discomfort) was used to assess the level of discomfort associate with each subtask, in each section. On the fourth section were integrated items to determine the presence of musculoskeletal symptoms, the respective frequency and intensity of pain. For these last two variables a four-level Likert scale was used (where, 1 means 1X per year/low intensity and 4 means more than 6X per year/very high intensity). Subjects were asked to answer about the musculoskeletal symptoms (annoyance, discomfort and physical pain) they had over the last 12 months and the last 7 days. Additionaly they were invited to mark them on the body discomfort chart and identify if they were prevented from carrying out the usual daily work (a 5-level Likert scale was used, where 1 means 0 (zero) days and 5 means all days). Symptoms of pain or discomfort were recorded as presence of pain. The last section integrate an open question where workers were invited to suggest changes to optimize their workplace.

To participate in this study a verbal consent form the operators involved was previously obtained. Workers filled in the 1st section of the questionnaire individually whereas the other sections were applied as an interview. In all cases, the confidentiality of data was guaranteed.

To quantify the risk associated to MSDs development the Rapid Upper Limb Assessment (RULA) method was used. As a criteria to select this method we considered [12]:

- It is a validated tool that assesses biomechanical and postural loading on the upper limb musculoskeletal system which is known to contribute to MSDs;
- It provides a method of screening a working population quickly for exposure to a likely risk of work-related upper limb disorders.

A complete description of the RULA method can be found in articles written by McAtamney and Corlett [13, 14].

In terms of methodology, RULA was applied considering the observation of frame-by-frame in each sub-task assessed. Each task was recorded during 10 min approximately. We opted by the assessment frame-by-frame considering the short length of the work-cycle duration, the high frequency of gestures and the rapid alternation between tasks as well. The right upper limb was the main limb assessed.

Due to time constraints, it was not possible to observe and to assess all the operators. Consequently, the selection of the operators was random and it depended on the operator that was in the shift in which the record/observation was being performed. Some operators were analysed during various tasks and others have never been analysed. For this reason, associations between the MSDs symptoms reported and RULA scores obtained could not be made.

Due to problems with some video records, it was not possible to assess all the tasks with RULA method.

2.5 Data Analysis

Data processing was performed with the Statistical Package for the Social Sciences (SPSS©) (version 22).

Descriptive statistics were used to summarize the socio-demographic data, job characteristics, the prevalence of complains and, the risk of MSDs development considering the RULA scores for the various body regions involved in each subtask assessed. Considering both, the sample dimension and the absence of differences, we decided to present the results for the whole sample instead of doing it by sections.

The Chi-square test and Cramer's V coefficient were used to assess associations between variables (socio-demographic/job characteristics) and the prevalence of complains (MSDs Symptoms) or the pain level of the working situation. In all cases, a significance level of 0.05 was adopted as a criterion to reject the null hypothesis. The Cramer's V interpretation adopted the following assumptions: 0–0.30, no association/to weak association; 0.31–0.70 a moderate association and 0.71–1.0 a strong association. Firstly, the association test was made for each work Section. Considering that no statistical significant association was found we opted to make all the others association tests for the globality of the sample (N = 28).

Table 1 shows the variables considered for the association tests. For associations between variables (demographic/work-related characteristics) and the pain level of the working situation the variable associated with pain (Global Pain Level (GPL)) was not considered.

Table 1. Variables (Socio-demographic and Work-related characteristics) used in the association Tests.

Socio-demographic	Work-related characteristics
• Gender (F/M) • Age: [18–24], [25–34], [35–44], [45–54], ≥ 55 • Seniority: [1–3], [4–6], [7–9], ≥ 10 • BMI: <18,5; 18,5–24,9; 25–29,9; >30 • Smoking (Yes/No) • Regularly exercise (Yes/No) • Medical history of systemic illness (Yes/No) • 2nd job (Yes/No)	• Work section (Section I/Section II) • Type of schedule (Fixed/Rotating) • Work breaks (Yes/No) • Weekly working time (h) (16 h, 20 h, 25 h, 40 h) • Global Pain level (GPL) (Low, Moderate, High, Very High)

The BMI variable was calculated considering weight (kg) and height (m) obtained from the workers.

The GLP variable was calculated considering the perception that worker had related to the task/subtask accomplished. This variable was defined considering the number of subtasks assessed in each Sect. (10 in section I and 14 in section II) and the level of discomfort associated with each subtask. Therefore, in Section I the values could variate between 10 $(10\,tasks \times 1)$ and 40 $(10\,tasks \times 4)$ and in Section II the values could variate between 14 $(14\,tasks \times 1))$ and 56 $((14\,tasks \times 4))$. Table 2 shows the criteria used.

Table 2. Global pain level by section.

Section	Global Pain level			
	1-Low	2-Moderate	3-High	4-Very high
I	10–17	18–25	26–33	34–40
II	14–24	25–35	36–46	47–56

The Action Level 2 of RULA method, which represents the final Grand Score RULA (GSR) equal to Score 3 or 4, was considered the level for which a high level of MSDs development is present. Scores A and B, available with RULA application, were highlighted. The first one assesses the biomechanical load considering how much the upper limbs (the upper arm, lower arm, wrist and wrist twist) are involved in doing the task and the second one assesses the biomechanical load considering the use of neck, trunk and legs. In all cases, we tried to understand the main reasons for obtaining such results considering the working postures and the working conditions involved (the frequency, the loads held and the amplitude of movements made).

3 Results and Discussion

3.1 Demographic Data and Job's Characteristics

In Table 3 it is possible to find the demographic details of the study participants and respective job characteristics.

Table 3. Socio-demographic and job characteristics, and their association to musculoskeletal symptoms (N = 28).

Independent variables (n)	MSDs symptoms		Statistics	Significant
	No (n = 4)%	Yes (n = 24)%		
Sector				
I (16) II (12)	12.5 16.7	87.5 83.3	χ^2 = .097, *df* = 1	$p > 0.05$
Gender				
F (20) M (8)	10 25	90 75	χ^2 = 1.05, *df* = 1	$p > 0.05$
Age (years)				
[18–24] (10) [25–34] (13) [35–44] (3) [45–54] (2)	20 15.4 0 0	80 84.6 100 100	χ^2 = 1.113, *df* = 3	$p > 0.05$
Body mass index				
Normal weight (22) Overweight (6)	9.1 33.3	90.9 66.7	χ^2 = 2.263, *df* = 1	$p > 0.05$
Medical history of chronic illnesses				
No (21) Yes (7)	19 0	81 100	χ^2 = 1.556, *df* = 1	$p > 0.05$
Regular sport/physical activity				
No (18) Yes (10)	16.7 10	83.3 90	χ^2 = .233, *df* = 1	$p > 0.05$
Cigarette smoking				
No (19) Yes (9)	21.1 0	78.9 100	χ^2 = 2.211, *df* = 1	$p > 0.05$

(*continued*)

Table 3. (*continued*)

Independent variables (n)	MSDs symptoms		Statistics	Significant
	No (n = 4)%	Yes (n = 24)%		
2nd job				
No (26)	11.5	88.5	$\chi^2 = 2.244$, $df = 1$	$p > 0.05$
Yes (2)	50	50		
Seniority(years)				
[1–3] (21)	14.3	85.7	$\chi^2 = 7.000$, $df = 3$	$p > 0.05$
[4–6] (2)	0	100		
[7–9] (1)	100	0		
≥ 10 (4)	0	100		
Type of schedule				
Fixed (14)	28.6	71.4	$\chi^2 = 4.667$, $df = 1$	$p > 0.05$
Rotated (14)	0	100		
Work breaks habits				
No (15)	13.3	86.7	$\chi^2 = .024$, $df = 1$	$p > 0.05$
Yes (13)	15.4	84.6		
Weekly working time (h)				
16 h (5)	20	80	$\chi^2 = .321$, $df = 3$	$p > 0.05$
20 h (14)	14.3	85.7		
25 h (1)	0	100		
40 h (8)	12.5	87.5		
Global Pain Level				
Low (17)	11.8	88.2	$\chi^2 = .522$, $df = 2$	$p > 0.05$
Moderate (10)	20	80		
High (1)	0	100		

Considering the socio-demographic data the age of participants ranged from 21 to 48 years (mean = 29 years; SD = 7.96 years). In general, the participants had:

- an average weight of 64.7 kg (SD = 11.5 kg; range = 46–94 kg);
- an average height of 168.3 cm (SD = 9 cm; range = 156–193 cm);
- an average BMI of 22.7 kg/m^2 (SD = 2.5 kg/m^2, range = 18.9 e 28.4 kg/m^2) where, 79% (22) of the operators have a Normal weight and 21% (6) have an Overweight.

Sixty-four percent of the operators reported that they were not involved in regular physical activities or sports. Those who practice physical activities regularly, were mainly males and the activities involved were: gym, walking, riding a bike, football, boxing, swimming and running.

Nearly one-third of the participants (32%) had smoking habits. It was also determined that 25% of them had a chronic health problem (70% of which worked in section II).

In terms of Seniority, the operators worked in their current job for 3 months to 10 years (mean = 3 years; SD = 3.48 years). This means that, 75% of the workers have

≤ 3 years' experience which is in accordance with the sector HORECA characteristics' where a high turnover level is usual.

Ninety-three percent of the operators reported not having a second job.

Considering the job characteristics, the average weekly working hours were 25.18 h (SD = 9.73; range = 16–40 h). Despite these results, 50% of the workers were working 20 h/week. In terms of work breaks, 46% of the participants take it on a regular base.

3.2 The Prevalence of Musculoskeletal Symptoms

The body region with the highest percentage of complains was the lower back (57.1%), followed by shoulders (35.7%), wrists (32.1%) and neck (29%) (Fig. 1a). It is possible to highlight that, in spite of a low percentage of complaints, the intensity, in the majority of the situations, ranged between moderate and very high (Fig. 1b). 75% of the complaints registered on the neck were found in section I. These results could be explained by the postures adopted where a continuous flexion of the neck was observed. The wrist was the only region with high intensity complaints, which could be explained by the repetitiveness of the movements associated with the tasks performed, in both sections. Nearly 50% of the complaints occurred 4–6 times/year in the majority of the regions assessed. The results also showed that the majority of the participants had not experienced MSDs over the last 7 days. Despite of these results, the pain level associated to their working situation was assessed between low (60.7%) and moderate (35.7%).

3.3 RULA Scores

Considering the RULA results, the risk for the development of MSDs is present in all tasks and in both assessed sections (GSR $\geq$ 3). These results suggest that investigation and adjustments in the work situation are relevant. Tables 4, 5 show the percentages of frames assessed with each RULA score for each sections, respectively.

For the majority of the tasks, the upper arms score, was ≥ 3 in sections I and II, with 64% and 73% of the cases, respectively. A result that was characterized by the upper arms being flexed between 45° and 90°, sometimes with a slight abduction or with a flexion higher than 90°. The lower arms' score, for the majority of tasks was ≥ 2 in sections I and II, with 64% and 90.5% of the cases, respectively, which reflect the need for operators to extend their arms across the midline of the body with elbow flexion above 100°. The wrist score, for the majority of tasks in section I, was ≥ 3 (76.6%) and, in Section II was generally equal to 2 (99.4%). These results reflect that in Section I the wrists were in $\geq 15°$ extension (sagittal plane) and sometimes with a radial or ulnar deviation. However, the wrists were in slight flexion/extension ($\leq 15°$), in section II.

The neck and trunk scores ≥ 3 for the majority of tasks also indicate a high proportion of neck and trunk flexion, more than 20° to the front and sometimes twisted or with a side bending.

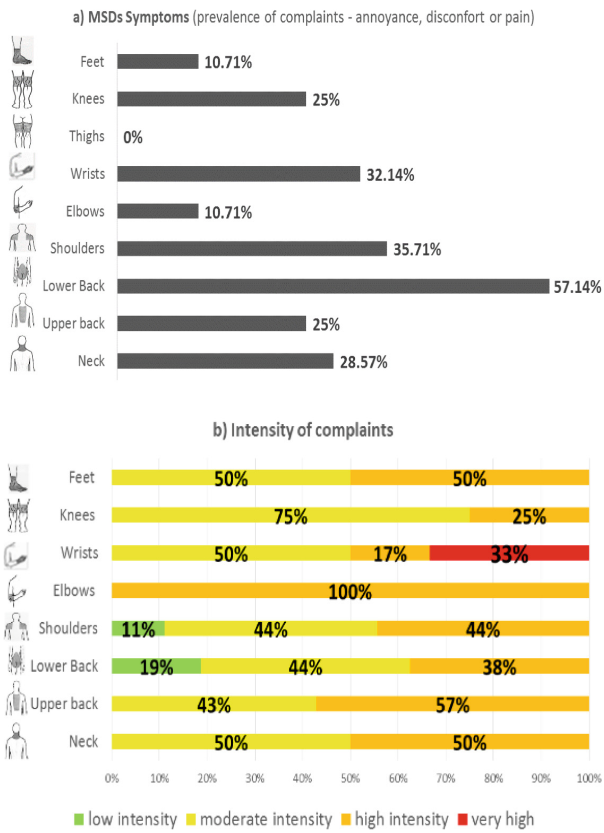

Fig. 1. (a) MSDs Symptoms (prevalence of physical complaints - annoyance, discomfort or pain) (b) Intensity of complaints registered, by each corporal regions assessed.

The most common postures of the legs were assessed to be neutral, which means there was no strain on the lower limbs.

The final Grand score RULA (GSR) ranged from a minimum of 3 (section I) and 4 (section II) to a maximum of 7 with an average value of 5.44 (SD = 1.08) and 6.19 (SD = 0.95) in sections I and II, respectively. These GSR indicate that employees' postures at their work stations need to be investigated and some changes are required soon or immediately.

For the majority of tasks (70.1%), in Section I, the GSR was determined to be 5 (25.3%) or 6 (44.8%), which indicates an action level of 3. The percentage of tasks with a final GSR at action level 4 was 6.4%. For the majority of tasks assessed (89%) in Section II, the GSR was determined to be 5 (5.1%) or 6 (38.3%) or 7 (45.65), which indicate an action level of 3 or 4.

None of the tasks assessed had a GSR of 1 or 2 (e.g. an acceptable working posture) in both Sections and GSR of 3 in Section II.

Table 4. Distribution of RULA scoring for section I (n = 3079 frames assessed for 7 tasks)

	RULA score								Mean (SD)
	1	2	3	4	5	6	7	8	
	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)	
Upper arms	35 (1.1)	1074 (34.9)	1446 (47)	503 (16.3)	21 (0.7)	–	n.a	n.a	2.81 (0.74)
Lower arms	967 (31.4)	1258 (40.9)	854 (22.7)	n.a	n.a	n.a	n.a	n.a	1.96 (0.77)
Hands/wrists	105 (3.4)	614 (19.9)	1968 (63.9)	392 (12.7)	n.a	n.a	n.a	n.a	2.86 (0.66)
Neck	238 (7.7)	814 (26.4)	1784 (57.9)	218 (7.1)	25 (0.8)	–	n.a	n.a	2.67 (0.75)
Trunk	188 (6.1)	669 (21.7)	1855 (60.2)	243 (7.9)	124 (4.0)	–	n.a	n.a	2.82 (0.75)
Legs	3079 (100)	–	n.a	n.a	n.a	n.a	n.a	n.a	1.00 (0.0)
Score A	–	–	956 (31)	1496 (48.6)	606 (19.7)	21 (0.7)	–	–	3.9 (0.72)
Score B	71 (2.3)	708 (2.3)	105 (3.4)	1818 (59)	114 (3.7)	30 (1.0)	208 (6.8)	25 (0.8)	3.73 (1.38)
GSR	–	–	253 (8.2)	281 (9.1)	778 (25.3)	1378 (44.8)	389 (12.6)	–	**5.44 (1.08)**

n.a - not applicable

3.4 Associations Between Socio-demographic/Job Characteristics and MSDs Symptoms or Pain Level of the Working Situation

In general there were no statistically significant associations between the MSDs symptoms and the variables (demographic/job characteristics) or the pain level of the working situation (Table 3). These results can be explained by the fact that the workers of these two sections joined the company not long time ago and they were mostly young and were not able to associate the perceived discomfort with the characteristics of the work.

Considering the importance that exposure time to adverse risks factors has on MSDs development (which was low, 75% had <3 years experience), and the high percentage of cases, with MSDs Symptoms (86%) reported, the low dimension of the sample may explain the obtained results. It is important to highlight that in all these cases the Cramer's V revealed a weak association (Cramer's V < 0.3).

Considering the association between Global Pain Level and demographic/job characteristics' variables, the only associations found were with Gender (χ^2(df (2) = 7.824 p = 0.008;), N = 28; Cramer's V = 0.529) and with Weekly working time (χ^2(df(2) = 12.302 p = 0.048;), N = 28; Cramer's V = 0.450) (Table 6).

Table 5. - Distribution of RULA scoring for section II (n = 3159 frames assessed for 12 tasks)

	RULA score							Mean (SD)
	1	2	3	4	5	6	7	
	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)	
Upper arms	–	840 (26.6)	1434 (45.4)	653 (20.7)	232 (7.3)	–	n.a	3.01 (0.87)
Lower arms	300 (9.5)	1131 (35.8)	1728 (54.7)	n.a	n.a	n.a	n.a	2.45 (0.66)
Hands/wrists	20 (0.6)	3139 (99.4)	–	–	n.a	n.a	n.a	2.99 (0.79)
Neck	–	1525 (48.3)	730 (23.1)	904 (28.6)	–	–	n.a	2.8 (0.85)
Trunk	–	642 (20.3)	2033 (64.4)	464 (14.7)	20 (0.6)	–	n.a	2.96 (0.61)
Legs	3045 (96.4)	114 (3.6)	n.a	n.a	n.a	n.a	n.a	1.04 (1.87)
Score A	–	–	310 (9.8)	2154 (68.2)	463 (14.7)	117 (3.7)	115 (3.6)	4.23 (0.82)
Score B	–	502 (15.9)	140 (4.4)	1423 (45)	170 (5.4)	630 (19.9)	294 (9.3)	4.37 (1.49)
GSR	–	–	–	345 (10.9)	162 (5.1)	1210 (38.3)	1442 (45.6)	6.19 (0.95)

n.a - not applicable

Table 6. Socio-demographic and job characteristics, and their association to Pain level (N = 28)

Independent variables (n)	Global Pain Level			Statistics	Significant
	Low (n = 17)%	Moderate (n = 10)%	High (n = 1)%		
Gender					
F (20)	50	50	0	χ^2 =7.824, *df* = 2	$p < 0.05$
M (8)	87.5	0	12.5		
Weekly working time (h)					
16 h (5)	40	40	20	χ^2 = 12.302, *df* = 6	$p < 0.05$
20 h (14)	85.7	14.3	0		
25 h (1)	0	100	0		
40 h (8)	37.5	62.5	0		

4 Conclusion

This cross-sectional study was conducted in two sections of a Portuguese enterprise integrated in the HORECA sector, where workers' and job factors' are in accordance with the general condition of that sector.

The prevalence of MSDs symptoms (particularly in the low back, shoulders, wrists and neck) among the operators assessed, in these two sections, sometimes with very high intensity of complaints, emphasises the need for ergonomic interventions for improving the working conditions. Nearly 50% of the complaints registered a 4–6 times/year frequency in most of the regions assessed. The results also showed that the majority of the participants had not experienced MSDs over the last 7 days.

The relatively high RULA scores in the study highlight a poor workstation design and suggests that in most cases the operators' postures need to be investigated and some changes are required soon or immediately. The high RULA scores obtained can also be explained by the type of work developed, which involves, in both sections, a lot of repetitive work and, in some situations, with considerable loads.

Despite of these results, the pain level associated to the working situations was assessed as low (60.7%), in the majority of the cases.

Considering the associations between the MSDs symptoms and the variables (socio-demographic/job characteristics) or the pain level of the working situation, no statistically significant associations were found. These results can be explained by the fact that the workers of these two sections joined the company not long time ago and they were mostly young and not able to associate the perceived discomfort with the characteristics of the work. Another reason for these results can be the small dimension of the sample.

Although no associations have been found, considering the presence of complains, some recommendations should be given to prevent the MSDs development. Some organizational recommendations are:

- reduce the number of working hours per shift or week;
- promote adequate rest breaks limiting the number of uninterrupted hours of work;
- redesign the workplaces considering good practices regarding manual handling of loads;
- workers should be trained regarding MSD risk factors, as well as on how to fit the workstation to their needs.

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Risk Assessment and Management

Investigation of the Effectiveness of European Assembly Worksheet in Assessing Organizational Measures for MSD Risk Assessment

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Abstract. MSDs have been shown to develop a high prevalence among working persons. Therefore the need to prevent working persons from developing MSDs has to assume even greater importance. Today, there are signs of a growing interest in reducing physical workload by applying organizational measures. However, there is an urgent need to provide appropriate ergonomic easy-to-use methods for business practice to investigate effectiveness of organizational measures. Today ergonomic methods seem to miss methodic assistance to address the investigation of organizational measures like job rotation or short breaks of production processes. We found that EAWS could not assess a decrease of workload by applying organizational methods. In future, an implementation of further organizational methods in work systems is expected due to the demographic change and an increase in the number of elder working persons, e.g. short breaks of production processes. Therefore, the need for an assessment of organizational methods will increase.

Keywords: Ergonomics · Job rotation · Task variation · Risk assessment

1 Introduction

Musculoskeletal disorders (MSD) are a common problem of many industrialized countries [1]. For example, in Germany MSDs are the main reason for most sick leave and second cause of early retirements [2]. Scientific research identified occupational risk factors like exposure to physical work with high workload and hazardous working postures for developing MSDs [3, 4], such as handling weights with back bent forward. Moreover, long-lasting static work has been identified as another risk factor which results in muscle fatigue and perceived discomfort [5]. Besides this, the current demographic change leads to an increase in the number of elder working persons. Due to changes of physical work capacity in older adults [5], MSDs have been shown to develop a high prevalence among working persons with an age of 50 years and older [6]. Therefore the need to prevent working persons from developing MSDs has to

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assume even greater importance. The assessment of working persons exposure to risk factors for developing MSDs has become a main part of the ergonomic improvement of work systems [4, 7]. Numerous methods have been developed for analyzing and assessing workload. A novel step was to use such methods as a tool for analyzing and assessing effectiveness of corrective measures which have been implemented in work systems to reduce workload. For example, well known ergonomic easy-to-use methods are the Ergonomic Assembly Worksheet (EAWS), the German Key Indicator Method or the NIOSH lifting equation.

Nowadays the ergonomic improvement of work systems is not limited to technical measures, such as adjusting work heights etc. There are signs of a growing interest in reducing physical workload by applying organizational measures [3, 8]. For example, job rotation is an appropriate organizational measure to prevent working persons from developing MSDs [9]. Furthermore, today manufacturing companies investigate the effectiveness of several organizational methods, such as short breaks of production processes. Nevertheless, research has shown that the effectiveness of organizational measures is highly dependent on determination of several factors. For example, Horton et al. reported rotation frequency and task order as main factors influencing the effectiveness of job rotation [10]. According to Bosch et al. optimal temporal patterns of work-rest schedules have to be designed with regard to worker performance and health when implementing short breaks in production process [8].

However, there is an urgent need to provide appropriate ergonomic easy-to-use methods for business practice to investigate effectiveness of organizational measures. Today ergonomic methods seem to miss methodic assistance to address the investigation of organizational measures like job rotation or short breaks of production processes.

Thus, the aim of this paper is the investigation of the methodological gap between ergonomic easy-to-use methods like (EAWS) and the latest research findings regarding job rotation. Based on these findings, it is discussed, how the methods can be adopted for better consideration of organizational conditions and for assessing corrective measures due to organizational changes, accordingly.

2 Method

2.1 Workload Assessment

In order to investigate the methodological gap between ergonomic methods and the assessment of effectiveness of job rotation we conducted a systematic analysis of physical workload in a German automobile manufacturing using EAWS.

The assessment of workload according to EAWS is based on a three-zone rating system. A point score represents the level of risk. The amount of the point score is determined by calculating the level of risk for musculoskeletal injury caused by awkward working postures, exceeded forces, weight handling and an additional section for assessing work environment and further working conditions. An amount of points up to 25 indicates a lower risk score. An amount of points between 25 and 50 points indicates a medium-sized risk. An amount of points above 50 points indicates a high risk [11].

The manufacturing process was analyzed by an observation of two shifts, each shift has a duration of 7 h 30 min. The whole production process is divided into different cycles, each cycle time is approximately 5 min. Within the entire manufacturing process 17 different cycles were analyzed. As an example, for our investigation we chose a sub-process of the entire manufacturing process which encompasses three cycles. The manufacturing activity of these cycles includes the installation of a trunk lid. Therefore, working persons need to work at a moving object. The observation revealed that working persons mainly spent their time in working postures, which are characterized by back bent forward and arms above shoulder level. In addition, working persons have to carry adjusting devices weighting 10 to 15 kg, mainly in an upright body posture. Furthermore, working persons have to place and to fix a boot trim, therefore a strength of 60 N is necessary while working persons are in a back bent forward body posture.

2.2 Task Variation to Reduce Workload

In order to investigate the methodological gap between ergonomic methods and the assessment of effectiveness of job rotation we started a simulation-based approach to reduce physical workload. Therefore, three different job rotation schedules were developed with regard to the following well-known recommendations to reduce workload. Schneider et al. reported that different body regions should be used after job rotation [12], Leider et al. 2014 and Horton et al. 2015 discussed the influence of rotation frequency and task variation on effectiveness of job rotation [13, 14]. Considering these recommendations, a compensatory task was created where working persons performed a sedentary activity without any physical demands, e.g. quality control. For our investigation, we supposed a daily work period of 7 h and 30 min. The first rotation schedule did not include any task variation so working persons performed the described assembly work for 7 h and 30 min. The second rotation schedule included one task variation per day so working persons performed the described assembly work for 6 h and the described sedentary activity for 2 h. The third rotation schedule included one task variation per day as well so working persons performed the described assembly work and the described compensatory task for 3 h and 45 min, respectively. An assessment of workload per day was conducted using EAWS for each rotation schedule.

3 Results

Previous studies investigated the effectiveness of eliminating or reducing workload using different job rotation schedules [13, 14]. In our study, missing methodic assistance to address the investigation of organizational measures like job rotation for business practice was analyzed.

Figure 1 shows the results of our workload assessment for three different job rotation schedules. A risk score of approximately 30 points indicates a medium-sized risk. EAWS recommends a redesign of workplaces considered as medium-sized risk. As can be seen on Fig. 1 the score for the assembly workplace without job rotation results in 33 points. A rotation after 6 h to our sedentary work place without perceived physical exertion results in 32 points. A rotation after 3 h and 15 min results in a score of 28 points.

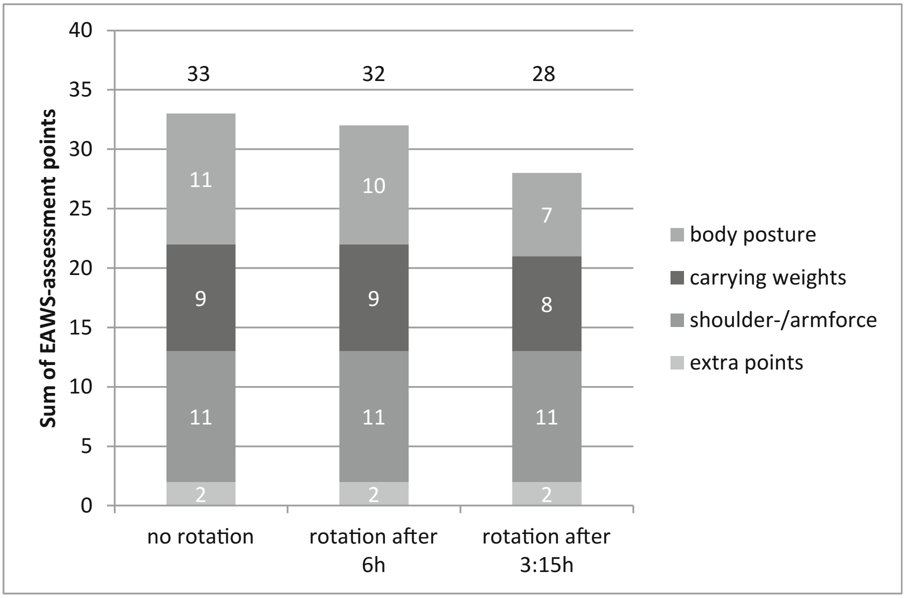

Fig. 1. Workload assessment of assembly activity and sedentary activity for three different job rotation schedules.

The influence of job rotation on the assessment results of workload is extremely low. A 50% reduction of work time at the assembly work place (no rotation vs. rotation after 3 h and 45 min) reveals a risk reduction of approximately 15%. Comparing the results for the three different rotation schedules only reveals a risk reduction for body posture and carrying weights. A decrease of time spent in awkward working postures results in a decrease of 35% of EAWS assessment points in the working posture category.

4 Discussion

Prior work has documented ambiguous results in Studies on effects of job rotation on workload. Luger et al., for example, report that effects of temporal variation and activity variation of work tasks on muscle activity and perceived discomfort are not very clear [15, 16]. However, thought should be given to the evaluation of effects of job rotation on workload. Previous studies evaluated effects of job rotation by rating workload of work groups. It was found that exposure to high workload decreases if workers who usually perform activities of high workload rotate to activities of lower workload. But this effect is at the expense of an increasing workload for workers who usually perform activities of low workload and rotate to activities of higher workload [14]. Since job rotation is not a method to eliminate workload but to reduce exposure time to workload an evaluation of workload should be done not only by investigating group levels of risk.

In this study, we investigated assessment results of workload applying EAWS for three different job rotation schedules. A decrease of exposure time to several risk factors in our investigation is evident: long lasting standing positions are compensated by terms of a sedentary activity, carrying of weights is compensated by levels of low workload. Since these job rotation schedules consider the characteristics of tasks workers are not exposed to activities with the same risks. In accordance to Yoon et al. and Schneider et al. our job rotation schedules avoid the development of cumulative workload by the use of different body regions after job rotation [9, 12]. Besides EAWS assessment decreases by five points if a rotation takes place after 3 h and 45 min. Compared to these findings it can be said that EAWS is an inadequate method for assessing job rotation schedules. A risk reduction of five points or 15% is disproportionate to the reduction of exposure time to risk factors. In our study the reduction of exposure time to high demanding assembly activities is 20% and 50% respectively.

However, some limitations are worth noting. It has to be taken into account, that EAWS originally was not developed to assess organizational measures like job rotation. EAWS was designed to serve as an ergonomic screening tool for clocked work [11]. An investigation of the effectiveness of job rotation schedules has to be implemented in the methodological procedure. The aim of our study was to show the methodological gap between ergonomic easy-to-use methods like EAWS and the assessment of job rotation. The application of EAWS in the intended context should not be restricted by our findings.

Nevertheless, job rotation is a widely-used method in business practice to prevent workers from developing MSDs [17]. Therefore, our investigation emphasizes the need for developing methods to assess workload regarding organizational measures like job rotation. Conceivable solutions to the problem could be an implementation of factors to minimize assessment points for body postures or weight handling if job rotation is applied. In line with the requirements for an effective decrease of workload future methods should offer opportunities to investigate consideration of these requirements during the development of job rotation schedules.

5 Conclusion and Outlook

Prior work has documented the effectiveness of job rotation to prevent working persons from developing MSDs [9, 10]. Yoon et al., for example, report that job rotation is appropriate for reducing exposure time to risk factors like workload on same body regions [9]. However, ergonomic easy-to-use methods are inappropriate to assess effectiveness of organizational methods for reducing workload like job rotation. In this study we investigated the influence of job rotation on EAWS assessment results. We found that EAWS could not assess a decrease of workload by applying organizational methods.

In future, an implementation of further organizational methods in work systems is expected due to the demographic change and an increase in the number of elder working persons, e.g. short breaks of production processes. Therefore the need for an assessment of organizational methods will increase. Nevertheless it has to bear in mind that organizational methods like job rotation could not decrease the physical workload in work systems and have no effect on peak load [18]. Organizational methods are qualified for an optimization of the distribution of workload. For that reason job rotation should be considered as part of a set of methods to prevent working persons from developing MSDs.

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Analysis of Exoskeleton Introduction in Industrial Reality: Main Issues and EAWS Risk Assessment

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Abstract. Exoskeletons are part of the technological and organizational innovation sought by the fourth industrial revolution to support and re-launch the manufacturing area. In the present study, we described the experimental protocol designed to test the usability and acceptance of an upper limbs passive exoskeleton. In total, 42 workers from FCA plants volunteered to participate in the research study. The testing campaign included static and dynamic tests aimed at evaluating the potential benefit of the exoskeleton (lessen muscle strain, higher comfort rating and dexterity) vs. possible restrictions to movements and work-device interactions in tasks resembling work activities. Open questions remain on how to assess the biomechanical workload risk, especially in the design phase, for which holistic methods like EAWS are needed.

Keywords: Passive exoskeleton · Upper limbs · Human-robot cooperation · Fourth industrial revolution · Usability · Workload

1 Introduction

The fourth industrial revolution faces the challenge of European industry growth with new policies to re-launch the manufacturing area, through technological and organizational innovation. Technological evolution has progressed from automated systems to human-robot collaboration, in which the human and the robot combine into one integrated system under the control of the human. The scope is to safeguard the worker's wellbeing while optimizing productivity and system performance.

An exoskeleton is a wearable device in which the physical contact between the operator and the mechanical structure allows a direct exchange of mechanical power and information signals [1–3]. The exoskeleton technology has originated from the military [4, 5] and rehabilitation [6, 7] fields and is now rapidly growing in industrial settings. Here exoskeletons could be useful when other preventive measures are not feasible or effective (i) to lower worker's fatigue, thus leading to increased worker's alertness, productivity and work quality, (ii) to support quality and experienced

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personnel in the work force longer, and (iii) to reduce work related musculoskeletal disorders [1].

Exoskeletons for industrial applications include upper limb and back supports, to reduce the load on the shoulder and back muscles while holding awkward postures. Chairless chairs, that can stiffen and lock in place, aim at decreasing the fatigue of crouching or standing in the same position for an extended period, while powered exoskeletons are designed to enhance the strength and the resistance to fatigue in stressful jobs. These exoskeletons, either passive or active, require different approaches towards fulfilling requirements such as usability, acceptability at the workplace and potential safety issues [8–10]. Literature studies generally look into the variation in the EMG level of the primary muscles involved in analyzed activity, to suggest a possible reduction in the overall muscle work when using an exoskeleton [11–15]. However, very few research projects and validation activities have been carried out concerning the estimation of the biomechanical load in exoskeleton-assisted work tasks and the potential impact of exoskeletons for the risk assessment and the work methods. In addition, evaluation studies on existing exoskeleton prototypes are often limited to laboratory trials on university students or staff [16–19]. Only in [12], a passive lift-assist device is tested in an automotive manufacturing plant with operators.

Testing protocols usually involve a repeated measure type experimental design, including within-subject comparisons of without and with exoskeleton use. Usability studies run on non-workers may suffer from a bias, since they lack the perception and acceptance assessment of the intended user. Introduction in the work environment brings in further constraints in the exoskeleton architecture and devices, nature of coupling to the human and user's acceptability.

Following a literature search and benchmarking of available commercial devices, FCA has planned a testing campaign to evaluate the applicability, usability and implementation of a passive upper-limb exoskeleton in working tasks. In total, 42 workers from FCA plants volunteered to participate in the research study. The paper illustrates the main aspects of the testing campaign. Potential issues associated to the implementation of this device in the automotive industry and to the biomechanical load estimation in exoskeleton-assisted work tasks are briefly addressed.

2 Experimental Protocol

2.1 Passive Exoskeleton

In the study, the Levitate exoskeleton [20] was used as presented in Fig. 1. This passive upper-limb exoskeleton aims at supporting the arms of workers exposed to repetitive arm motion and/or static elevation of the arms. The exoskeleton consists of a metallic frame for the core and two armrests for the upper arms (elbow and fore harm are not interested) and can be worn like a backpack. Mechanical passive elements along the arms partially support the upper limb muscles and shoulder joints. The support progressively increases when raising the arm. The exoskeleton can be custom-fit by regulating length of the core metallic frame, size of the armrests and shoulder and waist straps, to ensure comfort and optimal performance.

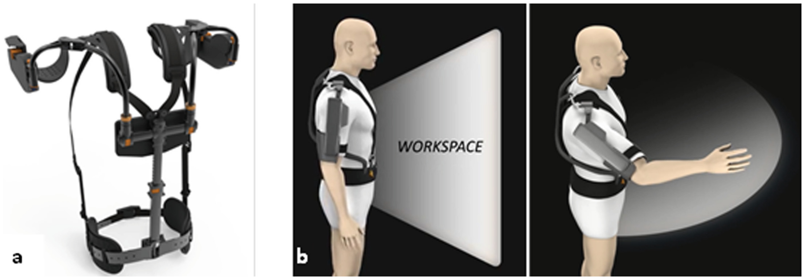

Fig. 1. The Levitate passive upper-limb exoskeleton (images available at: http://www.levitatetech.com; accessed 02/03/2017).

2.2 Participants and Procedure

The experimental campaign was conducted at the ergonomics laboratory (ErgoLab) of FCA Manufacturing Engineering and included static and dynamic tests to be performed without and with the exoskeleton. In total, 42 healthy male FCA operators volunteered for the research study. Workers were identified based on their anthropometry in order to fit the specification of the exoskeleton prototype. The tester we used was a medium size, corresponding to P50 American male, classical percentile approach. Other inclusion factors include no limitation in strength or musculoskeletal disorders at the upper limbs. Participants were informed in full detail about the aim and nature of the study and they signed an informed consent. The measurements were carried out in accordance with the Declaration of Helsinki.

Upon arrival at the lab, the worker was introduced to the working principles of the exoskeleton. Personal data and anthropometric measurements were collected to fill in the database and to regulate the exoskeleton as for lengths and choice of the mechanical passive element characteristics. Participants performed the tests, without and with the exoskeleton, in the same day and were video recorded using a frontal and lateral camera. Between tests, they were given an adequate time to rest and were allowed to familiarize with the device before they were asked to repeat the tests with the exoskeleton.

At the end of each task, both without and with the exoskeleton, a cognitive ergonomist held a semi-structured interview with the worker, aimed at understanding the quality of the interaction with the device. Other tools included the Borg Scale [21], to quantify the intensity level of the activities as perceived by the subjects when tasks were performed without and with the exoskeletons, a usability metrics questionnaire and a TAM 2 questionnaire [22], to analyse the technology acceptance in relation to perceived ease of use and perceived usefulness. In a final focus group, the moderator involved workers in discussing on the use of exoskeleton, focusing on positive and negative aspects in relation to their work context, and on the desirable characteristics of the device.

2.3 Tasks

The experimental campaign included two phases. The first phase saw the participation of 31 male FCA operators. Participant mean height and mass were 174.9 cm (SD ± 2.3 cm) and 81.6 kg (SD ± 9.1 kg), respectively. Mean age was 51.5 y (SD ± 4.7 years). Two workers were discharged because their anthropometric measures did not fully comply with the exoskeleton size. Full description of this first phase of the testing campaign is reported in [23]. The three tasks were designed for this first phase:

1. A *static task*, conceived as an endurance test to evaluate the potential benefit of the exoskeleton on the onset of muscular fatigue during a static action. Workers were required to stand upright with extended arms (90° with respect the trunk) while holding a 3.5 kg car spoiler, placed on the forearm so to exclude the wrist. The end of task was set at subject's will or because of a significant change in posture.
2. A *repeated manual material handling task*, developed from the FIT- HaNSA "Waist up" Protocol [24] to evaluate the potential benefit (lessen muscle strain) of the exoskeleton during a manual material handling activity vs. possible restriction to movements. While standing, subjects had to lift up/back down a 3.4 kg mass from waist level to shoulder level, following the beat of a metronome (30 actions/min). The end of task was set at 600 s. However, subjects could stop before time if experiencing fatigue, discomfort or if going off cadence three times.
3. A *precision task*, resembling a sealing operation, developed to evaluate the potential benefit of the exoskeleton (lessen muscle strain, higher comfort rating and dexterity) during a precision task involving a significant static load on the shoulder joint. The subject was standing, with the predominant arm almost extended, and used a felt-tip pen to trace a continuous wavy line between two pre-market traces on a paper fixed on a billboard. Subjects had to complete five different rows, containing 27 arches each, from shoulder height to an overhead position, without removing the felt-tip pen from the billboard. They could stop before the end of the billboard if experiencing fatigue or discomfort.

   In the second phase of the testing campaign, 11 FCA team leaders were selected to run additional tests. Participant mean height and mass were 177.2 cm (SD ± 5.0 cm) and 81.1 kg (SD ± 7.3 kg), respectively. Mean age was 45.8 y (SD ± 6.9 years).

   Team leaders possess a wider knowledge of the different work activities performed by different workers and are usually involved in the work methods and work organization. Subjects were initially asked to perform the *static task* and the *precision task* developed in the first phase and described above. These additional tests ensure a larger data set and allow confirming what observed on the first 31 workers.

   The team leaders were then asked to carry out extra tests, conceived to simulate real-work tasks, for which the subjects are adequately trained. The tests focused on the following operations:
4. *Mounting the clips of brake hoses underbody*. While standing with arms above head, subjects had to insert and remove 14 clips underbody (Fig. 2).

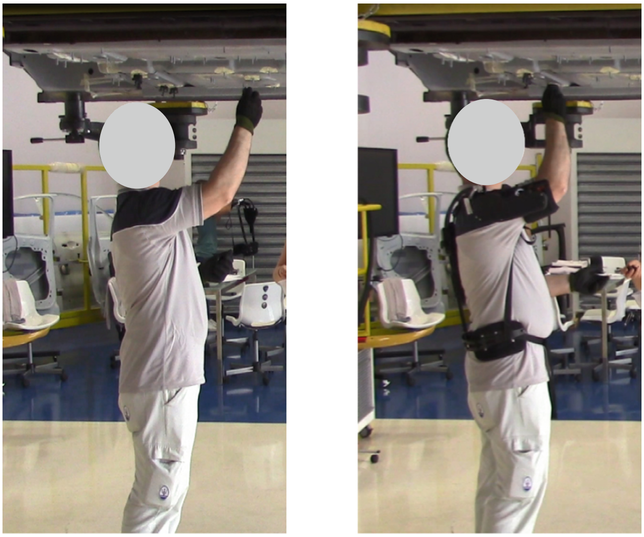

Fig. 2. Mounting the clips of brake hoses underbody without and with exoskeleton

5. *Sealing underbody using the sealing gun*. While standing with arms above head, subjects had to use the sealing gun to complete a 10-m close loop for as long as he can endure (Fig. 3).

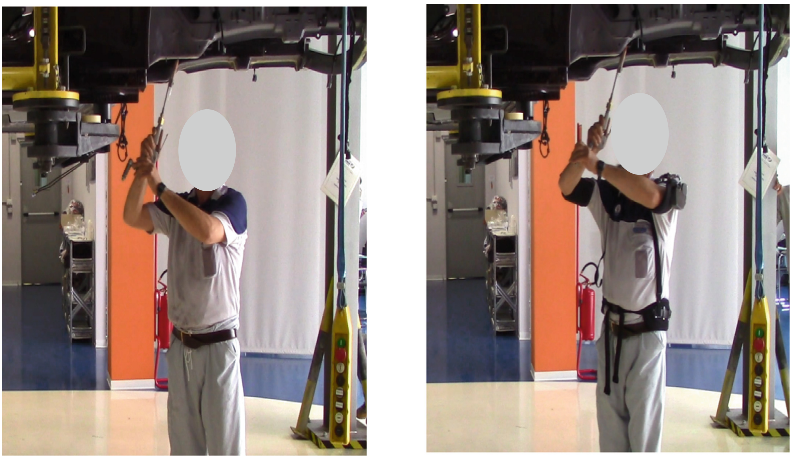

Fig. 3. Sealing underbody using the sealing gun without and with the exoskeleton

These first two tests mainly addressed prolonged awkward arm postures that could emerge from underbody work. The posture is cumbersome and subjects knew they could stop any moment if experiencing any fatigue or discomfort.

6. *Mounting the seal on the rear door*. While standing, subjects had to assemble and disassemble the seal on the rear door (no roll forming) using both arms. The complete task was to be repeated twice. The altimetry of the car frame was chosen so that subjects carried out the task between shoulder and knee height (Fig. 4).

Fig. 4. Mounting the seal on the rear door without and with the exoskeleton

The mounting task was conceived to investigate the effective activation and deactivation of the exoskeleton through repetitive movements that involve a wide range of motion of the arms as well work to be performed with the hands at or below waist level, beneath the area of intervention of the exoskeleton.

3 Results and Discussion

Quantitative and qualitative parameters were analysed according to the main aim of the test. In endurance tests, posture maintenance was monitored during the trial as well as by visually inspecting the recorded video images. A comparison of the postures without and with the exoskeleton was assessed, with particular attention to the arms and the spine. No substantial differences were found.

Table 1 reports mean and standard deviation values of the endurance time registered for the static task for the 11 team leaders, without and with exoskeleton. The time variation interval ($\Delta t = T_{EXO} - T_{NO\_EXO}$) and the relative variation ($\Delta t\% = (T_{EXO} - T_{NO\_EXO})/T_{NO\_EXO}$) are also reported. The time variation Δt is very similar to the 62.3 s registered for the 31 plant workers [23], while the relative variation $\Delta t\%$ outgrows the 31.1% registered for the 31 plant workers due to a lower T_{NO_EXO}.

Table 1. Results of the static task

	T_{NO_EXO} [s]	T_{EXO} [s]	Δt [s]	$\Delta t\%$
Mean	156.5	222.9	66.5	52.5%
SD	±86.1	±110.0		

Table 2 reports the number of arches traced by the team leaders without and with the exoskeleton, as for mean and standard deviation. The increase in the number of traced arches with the exoskeleton is rather significant, even though there is a ceiling effect, since many participants were able to complete the 135 arches when wearing the device. When the percentage increment is computed only on those participants who did not complete the arches, it increases to 34.0%, in line with the percentage increment of 33.6% observed for the 31 plant workers [23]. The level of precision increased with fewer portions of the wavy lines falling outside the pre-marked traces.

Table 2. Results of the precision task

	No arches NO EXO	No arches EXO	Δ No arches	Δ% No arches
Mean	108.3	127.3	19.0	17.5%
SD	±31.7	±18.1		

The positive outcomes on increased endurance time and precision level were confirmed for mounting the clips and sealing underbody. Workers positively judged the exoskeleton and declared it helped them to carry out the tasks with less physical and mental effort, although they recognized the posture was still awkward and luckily not common in real work tasks.

In the mounting task, operators complain potential interference of the exoskeleton with the car frame. Also, the coupling between the worker's arm and the device was not always effective in the wide range of movements of the arm requested in the task. Some participants reported some difficulties when working with the hands at or below waist level, due to the force they had to exert to maintain the posture against the device. As expected, introduction in the work environment brings in further constraints in the exoskeleton architecture and devices, nature of coupling to the human and user's acceptability (Fig. 5).

Fig. 5. Potential interference of the exoskeleton with the car frame

In all, workers judged positively the exoskeleton and declared it helped them to carry out the tasks with less physical and mental effort. The device was perceived particularly useful in tasks requiring raised-arm postures and when precision was involved. In the "reaction adjectives" questionnaire, workers chose positive adjectives to describe qualities like easy to use, innovative, easy to understand, effective, efficient, and useful. In the usability metrics questionnaire, the positive characteristics had high score (>4) implying a good human-device interaction, but, on the other hand, operators considered the work-device interaction critical.

TAM2 results showed that workers assigned high values (>4) to items that refer to perceived ease of use and voluntariness, while they assigned low values (<4) to items connected with intention to use, image and job relevance. Focus group results were similar: workers affirmed that the exoskeleton can be useful in carry out work activities, but the use should be on a voluntary-base.

Before adoption in real work environments, more information on worker's acceptance of the devices and long-term use is needed. Industry experience can reveal obstacles to worker's acceptance that are not evident in a controlled laboratory environment. Also, the introduction of such devices requires a deeper understanding of the biomechanical workload in exoskeleton-assisted work tasks and of how to appropriately evaluate the impact of exoskeletons on safe physical works. Holistic risk assessment methods, like EAWS [25], are required to specifically address the risk factors influenced by the use of passive exoskeletons like posture, in this specific case the posture of the shoulder, request of force and static muscle effort.

4 Conclusions

In summary, the present study demonstrated that passive upper-limb exoskeletons may assist workers in activities that involve prolonged raised-arms working postures. In total, 42 workers from FCA plants participated in the research study. It was found that, by wearing the exoskeleton, participants increased the endurance time and the level of precision (when applicable) in the task execution. Positive feedbacks also emerged from the workers' interview, who chose positive adjectives to describe qualities for the exoskeleton such as easy to use, innovative, easy to understand, effective, efficient and useful. Still, during the focus group, workers affirmed that the use of the exoskeleton should be on a voluntary-base.

The positive outcome of this first experimental campaign opens to interesting next steps but also to questions concerning the potential impacts of these devices in the work environment. Further research should be conducted concerning the issue of the biomechanical load estimation in exoskeleton-assisted work tasks and how exoskeletons may affect the risk assessment and work methods.

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A Successful Ergonomic Solution Based on Lean Manufacturing and Participatory Ergonomics

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Abstract. This project was developed in a 1,500-employee multinational metallurgical factory. A multidisciplinary team of certified ergonomists, engineers, managers and direct employees used concepts of Participatory Ergonomics and Lean Manufacturing methodology to develop a workstation improvement project of large subsets, where male and female employees, simultaneously, handle large parts 96 times per shift. This study was structured in seven steps: (1) Identification of the problem; (2) Problem specification through ergonomic assessment using RULA and observational method; (3) Problem analysis, added-value classification and determination of causes; (4) Action Plan; (5) Implementation; (6) New ergonomic analysis; (7) Validation of results. The results are significant for the employees and company: the working procedure was suitable for both men and women, it eliminated unnecessary activities, it reduced costs and lead time as well as it maintained the health and safety of workers.

Keywords: Lean Manufacturing · Macroergonomics · Participatory Ergonomics · RULA assessment · Value adding and non-value adding activities

1 Introduction

Several articles in the literature in Macroergonomics provide evidence of the success of ergonomic interventions and their positive impact on workers and businesses [1–4].

The main purpose of an ergonomic intervention it to design or adapt the workstation to the worker. The results of such interventions may be: 1. gain in worker health; 2. satisfaction of the worker; 3. optimization of the production process; 4. gains in productivity and 5. improvement in product quality [5]. There is a direct link between satisfaction of the employee at work and satisfaction in his/her personal life [6]; this fact is closely related to what we experienced in this study. However, it is necessary to point out that Participatory Ergonomics is an area within Macroergonomic methodology.

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According to Hendrick and Kleiner [7] Macroergonomics is the perspective, methodology and subdiscipline of Ergonomics that prioritizes the technology of human-organization interface. The goal of Macroergonomics is to optimize work systems, including the participation of those involved (empowerment) in the several hierarchical levels, enabling continuous improvements within the production process.

Under the practical perspective, Macroergonomics can be understood as: 1. top-down (since it requires the involvement of the company's board of directors); 2. bottom-up (for being of participatory character) and 3. middle-out (focus on the production process) [8].

Participatory Ergonomics is the most commonly used approach of the Macroergonomics field because it has produced extremely satisfactory results and it has, therefore, assisted in the dissemination of the field of Ergonomics in companies [8].

The concept of Participatory Ergonomics is proposed by several authors in different ways, however, these definitions complement each other. Participatory Ergonomics can be understood as a Macroergonomic approach that requires the involvement of workers in the implementation of new technologies in the organizational system [9]. Another definition is the involvement of people from different areas of the company in planning or re-planning their work activities; these people possess enough technical and scientific knowledge to influence the process in order to achieve the expected results [10].

This study is based on Macroergonomics and Participatory Ergonomics as well as on the Lean Manufacturing Methodology. Because one of the main goals of Ergonomics and Lean Manufacturing is the continuous improvement, the objective of this research was to demonstrate that this can be achieved without compromising the safety of health of the workers, generating, consequently, gains for the production process. According to Koukoulaki [11], Lean Manufacturing can be conceptualized as the strategy that generates internal flexibility to meet customer requests and eliminate wastes in the production process. There are excellent articles and books that discuss the conceptualization of the Lean Manufacturing methodology. Thus, we will focus on this article to report the practical results of our intervention, based on Lean Manufacturing and Participatory Ergonomics in a multinational metallurgical company.

It should be noted that a multidisciplinary team, including a certified ergonomist, an occupational safety engineer, a process engineer, a manufacturing manager and workers, was involved in this study of continuous improvement and it received support by the company's board of directors.

2 Methods

2.1 Study Setting

This study was developed in a multinational metallurgical company that employs 1,500 workers. The company has two work shifts, the first shift is from 7:00 a.m. to 4:48 p.m., and the second shift from 4:48 p.m. to 1:55 a.m. from Monday through Friday.

2.2 Participants

Because this was a study of continuous improvement aimed at the production process, there was no need to establish inclusion or exclusion criteria for the participants.

The ergonomic intervention directly benefited a total of 8 workers, that is to say, those who perform the activity. Moreover, the intervention indirectly benefited 22 employees, totaling 30 workers involved in the production of the sets.

2.3 Demand for the Study

The initial demand of the project that resulted in this study was to apply the Lean Manufacturing methodology associated with the Participatory Ergonomics approach in the assembly and welding of four reinforcements of a 133-kg steel plate (Fig. 1). Before the intervention, two workers, male or female, had to lower the plate simultaneously. The process of welding the reinforcements of the subset required the workers to irregularly move the pieces 96 times in the work shift (six handling per subset - four subset per final product - four final product per shift).

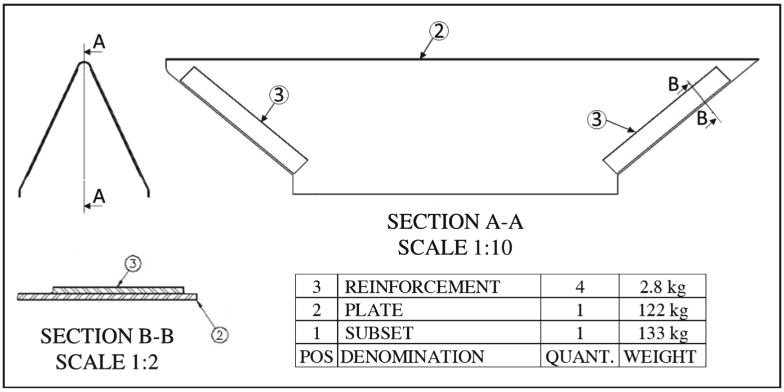

Fig. 1. Technical drawing of the subset.

2.4 Procedure

This study was structured in the following seven stages:

1. Identification of the problem; 2. Problem specification through ergonomic assessment using RULA and observational method; 3. Problem analysis, added-value classification, and determination of causes; 4. Action Plan; 5. Implementation; 6. New ergonomic analysis; 7. Validation of results.

Step 1 - Identification of the Problem. The surveyed company possesses an Ergonomics program coordinated by a certified Senior Ergonomist who performs ergonomic analyses of work in a preventive way. The purposes of those analyses are to identify work situations presenting room for improvement and verify the compliance of the work stations with the Brazilian regulatory norm (NR-17) of the Ministry of Labor and Employment [12].

The company holds monthly meetings in which ergonomic reports are presented to an Ergonomics committee, represented by employees from different areas of the company. In one of these meetings, the presentation of an Ergonomic Analysis of Work (E.A.W.) containing images and videos of the workplace allowed the participants to identify the need for improvement in the welding of the subset reinforcements.

Step 2 - Problem Specification through Ergonomic Assessment. RULA (Rapid Upper Limb Assessment) instrument was chosen to assess the ergonomic issues involved in the performing of the welding of the subset reinforcements. RULA, which is a “screening tool that assesses biomechanical and postural loads on the whole body with particular attention to the neck, trunk and upper limbs” [13], contains values ranging from 1 to 7 which, in turn, define the action level, as shown in Table 1.

Table 1. Action levels and results for RULA.

Action level	Scores	Indication
Action level 1	1 and 2	Acceptable posture
Action level 2	3 and 4	Changes are recommended
Action level 3	5 and 6	Changes are needed soon
Action level 4	7	Changes are needed immediately

During the welding of subset reinforcement, the manual handling of the 133-kg workpiece on the workbench was assessed. The RULA score before the ergonomic intervention was 4 (Action level 2), indicating the need for investigation and potential changes in the production process (Fig. 2).

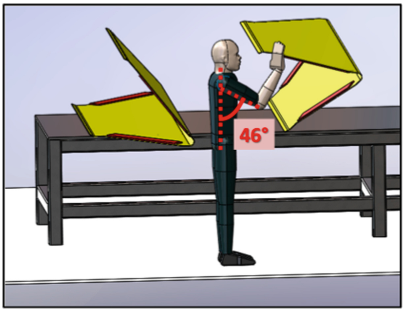

Fig. 2. Handling of the workpiece - RULA score of 4.

Step 3 - Problem Analysis, Added-Value Classification and Determination of Causes. The result obtained in step 2 justified the analysis of the workstation for developing an improvement that would eliminate the need for tipping the heavy pieces.

According to Pattanaik and Sharma [14], it is essential to the eliminate activities that do not add value to the production process because it is the customer that generates value, not the company [15]. The literature also points out that these activities can be: 1. Overproduction: production before or beyond that which is necessary; 2. Defects: Frequent information errors, product quality issues or poor performance in the delivery; 3. Unnecessary stocks: excess storage, resulting in excessive cost and poor customer service; 4. Inadequate process: execution of a working process using wrong tools, procedures or systems, when a simpler way could be more efficient; 5. Excessive transportation: excessive movement of people, information, materials or products, resulting in loss of time and effort as well as added costs; 6. Waiting: long periods of inactivity of people, information, materials or products, resulting in poor flow, delays and longer delivery times; 7. Unnecessary movements: poor organization in the workplace, resulting in poor ergonomics, for example: excessive bending or stretching movements and frequent loss of items [16].

Thus, in order to ascertain whether there was any waste in the production process, the process engineering team and the area management applied Lean Manufacturing methodology and categorized the value of activities in the flow of pieces in AV (Added Value), NAV (No Added Value) and NAVn (No Added Value, but necessary).

It was found that, among the 25 manipulations, three technical actions (OP.70, O.P. 100 and OP.130) did not add value to the production process and also did not comply with ergonomic requirements.

The main cause for the identified waste of the workpiece handling was that bending (OP.20) was performed before welding the reinforcements (OP.80 - OP.110). It required two workers to tip the folded workpiece on to a flat surface so the reinforcements could be welded. The last handling action (OP.130) is also carried out so the workpiece is placed into the moving position (OP.140). In Fig. 3, the operation numbers of Table 2 are illustrated.

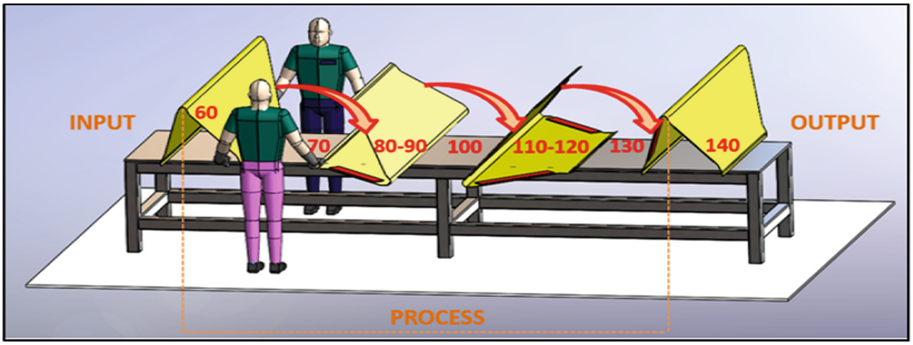

Fig. 3. Partial Flow: welding of four reinforcements before ergonomic reinforcement.

Table 2. Classification of technical actions before the ergonomic intervention.

Operation	Process	Items	Technical action	Classification
OP.10	Cut	2 Part number	1 and 2	AV
OP.15	Transport	2 Pallets	3 and 4	NAVn
OP.20	Bend	1 Part number	5	AV
OP.25	Transport	1 Pallet	6	NAVn
OP.30	Transfer	2 Part number	7 and 8	NAVn
OP.35	Transport	2 Pallets	9 and 10	NAVn
OP.40	Store	2 Pallets	11 and 12	NAVn
OP.50	Transfer	2 Part numbers	13 and 14	NAVn
OP.55	Transport	2 Pallets	15 and 16	NAVn
OP.60	Position	1 Part	17	NAVn
OP.70	**Handle**	1 Part	18	**NAV**
OP.80	Position	2 Reinforcements	19	NAVn
OP.90	Weld	2 Reinforcements	20	AV
OP.100	**Handle**	1 Subset	21	**NAV**
OP.110	Position	2 Reinforcements	22	NAVn
OP.120	Weld	2 Reinforcements	23	AV
OP.130	**Handle**	1 Subset	24	**NAV**
OP.140	Position	1 Subset	25	NAVn

The number of operations in Table 2 were added to the layout for the visualization of the flow of pieces in the factory (Fig. 4).

Step 4 - Action Plan. The action plan prioritized eliminating the handling of parts. The proposed solution was to invert the welding process so it is performed before the bending and check if there would be any undesired impact, according to the following steps:

(a) define the layout and the resources necessary to the welding of reinforcements; (b) provide resources; (c) define the pilot process; (d) perform the welding; (e) perform the bending with welded reinforcements; (f) analyze the impacts; (g) implement a new process; (h) monitor and measure results.

Step 5 - Implementation. Once the new process was defined and validated, it was only necessary to create a safety stock of the welded subsets so that it did not impact the supply in the final production line. With the stock produced in the new process, the operation involving the assembly and the welding of the reinforcements was transferred from the assembly line and started to be delivered as a subset composed of five pieces.

Step 6 - New Ergonomic Analysis. In the welding of the reinforcements of the subset, the task of manual handling of the 133-kg pieces on the workbench was assessed and the need to tip the workpiece was eliminated. The RULA score after the ergonomic intervention was 2, action level 1, indicating acceptable posture (Fig. 5). This result demonstrates the success of step 5.

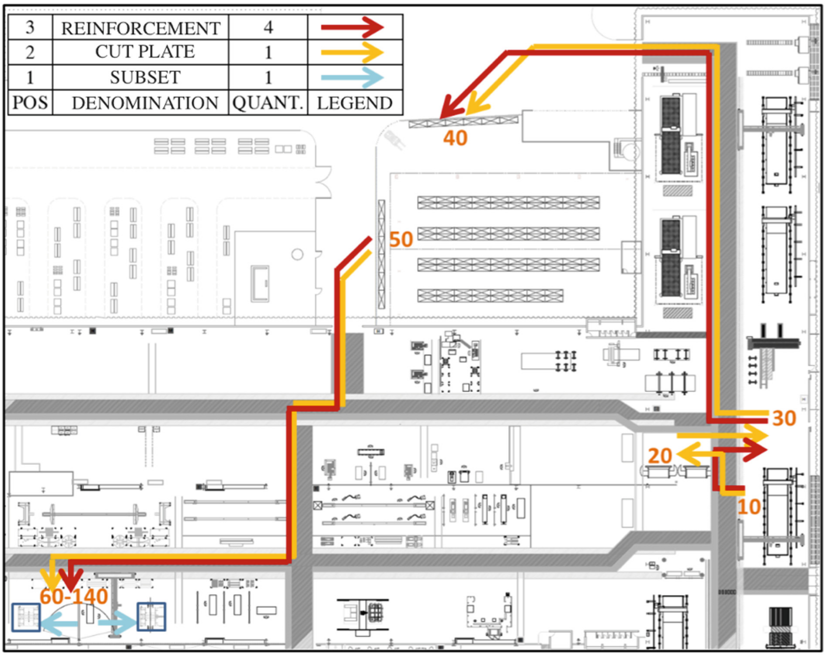

Fig. 4. Flow of workpieces in the factory layout before the ergonomic intervention.

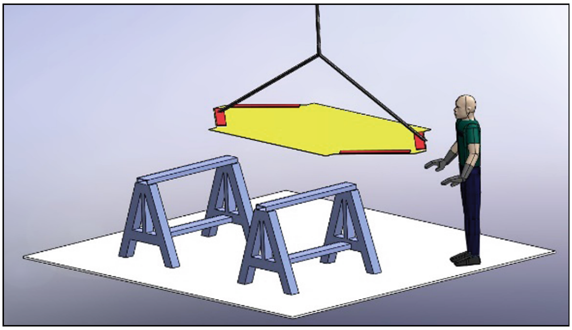

Fig. 5. Handling of the workpiece without tipping by using an electric hoist. RULA score of 2.

Step 7 - Validation of the Results. In addition to the ergonomic assessment before and after the ergonomic intervention, the authors administered a questionnaire on the worker perception of comfort to verify the added value of the modification of the production process for the worker. Fifteen professionals from the first shift were interviewed.

The questionnaire was answered voluntarily by the participants, and the identification of the worker's name was optional, so the informant's privacy was maintained. In the questionnaire two closed questions were asked in order to identify the employee's perception of comfort when performing the activity. We also inquired about the comfort of the worker when reducing the number of technical actions required to perform the activity as a result of the ergonomic intervention. Prior to the intervention, 25 technical actions were necessary. However, a total of 16 technical actions were needed after the intervention. Furthermore, workers from the entire production chain of the assembling and welding of the reinforcements responded to the questionnaire. They were categorized into 4 groups: group 1 - those who are required to tip the metal workpiece; group 2 - logistics workers who count, sort, transfer, store and supply the workstation; group 3 - operators of bending machines and group 4 - workers who receive the welded subsets.

3 Results and Discussion

3.1 Identification and Description of Intervention in the Production Flow

It was identified that, by adjusting the production flow in the assembly line and reducing the number of movements, the primary production processes (laser or plasma cutting and bending and welding) could be carried out in compliance with ergonomic standards and requests. This eliminated the need for transfers, dismissals as well as the hiring of new labor, since the welding process could be incorporated into activities already existing in the manufacturing area.

3.2 Classification of Technical Actions and New Production Flow After Ergonomic Intervention

After the ergonomic intervention, the new production flow led to a reduction in the number of technical actions. This is demonstrated in Table 3.

Table 3. Classification of technical actions after the ergonomic intervention.

Operation	Process	Items	Technical action	Classification
OP.10	Cut	2 Part number	1 and 2	AV
OP.15	Transport	2 Pallets	3 and 4	NAVn
OP.20	Position	1 Part	5	NAVn
OP.30	Position	4 Reinforcements	6	NAVn
OP.40	Weld	4 Reinforcements	7	AV
OP.50	Position	1 Subset	8	NAVn
OP.55	Transport	1 Subset	9	NAVn
OP.60	Bend	1 Part number	10	AV
OP.65	Transport	1 Pallet	11	NAVn
OP.70	Transfer	1 Part number	12	NAVn
OP.75	Transport	1 Pallet	13	NAVn
OP.80	Store	1 Pallet	14	NAVn
OP.90	Transfer	1 Part number	15	NAVn
OP.95	Transport	1 Pallet	16	NAVn

Once the handlings that did not add value were eliminated, it was evident that the flow of the workpieces, reinforcements and cut plates was reduced. This happened because after the intervention they were joined as a subset in the initial stages of the process (OP.20 - OP.50). Thus, five workpieces of two distinct items are already included when transporting, transferring or storing a subset.

The new process of welding of the reinforcements is performed on the flat, unbent plate, which makes it possible for only one worker, male or female, to perform all the activity because the positioning through the input, process and output of the workpiece (Fig. 6) is carried out by an electric hoist.

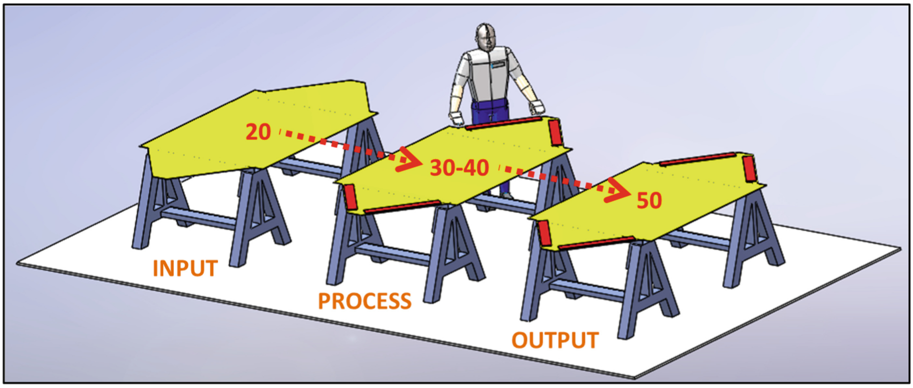

Fig. 6. Partial flow: Welding of the four reinforcements after the ergonomic intervention.

3.3 Positive Results of Applying Lean Manufacturing

In the researched company, the ergonomic intervention in conjunction with the Lean Manufacturing methodology generated positive results both for the company and for the worker regarding the organizational aspects of the workstation. These results are shown in Table 4.

Table 4. Results of the Lean Manufacturing intervention focusing on ergonomics issues.

Metrics	Before intervention	After intervention	Results (%)
Number of technical actions	25	16	36
Labor	2	1	50
Productivity man-hour	0.53 MH	0.35 MH	34
Cycle time	16 min	21 min	31
Recovery time	12 min	7 min	41
Daily transport	550 m	300 m	45
Physical space in operation	100 m^2	50 m^2	50
Transport/Storage	2 Part number	1 Part number	50

The 36% reduction in the tasks needed for the activity associated to the increase in the cycle time to 21 min and to the decrease of recovery time to 7 min contributed positively both to the production process and to the health of the worker.

Moreover, the physical space for the task decreased by half, freeing the layout for other operations.

After the intervention, the number of employees and man-hours necessary to perform the technical actions was reduced to 1, allowing the remaining workers to perform other tasks and even develop new skills.

Gains in movements were also very significant. Before the intervention, there were 4 types of parts being moved to the assembly line, afterwards, this number was reduced by 50% once the parts began to be supplied after having been assembled (Fig. 7).

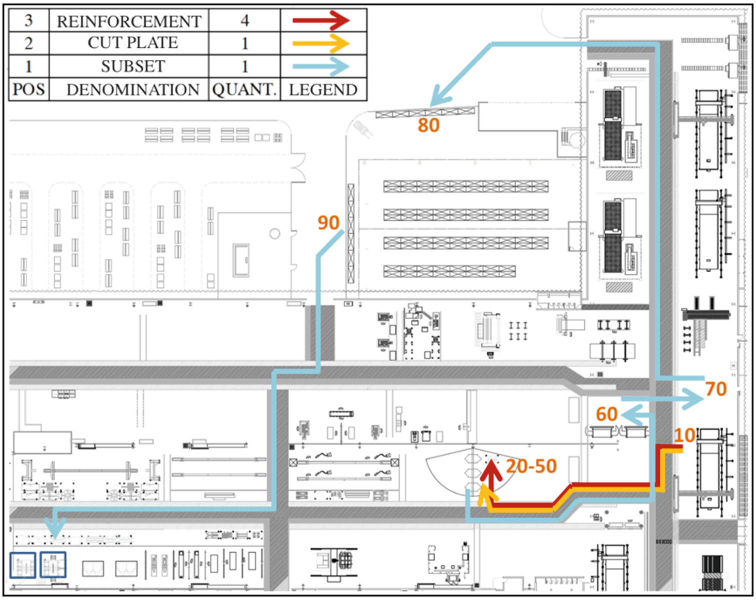

Fig. 7. Flow of workpieces in the factory layout after the ergonomic intervention.

3.4 Other Positive Results from the Ergonomic Intervention

Participatory Ergonomics is key to the success of ergonomic interventions [17]. The following results demonstrate the positive outcomes of associating the technical knowledge of the worker with the expertise of a professional multidisciplinary team:

1. It was observed that the positioning time of the reinforcements could be reduced with the aid of a template that replaced the need to measure the position of the parts, guaranteeing standardization and quality of the assembly;
2. Prior to the ergonomic intervention, the reinforcements were welded on a fixed height table and in the new process, height adjustable trestles of 0.80 m to 1.0 m were used, allowing the worker to adjust it according to his/her height;
3. In defining the resources required to carry out the activities, only the radial arm with electric hoist was required, freeing the workbench, the racks and the semi-gantry crane used for positioning the pieces;

4. Storing the plates with welded reinforcements facilitates the work along the processes since the space between each plate is the width of reinforcement, which allows the positioning during the lifting and facilitates the counting of the sets;
5. Freeing physical space on the assembly line makes it possible to combine two processes that were being carried out in different locations;
6. Elimination of transferring, storage, separation and forklift transportation of the reinforcements.

3.5 Result of the Questionnaire on Worker Comfort Perception

People can easily tell the difference between comfort and discomfort [18] and each worker has their own perception of comfort from their experiences. Therefore, a questionnaire was necessary to determine if the ergonomic intervention resulted in comfort for the workers when performing the activity.

The fifteen workers who answered the questionnaire reported that the new way of performing the activity at the workstation meets the comfort requirements, rating the ergonomic intervention as "*Very good*" in regard to the entire production chain.

3.6 Return on Investment in Ergonomic Intervention

A multidisciplinary team is needed to reduce costs [19]. In this study, our initial multidisciplinary approach was to optimize the performing of the activity to bring more comfort to the worker and, as a consequence, we also achieved a reduction of man-hour costs, among others shown in Table 4. Furthermore, there was no financial investment by the company, since it was not necessary to acquire new equipment or materials. All that was done in this ergonomic intervention was to reallocate resources and people, increasing the production of the final product by 33%.

It should be noted that, in the assembly flow of the final product, the two workers involved in the activity produced the parts according to the demand of the next post; in terms of manufacturing, they performed the "pull production", which in certain assembly lines shows to be very efficient. However, in this case this generated a loss in production, since the cycle time of the next stage was greater than the stage under study. This caused the workers to disperse their activities while waiting for the end of the assembly of the next stage.

4 Conclusion

From the point of view of managing the relationship between leaders and employees, this study promoted a deep analysis of how to integrate Lean Manufacturing with the expectation of people and with the constant development of practices that ensure the safety, health and quality of life of the worker. In addition, this integration resulted in higher productivity and in the elimination or reduction of waste, be it related to movements or rework.

It has been shown that the lack of ergonomic analysis can be considered waste within the Lean Manufacturing philosophy. Ergonomics can be applied in organizations to increase efficiency through activities that add value and through the continuous elimination of waste. This contributes to the expansion of Ergonomics in design projects to achieve goals related to the health of the worker as well as to the financial health of the company.

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Assessments of Ergonomic Risks in Banana Cultivation and Production

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Abstract. In banana cultivation, there are tasks that involve exposure to ergonomic hazards by the adoption of awkward postures, performing cyclical tasks and handling loads with a weight greater than 3 kg.

We evaluated 44 work positions with medium and high risk levels; the most affected body segments are trunk, neck, arms and wrists.

In the repetitive tasks was determined a medium risk, the factors that influence are the lack of pauses, high frequency of work and excessive muscular overload of wrists. The most critical risk is in lifting and transporting the fruit with an unacceptable level in all tasks evaluated. The results demonstrate an unacceptable ergonomic load in banana activities in the country, so that short-term safety and health programs should be integrated in the personnel involved to improve their work environments and prevent musculoskeletal disorders.

Keywords: Ergonomic risks · Awkward postures · Repeatability · Load handling

1 Introduction

- Ecuador is the largest exporter of bananas in the world and its presence in world trade is increasing. Exports grew from one million tons in 1985 to 5.7 million tons in 2013. This growth was mainly supported by the increase in planted area. About 18% of the bananas marketed in the world during the 1970s and 1980s came from Ecuador and this percentage increased in the 1990s to 30%. Banana production and trade in Ecuador offer direct employment to an estimated 380.000 people.
- Most companies have health and safety policies and only less than 50 of the 6,000 banana producers have legalized their occupational safety and health regulations at the Ministry of Labor. There is no health and safety management and workers work in precarious conditions and situations [1]. The tasks performed are performed and standing postures with inappropriate postures, with horizontal and vertical movements and movements, with high repetitiveness and highly demanding physical efforts [2, 4].
- Agriculture is a hard work and its workers suffer injuries and pains in various parts of the body, generating economic costs for compensation. In banana cultivation, there

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are multiple tasks involving the exposure of workers to multiple risks, including ergonomic ones, because people must adopt inappropriate postures, perform tasks characterized by cycles and manually manipulate loads that weigh more than 3 kg [3].

2 Materials and Methods

- The objective of this study was to determine the level of risk of workers exposed at each stage of banana cultivation and production. For the evaluation, specific analysis methods were used for postural loading such as Rapid Entire Body Assessment (REBA), for repetitive tasks the OCRA (Occupational Repetitive Actions) Check List, and for manual handling of loads the ISO 11228-1 international standards, and ISO 11228-2.
- The REBA Method allows to establish the level of risk resulting from the adoption of awkward postures of the different body segments such as neck, trunk, legs, arm, forearm and wrists considering additional factors such as the application of force, and the type of activity performed.
- The OCRA Check List Method makes it possible to determine the risk for repetitiveness derived from various components such as frequency, strength, posture, duration and recovery in the execution of labor tasks.
- The ISO 11228-1 and ISO 11228-2 standards make it possible to know the risk of lifting, transporting, pushing and pulling in handling tasks in banana cultivation and production activities.
- The data collection was carried out in the middle of work activity and the evaluations were carried out in all the stages of cultivation and production of the fruit in four haciendas of the province of El Oro in Ecuador in the year 2016.
- The work stages evaluated were the tidy, garruche, dehanding, trimmed, chopped, weighing, gluing, removing and palletizing.
- The workforce consists exclusively of male staff, ranging in age from 18 to 45 years, with an average working time of 8 years in different plants.
- Exposed workers have not been given occupational medical assessments, so there are no official occupational medical data, although a high percentage refer to musculoskeletal pain mainly at the shoulders, neck, wrist and lower back. Although it is a legal requirement to implement a Health Surveillance Program for all workers of all companies in the country, this type of activities is not done because there are no regular controls established by public institutions.

3 Results

- The results of the specific evaluations of forced positions in the various stages of banana production and cultivation are:
- In the stage of dehanding in which the worker cuts the various hands of the fruit cluster, a mean risk level with a final average REBA score of 4 is evidenced, mainly due to the asymmetry of the neck, arms and trunk.

- In the trimming phase in which the worker receives fruit hands for later placement in the wash pools, a mean risk level with a final REBA average score of 5 could be determined due to the asymmetry of forearms, wrists, Trunk, arms, and neck.
- At the chopping point, the worker cuts banana clusters and classifies the appropriate fruit, and established a mean risk level with a final REBA average score of 5, due to the asymmetry of forearms, wrists, neck, trunk and arms.
- At the weighing station operators took the fruit clusters from the pool and proceeded to weigh them, and an average level of risk was established with a final REBA average score of 4.75, due to the asymmetry of wrists, neck, trunk and arms.
- In the bonding activity, the operators assemble the banana boxes, and a mean risk level with a final REBA average score of 6.25 was established, due to the asymmetry of wrists, neck, trunk, forearms and arms.
- In the removal phase of the boxes the operators proceed to pick up the different boxes and place them in the palletizing zone, and a high-risk level was established with a final REBA average score of 7.66, due to the asymmetry of wrists, neck, trunk, forearms, arms and legs.
- In the palletizing activity, the operators placed the different banana boxes on the pallet for later distribution, and a high risk level was established with a final REBA average score of 8.66, due to the asymmetry of wrists, neck, trunk, forearms, arms and legs (Fig. 1).

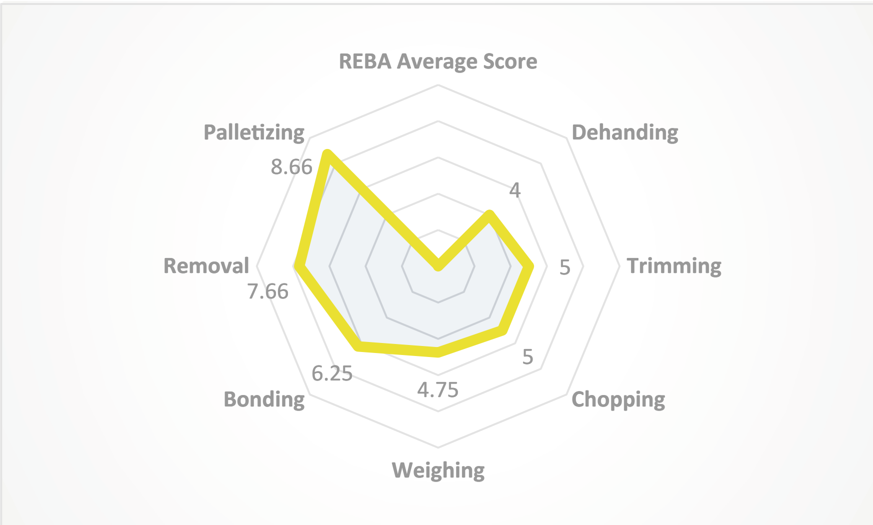

Fig. 1. Final score REBA in each activity of the cultivation and production of banana

At all stages of production, 44 work positions were evaluated, with a medium-risk level of 81,8% and a high-risk level of 18,2%; Being the body segments most affected trunk, neck, arms and wrists; Some positions are due to the requirement of the task and others due to the poor design of some work areas (Fig. 2).

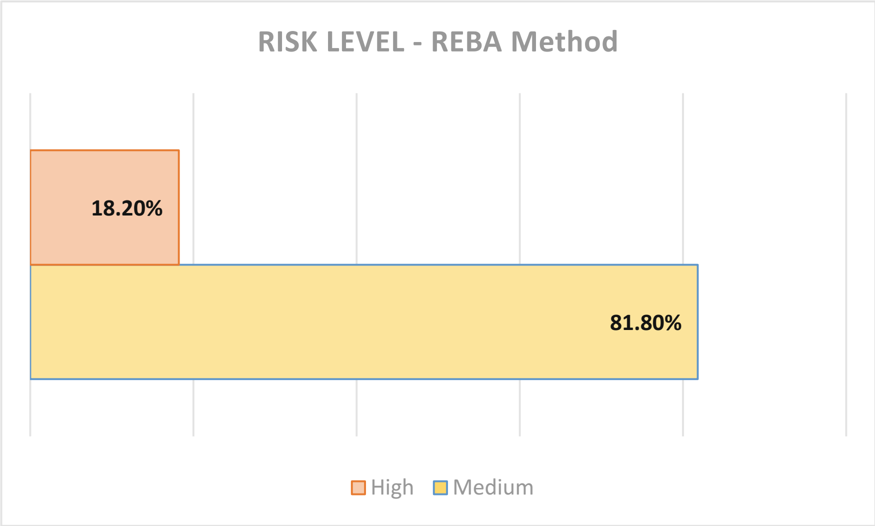

Fig. 2. Risk level for awkward postures per the REBA method

The results of specific evaluations of repetitive tasks in the various stages of banana production and cultivation are:

In the labeling phase, a mean risk level was established with an OCRA Check List final score of 21.25, due to insufficient recovery, high frequency and influence of asymmetric postures.

At the gluing station, a mean risk level was established with an OCRA Check List final score of 18.87, due to insufficient recovery, high frequency, force application, and influence of asymmetric postures.

In the chopping activity, a medium risk level was established with an OCRA Check List final score of 22.10 due to insufficient recovery, high frequency, force application, and influence of asymmetric postures.

In terms of repetitive actions, three activities were evaluated, all of them presented a medium-risk level, with the risk factors being the lack of breaks, a high frequency of work and an excessive overload on the structure Muscle of the wrists.

The results of the specific evaluations by manipulation of loads in the diverse stages of production and cultivation of banana are:

In the tidying activity, there is lifting and transport of fruit clusters determining a totally unacceptable level of risk due to handling height (shoulder level).

- In the Garruchero phase, a convoy of clusters was dragged, a level of risk totally unacceptable was determined by the handling distances greater than 61 m and by the excessive weight involved in the application of excessive initial and sustained traction forces, in addition of the irregularities of the transit area.
- In box removal activity, the level of risk is unacceptable due to the elevated frequency of lifting and transport, and to the elevated vertical distances.

- In the case of palletizing boxes, the level of risk is unacceptable due to excessive horizontal distances of manipulation (greater than 40 cm) and inadequate vertical distances (less than 50 or greater than 125 cm).
- In the activity of pushing pallets of banana boxes with a weight of 1190.66 kg there is an unacceptable level of risk due to the application of both initial and sustained excessive forces.
- The most critical risk is in lifting and transporting the fruit, with an unacceptable level of risk in 100% of the tasks evaluated. The level of risk found is mainly due to the high manipulated weight, excessive handling frequency, inadequate geometries, and the size of the boxes leading to forced gripping of the same (Fig. 3).

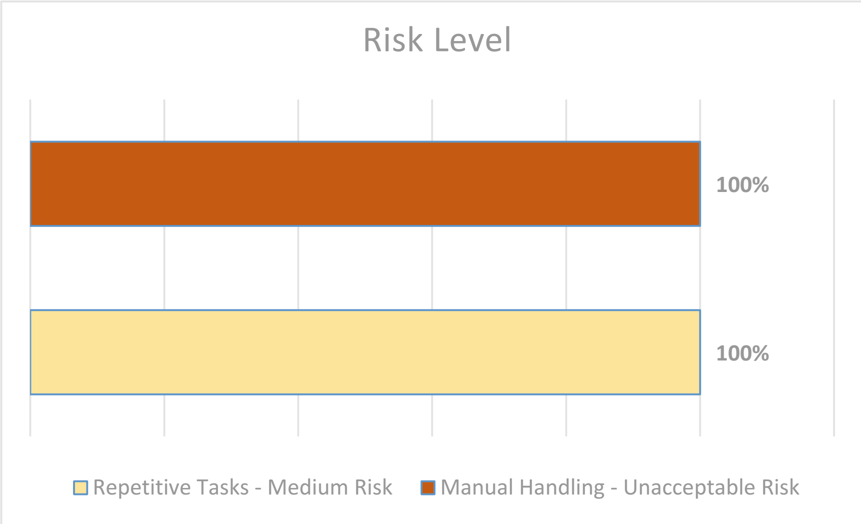

Fig. 3. Level of risk for repetitive tasks and manual handling of loads in all jobs evaluated

4 Conclusions

- These results show that there are levels of ergonomic load that are not acceptable in banana activities in the country and short-term safety and health programs should be integrated in the personnel involved in order to improve their work environments and prevent musculoskeletal disorders.
- The most critical level of risk is found in activities involving manual handling of loads. These tasks must be modified immediately because of the high risk they pose to workers. Boxes with high weights and excessive dimensions are handled through inappropriate geometries and extreme distances.
- With respect to postural load and repetitiveness, the risk is also high, either because of poor postural habits, bad job designs, or excessive work rhythm, all of which lead

to the conclusion that exposed workers are potential candidates to develop musculoskeletal disorders in the upper limbs and back in the medium and long term.

- This study wants to highlight the need to implement technical and/or organizational improvements in the jobs of banana plantations, technical actions such as the redesign of jobs and organizational such as the training of workers; the implementation of a health surveillance program that can detect at an early stage any discomfort or damage that may be suffered by workers should also be immediately implemented.

There are few studies on the subject of banana cultivation and production, so new evaluations should be carried out to complement the results found and support the improvement of working conditions, in addition to being able to determine the prevalence of musculoskeletal damages of work origin in the field evaluated.

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A Proposal for Field-Oriented System to Support Medical Risk Management. Support of Risk Management in Small and Medium Sized Hospital

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Abstract. Nowadays there is increased need for utilizing big data efficiently. In addition to using data to provide new information, combining various data sources can help create value-added information which provides new insights. In medical safety, there is increased attention for big data applications in healthcare and medical safety. Medical safety is supported by applying big data to the medical research fields. After considering the overall configuration of current system different applications were proposed. Because the database environment is not in place, authors could not consider the system in operational use, however researchers examined each application and formulated future policy.

Keywords: Database of medical · Safety management system · Prevention of medical adverse events · Human factors · PSF · Medication error · Fall down

1 Introduction

In today's information society, the world is filled with various data. In order to use this data well, there is a way of thinking such as big data and database. Big data is a collection of various data which is simply used as information. In addition to it, it is assumed to be used as derive value-added information by combining various data.

We are considering to adapt these big data systems to medical safety. We will collect various information on the medical site and make it into a database. We aim not only to use data as a single information, but also to combine data. Thus, we get noticed from a new viewpoint that has never been before. We aim to support safety activities at medical sites by designing a database system that supports medical safety.

In Japan, medical safety has come to draw due to the " Patient misunderstanding accident at Yokohama City University " and the "Erroneous medicine accident at Metropolitan Hiro Hospital " in 1999. After that, the government also took various medical measures, and revised the "medical law" several times. Various medical safety studies have been conducted in that process. Especially, research on 'drug countermeasures' [1] "against falling accidents" [2, 3] and 'medication accident countermeasures' has been taken up many times.

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Many researches on medical safety measures for medical safety managers are utilized in improving medical safety in Japan.

However, in the present situation, since each necessary medical data is managed for each medical safety measure, the necessary data is often duplicated in two measures. This is called a file-based data management method. This cannot share the data with multiple programs. Therefore, when deriving the countermeasure, files in which each data must be accessed. When it has to be updated, they have to do same thing twice. Furthermore, the process of data management also increases.

A database exists as similar as a file base. However, unlike file-based, databases enable data sharing.

Therefore, since data can be shared by a plurality of programs, data can be easily used, and managed updating and maintenance very simply.

In this research, in order to support medical safety management activities, the purpose are set from two perspectives.

- Construction of database type management system
- Creating value-added information by integrating multiple data

Construction of Database Type Management System. Currently, data is often managed individually. In this research, first, create a database that collects various data in the hospital. Based on the premise of making these data, think about a method suitable for that analysis, standardize for that, and think about storing it on a database.

Creating Value-Added Information by Integrating Multiple Data. The basic medical safety measure is to convert the data that is necessary for deriving the countermeasures to information as it is. But by combining other information with it, the value of use as information increases. And we can derive information that we cannot care only with the countermeasures so far and think from a diverse perspective on medical safety

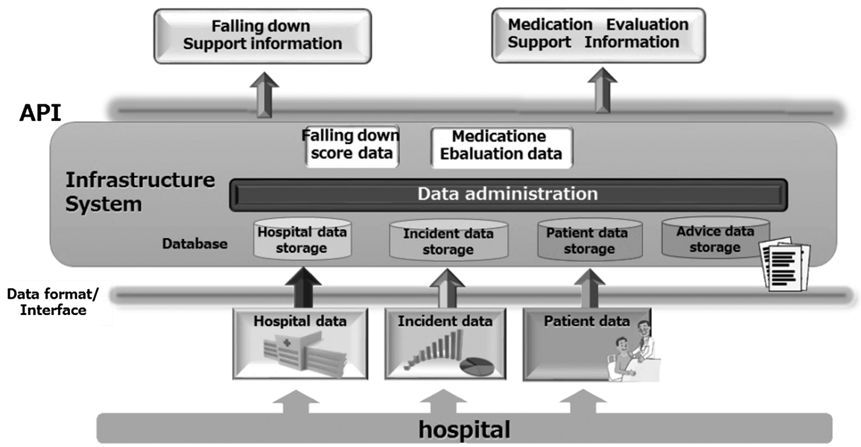

Fig. 1. A rough diagram of support medical risk management system.

activities. It may help medical safety managers, who are promoting medical safety activities, to analyze measures and may help to alleviate workload.

Based on the above two points, we designed the database type support system. Considering the countermeasure information to be output and the application for output, firstly, the overall configuration diagram of the system is created. The following is a rough diagram of the system (Figs. 1, 2, 3, 4, 5, 6).

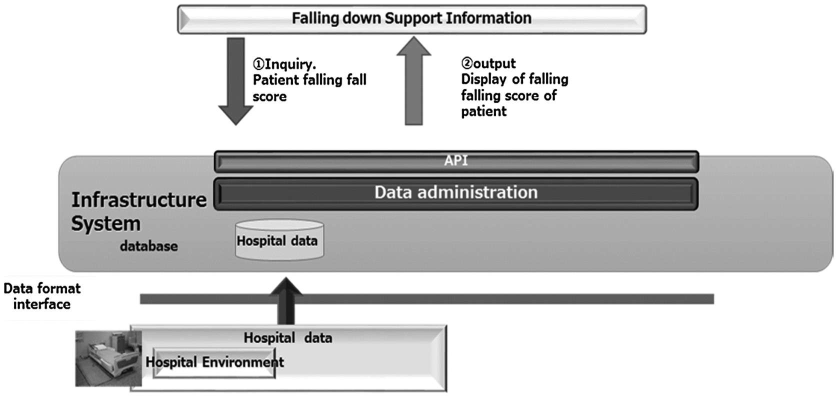

Fig. 2. Fall risk assessment diagram

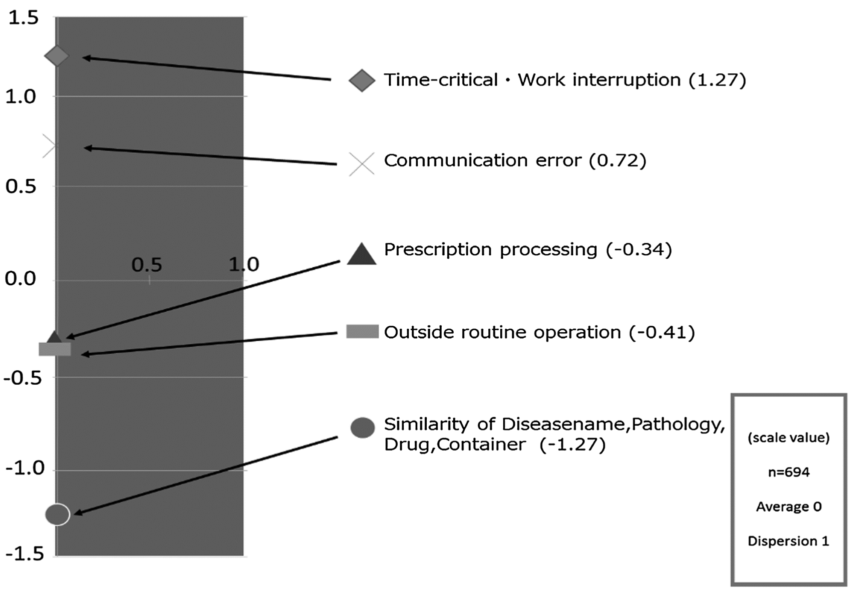

Fig. 3. Reliability evaluation about intravenous drip

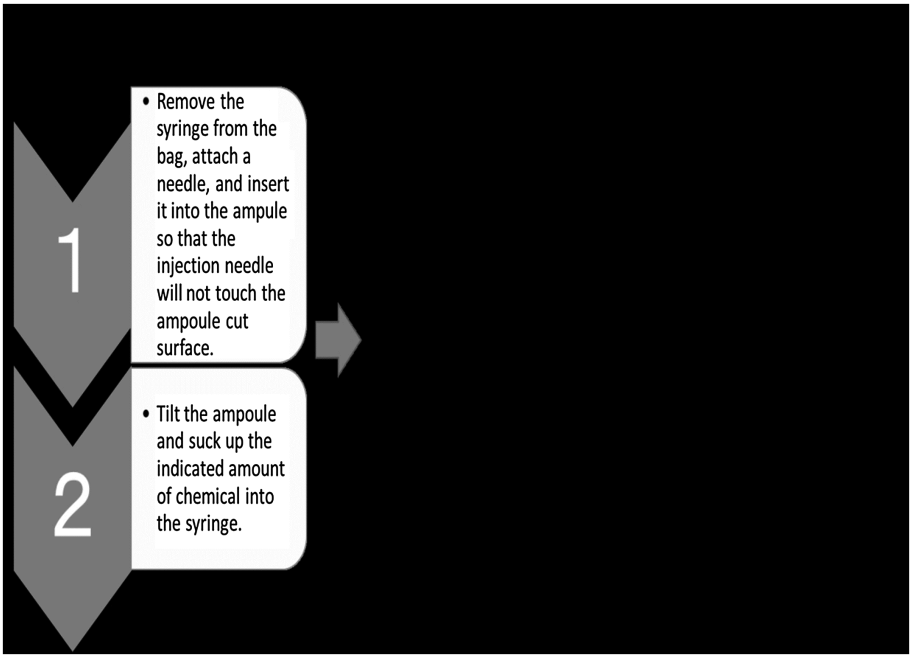

Fig. 4. The extract of detail procedure of intravenous drip

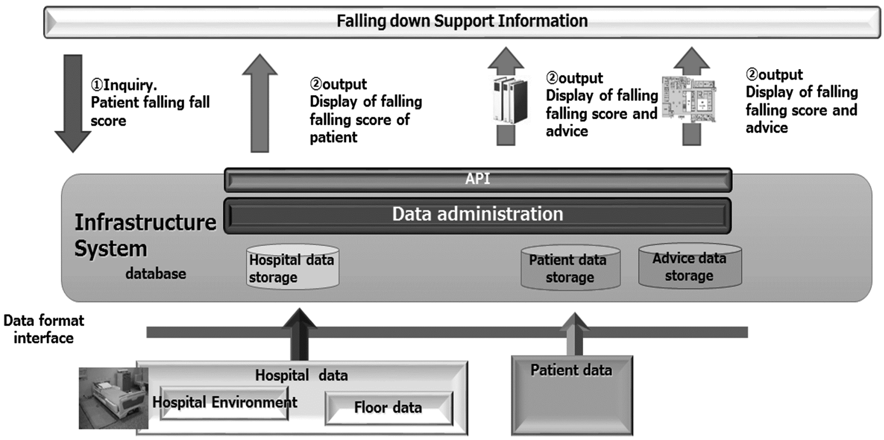

Fig. 5. Future application of fall risk assessment

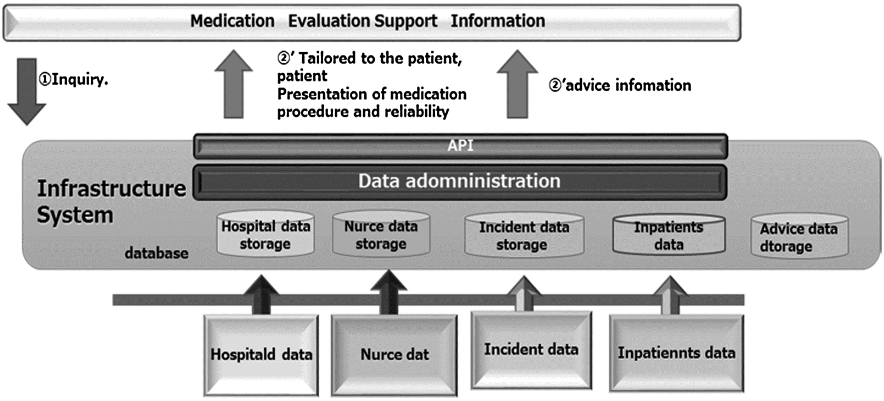

Fig. 6. Future application of reliability evaluation

Here, the API is an abbreviation for application program interface, it is a system usage specification and output also in utilizing the actual system.

2 Methods

For this research, since there are no hospitals that are equipped with enough database environments to make use of the system at this stage, at this fiscal year, the researchers conducted the study by examining each countermeasure. Researchers studies two measures: "Fall risk assessment" and "Evaluation of Reliability in Medication." The researchers introduced the two measures and their application for these assessments.

2.1 Fall Risk Assessment

We created a fall risk assessment sheet on our own. The one shown below is the one.

The assessment is based on patient information and facility information in hospitals. In the system, when inquiring of API, fall risk assessment of each patient is carried out, and fall score is displayed. Information about patients and hospital environment are obtained from the database and applied to the following fall risk assessment sheet to calculate and display the fall risk of the patient.

2.2 Reliability Evaluation and Proposal of Procedure Manual on Medication

We divided medicine work into three flows "medicine" "intravenous drip" and "medication". When inquiring about each business, the risk manager is given a procedure written to the maximum detail and reliability evaluation of error factors of each work.

The following is an example of output.

Advice Data Collection. This is a summary of advice for various error factors for organizations and individuals. Advice is based on not only medical, but also literature such as ergonomics and cognitive engineering.

Therefore, it is advice from various perspectives.

3 Discussion

3.1 Fall Risk Assessment

The nurse can easily obtain the fall score of the patient, and it becomes possible for the nurse to pay attention to the patient who is liable to fall in the work at the daily medical site.

Future Application. We use data such as incident report, hospital floor map, advice data and so on. By using the incident report and the floor map, we aggregate points where fall accidents occurred frequently for each floor in the past and output these points on the floor map.

By applying the advice data, we aim to support fall prevention activities by displaying work advice to nurses in addition to the fall score of patients with a high risk of falling.

3.2 Reliability Evaluation and Proposal of Procedure Manual on Medication

Procedures written in full detail can be used for education for new care nurses. In addition, it is an opportunity to notice that the nurse is omitting the procedure that should be done.

Reliability evaluation chart enable a nurse to understand error factors in each work, so that even a little attention can be paid to daily tasks.

Future Application. Data such as the number of inpatient, nurse career data and advice data are applied. Currently, only the procedures written in the maximum detail are outputted, but we will also review applications that can propose a procedure manual corresponding to the situation (work volume, nurse data). Procedural documents corresponding to the site, it should not be omitted from the detailed procedure manual in a timely manner, displays the extracted procedure which can be omitted. Also, it displays that the error rate rises because the procedure is omitted. This will make them understand that the work is not perfect, and give a moderate anxiety to the work.

Also, based on error factors that can be seen by removing the procedure, advice is displayed from the advice data collection.

4 Conclusion

Since there is no database environment developed at this research stage, this paper provided an introduction of the application of big data analysis to demonstrate the value-added by information analysis, which used in various datasets. This paper demonstrated applications for medical safety support system that can be used for various kinds of information analysis application in medical safety.

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Risk of Developing Musculoskeletal Disorders in a Meat Processing Plant

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Abstract. The present study aimed to evaluate the risk of developing UL-WMSDs in a pig meat processing plant using the OCRA checklist. The study was conducted in a company with 3000 workers. The average of occupational repetitive actions performed by workers was 64.1 ± 14.3 per minute, representing nine points in the OCRA's scale. The average score of OCRA's checklist was 22.2 ± 7.7, which is considered as a moderate risk. The scores for the right upper limb (22.2 ± 7.8 - moderate risk) did not differ ($p = 0.192$) from the left upper limb (21.6 ± 8.1 - moderate risk). Considering the five risk categories proposed by the OCRA method, six work tasks were considered as high risk (27%) and 16 represented moderate risk (73%). When performing simulations, in 19 of the 22 activities it was possible to reduce the risk of UL-WMSDs to very low levels, by reducing only the working pace (−46.7 ± 14.8%).

Keywords: Meat processing · OCRA · Risk assessment · Musculoskeletal disorders

1 Introduction

Brazil is the fourth leading producer and exporter of pork meat in the world [1]. However, improvements in the working conditions in meatpacking industry have not grown at the same rate as production growth [2]. Slaughtering and meat processing work involve high loading intensities and cyclic repetitive muscle actions of the upper limb and thus implies an elevated risk of work-related musculoskeletal disorders [3–7]. Additionally, the Occupational Safety and Health Administration (OSHA) [8] indicates as risk factors for musculoskeletal disorders (MSDs) in meatpacking plants the repetitive and/or prolonged activities, forceful exertion, awkward and static postures, continued physical contact with work surfaces (edges), excessive vibration from powered tools, cold temperatures and inadequate hand tools.

Recently, Sundstrup et al. [9] found among 645 Danish slaughterhouse workers a prevalence of pain in the shoulders (60%), elbows (40%) and hands/wrists (52%). Moreover, 38% of the workers reported work disability due to upper limb pain emphasizing the functional consequences of arm, shoulder and hand pain on daily work

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performance. Tirloni et al. [10] 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. [11] study revealed that the workers felt discomfort in the shoulder (45%), neck (29%), spine (26%), arms (23%), and hand and wrists (20%). According to Sundstrup et al. [12], chronic upper limb pain is associated with reduced neuromuscular function of the shoulder and hand, along with work disability in slaughterhouse workers.

High rates of acute injuries and chronic diseases are reported in pig slaughterhouses [13]. The majority of injury (63%) reports of a pork processing plant occurred at a cold worksite, and the main source of injury was the tasks that required the use of handheld tools [14]. Recent tool sharpening and equipment malfunction were associated with the highest rate ratio of laceration injury [15]. Furthermore, high-velocity and high-force manual work is a risk factor for musculoskeletal injuries in pig slaughterhouses [16]. Moore and Garg [17] give additional epidemiological evidence that upper extremity musculotendinous disorders may be causally associated with work in pig slaughterhouses. The disorders included nonspecific hand/wrist pain, epicondylitis, carpal tunnel syndrome (CTS), trigger thumb, trigger finger, and De-Quervain's tenosynovitis.

The OCRA checklist was developed to analyze the workers' exposure to various risk factors of developing upper limb work-related musculoskeletal disorders (UL-WMSDs) (strength demand, repetitiveness, inappropriate posture and inadequate movements, lack of recovery periods, and others, defined as "complementary") related to activities performed [18, 19]. This checklist was based on a consensus document of a technical committee in musculoskeletal injuries of the International Ergonomics Association (IEA) [18, 19]. Although there are several studies evaluating the risk factors for the prevalence of upper limb work-related musculoskeletal disorders among poultry slaughterhouse workers [20–24], no studies involving pig slaughterhouses were found.

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 pig slaughterhouse, using the OCRA checklist.

2 Method

The procedures in this study were approved by the local Ethics Committee in Research with Human Beings, in accordance with the Helsinki Declaration.

The study was conducted in a pig slaughterhouse with a total of 3,000 workers employed. In order to evaluate the risks associated with repetitive movements of the upper limbs, the OCRA checklist (Table 1) [25] was used to assess the risk of 22 work activities, which included the majority of the workers in the meat processing plant. Videos of 10 task cycles were recorded for each worker while carrying out their work tasks, for subsequent analysis.

For data presentation, descriptive statistics in terms of mean, standard deviation and percentage were 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 [25].

Color	Risk	Checklist points	Incidence of UL-WMSDs (%)
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 that a shift totaled 7 h 20 min of work with three rest breaks of 15 min, the net time of repetitive work ranged from 361 to 420 min (multiplier factor 0.95). Three points were assigned to the "Recovery" risk factor (on a scale of zero to 10). Regarding the other risk factors considered by the OCRA method (frequency of technical actions, force applied, posture and complementary factors), scores were assigned according to the characteristics of each activity.

The average of occupational repetitive actions performed by workers was 64.1 ± 14.3 per minute (Table 2), representing nine points in the OCRA's scale (0 to 10 points scale). In a poultry slaughterhouse industry, Colombini and Occhipinti [26] found 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 poultry slaughterhouse, Reis et al. [22] observed 55.2 ± 27.6 technical actions per minute, which represents 7 points in the OCRA checklist. Researchers of the same study group [23] reported similar results (63.7 ± 25.3 technical actions per minute) for another Brazilian poultry slaughterhouse. In a pig head processing company, Pellegrini et al. [27] reported that the ergonomic analysis of work showed an elevated risk for disorders of the upper limbs due to the high frequency of technical actions (between 15 and 82.5) combined with awkward postures, use of force, complement factors and the lack of the necessary time for recovery.

According to Kilbon [28] the worker should not exceed 25–33 actions per minute, considering that frequencies above these values interrupt the physiological recovery mechanisms from operating efficiently, increasing the incidence of tendon injury.

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 [9].

The average score of OCRA's checklist for all jobs analyzed in the company was 22.2 ± 7.7 points (Table 2), which is considered as a moderate risk (Table 1). The scores for the right upper limb (22.2 ± 7.8 - moderate risk) did not differ ($p = 0.192$) from the left upper limb (21.6 ± 8.1 - moderate risk). Although no other studies evaluating the risks of UL-WMSDs in pig slaughterhouse workers have been found, there are studies utilizing the OCRA checklist to evaluate these risks in poultry slaughterhouses [20–23, 26].

Table 2. Risk assessment for repetitive movements of the upper limbs performed by the slaughterhouse workers, and the 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
Closing ham baking pan	10	50	15	M	7	35	11	VL
Secondary packaging - 5 kg sausage	6	48	15	M	4.3	35	11	VL
Meat hanging for seasoning - bacon	17.6	53	16	M	10	30	11	VL
Removing ham from cage	10.7	43	16	M	7,5	30	11	VL
Removing sausage from cage	8.1	48	16	M	6	35	11	VL
Removing staples from 4 kg bologna	7.8	62	17	M	5	40	11	VL
Secondary packaging – Ham	8.3	58	18	M	5	35	11	VL
Packing sliced bacon	1.15	69	18.5	M	0.67	40	11	VL
Filling sausage casings	2.5	60	18.5	M	1.5	35	11	VL
Secondary packaging - 1 kg sausage	3	60	19	M	1.7	35	11	VL
Hanging bologna	2.8	78	20	M	1.25	35	11	VL
Sealing 1 kg sausage package	3	75	21	M	1.4	35	11	VL
Positioning 4 kg bologna on sealing machine	30	90	21	M	12	35	11	VL
Packing pepperoni	10	70	21	M	5	35	11	VL
Secondary packaging - 5 kg franks	3.8	56	21.5	M	2	30	11	VL
Placing ham on baking pan	18.8	56	22	M	10	30	11	VL
Fueling bacon slicer	15	90	24.7	H	3.3	20	11	VL
Positioning 4 kg bologna on belt conveyor	30	90	24.7	H	10	30	11	VL
Secondary packaging – bologna 3.5 kg	24	72	24.7	H	7.5	20	11	VL
Removing 3.5 kg bologna from cage	12	48	38	H				
Removing 4 kg bologna from cage	6	60	38.5	H				
Hanging 4 kg bologna in cage	4.6	74	41.8	H				
Average	10.7	64.1	22.2	M	5.3	32.6	11.0	VL
Standard-deviation	8.6	14.3	7.7		3.5	5.4	0.0	

Risks: H-high; M-moderate; VL-very low

Colombini and Occhipinti [26] found similar results in a poultry slaughterhouse industry, with 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 laboratory and clinical tests). Other studies conducted in Brazilian poultry slaughterhouses presented also moderate risks (21.8) [22], (18.3 ± 2.7) [23] and (16.8 ± 4.2) [21].

Considering the five risk categories proposed by the OCRA method, six work tasks analyzed in the present study were considered as high risk (27%) and 16 represented moderate risk (73%) (Table 2). Some previous studies have reported much higher rates of high-risk activities that contribute for the development of UL-WMSDs in Italy poultry slaughterhouses (90%) [26], Iran (67%) [20], and in Brazil (56.5%) [22].

Recent Brazilian studies have shown lower percentages of high-risk activities in poultry slaughterhouses (between 8 and 9%) [21, 23]. It is hypothesized that the findings of a smaller number of high-risk activities, observed in these studies, have been influenced by the recent implementation of the Standard Regulatory Norm 36 (NR-36) [29], 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 the OCRA checklist, there is the definition of the minimum duration of the psychophysiological recovery periods (20 min, 45 min or 60 min). This requirement should be adopted in the productive sectors of the industries, according to the duration of the shift (up to 6 h, up to 7 h 20 min or 8 h 48 min, respectively). In addition, the recovery periods should be at least 10 min and at most 20 min, distributed in a fashion as not to affect the first hour of work, contiguous with the meal interval and at the end of the last hour of the working day. When adopting these measures, there is a reduction of the time of exposure to repetitive activities and/or muscular overload, reducing the score of the variable "recovery" of the OCRA checklist. Thus, the hypothesis is evidenced by the disparity between the results of the most recent studies [21, 23] and the results of Reis et al. [22] study. These authors evaluated a Brazilian slaughterhouse prior to implementation of the NR-36, and found greater exposure to repetitive activities (480 min), with a shorter duration for daily rest break (10 min).

Starting from statistical procedures (regression analysis), the precursors of the OCRA method [25], based on epidemiological data, developed hypotheses of disease prevalence expected in a particular occupational setting. 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 et al. [25] found an incidence of UL-WMSDs of 47.7% of workers from workstations classified with 28 points in the OCRA checklist (high risk). Thus, it is possible to affirm that the individuals analyzed in the present study who performed activities of moderate risk have a probability of developing UL-WMSDs between 10.76 and 21.51%, whereas in high-risk activities the probability is >21.51%.

According to Vergara and Pansera [30], pig slaughterhouse employees are exposed to ergonomic risk related to the physical load and physical environment. Musculoskeletal problems resulting 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 government and for companies, and especially for the family [31, 32]. Thus, providing an ergonomically appropriated work place 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 [31, 32]. In this manner, Pellegrini et al. [27] recommend to consider some organizational factors for the prevention of UL-WMSDs in pig slaughterhouses. These factors include: adoption of a rational distribution of rest breaks (preferably hourly); alternation of tasks with the rotation of workers on more tasks; use of knives that have the handle covered by adherent material and do not cause compression in the hands; sharpening the knives several times a day; do not neglect information and training of workers on the proper use of knives and education on sharpening knives at the first signs of fatigue.

Due to predominant highly repeatable movements of the upper limbs in pig slaughterhouses [4, 16, 27], and previous studies suggesting the reduction in working pace to prevent UL-WMSDs [10, 21–23], simulations of reduced working pace to achieve very low risk levels utilizing the OCRA checklist were performed (Table 2). When performing simulations, in 19 of the 22 activities it was possible to reduce the risk of UL-WMSDs to very low levels, by reducing only the working pace (−46.7 ± 14.8%). In the remaining activities analyzed, it was not possible to achieve very low risk levels by reducing only the working pace, due to the high demand for strength required to perform the tasks (Removing 3.5 kg bologna from cage, removing 4 kg bologna from cage, hanging 4 kg bologna in the cage). Reis et al. [21, 23] also carried out simulations of reducing the work pace in poultry slaughterhouses activities, aiming to reduce the risk of UL-WMSDs. When the pace was reduced to −42.1 ± 14.5% and −38.8 ± 13.3%, very low risk levels were achieved for most of the activities analyzed (24/26 and 20/22, respectively), with the exception of those activities requiring significant force exertion.

4 Conclusion

Based on results of this study and the postulation of the literature, the following can be concluded:

- Most of the activities carried out by the workers were classified as moderate risk;
- There was no difference between the risks observed in both upper limbs;
- Simulations of reducing the working pace showed the effectiveness of this organizational measure to reduce the risk of UL-WMSDs.

Workers exposed to moderate risk activities have two to four times more chances of developing UL-WMSDs than the population that was not exposed.

Future studies are needed to determine whether the present findings can be generalized to other pig slaughterhouses, given that the current study was limited to analyzing only those employees within a Brazilian slaughterhouse.

Lastly, some organizational measures should be considered to reduce the risk of work-related musculoskeletal disorders of the upper limbs. Some of the suggestions are: reducing the working pace, adopting job rotation between tasks with different biomechanical requirements, adopting rest breaks well distributed throughout the workday (preferably hourly), increase the number of employees, use of sharp knives to reduce the effort required to perform cutting task and monitor the risk level of work activities through objective tools such as the OCRA checklist.

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Work Related Musculoskeletal Disorders (WRMSD) in Construction Workers and Main Causes

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Abstract. Construction industry still is characterized with physically demanding work duties despite the ongoing modernization of new technology. Construction work requires physical and psychosocial effort, working in compulsory and awkward postures. WRMSD are the most common health problems among employees in construction. The aim of this study was to determine WRMSD reasons caused by physical load and psychosocial risks at work for painters and tilers in the construction enterprise. Results of the study shows that causes of WRMSD in employed in construction, are not only physical risks at work, but also psychosocial risks, as well as individual attitude towards one's own health.

Keywords: WRMSD · Construction · Questionnaire · Painters · Tilers

1 Introduction

Construction is one of the biggest Latvian national economy sectors. Many jobs in the construction industry are still physically demanding. The construction site is a temporary workplace, meaning that material and tools may have to be carried and the demands may vary (e.g., between renovation and the construction of new buildings). Construction work also requires climbing ladders and sometimes working in awkward postures. WRMSD and injuries are among the most frequently reported causes of lost or restricted work time [1]. WRMSD are the most common health problems among employees in Latvia, incl. construction. Research in other countries has also proved that construction workers most of all suffer from WRMSD, especially older employees [2]. Opposite to other occupational diseases, WRMSD are of multifactor origin [3], where significant are not only physical risks [4], but also psychosocial and organizational [5, 6], as well as individual risk factors [7]. Cigarette smoking, obesity, diabetes, hypertension, and high cholesterol level are major health risk factors for builders [8]. Research has proved that cigarette smoking 12 to 13 times increases risk of death from chronic obstructive pulmonary disease (COPD) and accounts for nearly one of every five deaths in the United States [9, 10]. Obesity has been linked with stroke, diabetes,

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and several other chronic conditions. The prevalence of obesity among adults, measured by body mass index, has increased significantly since the 1980s in US [11].

Physical overload at work (lifting and moving heavy loads, repeated hand movements, awkward postures, including long-term bending or sharp turning of the body, work on knees, work with hands raised above shoulder level are considered to be the main reasons in the origin of WRMSD [12, 13]. Construction workers, comparing to office workers, suffer from arthritis, back health disturbances, chronic pulmonary diseases, limitation of movements, and traumata much more often [14, 15]. Work environment is an important predictor of disability pension among construction workers with those in physically heavy jobs having the highest burden of disability [16]. Research in Finland, in its turn, has proved that disability in relation to health problems due to strain at work occurs 1.5 to 2.4 times more than due to WRMSD [17]. Psychosocial risks at work are also significant in the health of employees in relation to WRMSD. A lot of researchers consider that work stressors have a negative effect on employees' health, which manifests as anxiety, depression, burn-out and cardiovascular diseases [18, 19].

Therefore, in order to avoid health problems related to the effect of ergonomic risks on construction workers, thorough analysis of WRMSD reasons and working out of ergonomic interference plan are necessary [20].

The aim of this study was to determine WRMSD reasons caused by physical load and psychosocial risks at work in painters and tilers in the construction enterprise. 24 painters and 31 tilers participated in this investigation. All of them were males and complained about feeling discomfort (4 months or longer) in different body parts every day after work. Exclusion criteria were: acute musculoskeletal and peripheral nervous system diseases, as well as other diseases.

The study was approved by the Human Ethics and Institutional Review Board of Riga Stradins University, Latvia in 2015.

2 Methods

2.1 Participants

Research group consisted of 24 painters and 31 tilers. Background factors of the research group are shown in Table 1.

2.2 Extended Version of Nordic Musculoskeletal Questionnaire (NMQ-E)

The extended version of Standardized Nordic Musculoskeletal Questionnaire (NMQ-E) was used to assess WRMSD reasons in painters and tilers [21]. The extended version of NMQ-E in our study contains some additional questions regarding body postures, job demands and social support.

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, m ± SD	Mean weight, kg ± SD	Mean BMI, kg/m^2 ± SD
Painters	24	42.17 ± 17.75	18–71	1.71 ± 0.08	79.42 ± 7.10	27.16 ± 2.94
(0–5 years)	9	3.22 ± 1.39	18–39	1.71 ± 0.11	75.11 ± 8.85	25.94 ± 3.42
(6–10 years)	3	39.00 ± 5.57	33–44	1.73 ± 0.08	79.33 ± 1.15	26.50 ± 2.14
(11–20 years)	7	49.14 ± 7.13	38–60	1.70 ± 0.04	84.14 ± 3.53	29.23 ± 2.19
(>20 years)	5	66.60 ± 5.86	65–71	1.73 ± 0.05	80.60 ± 5.59	26.85 ± 2.32
Tilers	31	50.32 ± 16.17	19–72	1.73 ± 0.09	81.13 ± 7.03	27.11 ± 1.74
(0–5 years)	3	21.00 ± 1.73	19–22	1.69 ± 0.01	82.00 ± 3.46	28.60 ± 1.32
(6–10 years)	5	43.40 ± 10.67	36–56	1.76 ± 0.10	81.60 ± 5.86	26.39 ± 2.48
(11–20 years)	14	49.36 ± 12.48	34–72	1.72 ± 0.10	80.43 ± 7.73	27.30 ± 1.55
(>20 years)	9	65.44 ± 7.68	46–71	1.75 ± 0.08	81.67 ± 8.14	26.70 ± 1.60

2.3 Statistical Analysis

The acquired results were processed, using statistical data processing software SPSS.20 [22] according to popular descriptive statistical methods. Confidence interval (95% CI) and prevalence proportion ratio (PPR) were used to indicate the reliability [23].

3 Results and Discussion

Analyzing the participants of the study it should be noted that the involved painters and tilers were at the age of 18–72 with disposition to obesity. It is confirmed by BMI calculation data (BMI > 25). Overweight people are more susceptible to heart and blood circulation diseases, as well as to musculoskeletal health problems. Above mentioned observations are also described in other studies related to construction workers [24]. 75% of them had primary school education, 15% - secondary school education, 10% - professional qualification. All of the involved males were heavy smokers and willingly used alcohol in their spare time, which suggests unhealthy life style and free time activities.

Observing the work process of the participants it was concluded that painters move and lift heavy loads manually, they are subjected to chemical risks, noise and fluctuations of microclimate parameters in the work environment. Work is performed in standing, sometimes in squatting position and kneeling down. Specifics of tilers' work is: work with sharp manual instruments cutting or leveling out tiles, work in awkward position, standing or kneeling down, as well as in squatting or crawling position. Apart from that tilers are more subjected to dust and fluctuations of microclimate parameters in the work environment.

The distribution of persistent complaints in each part of the body and psychosocial conditions, for painters and tilers separately, according to the extended version of Nordic musculoskeletal questionnaire NMQ-E, was shown in the Tables 2 and 3.

Table 2. Distribution of persistent complaints in different parts of the body, psychosocial conditions of painters, prevalence proportion ratio (PPR) and 95% confidence interval (CI), compared with joint group (n = 24).

	Painters* (n = 24)		Reference groups (length of service, years)							
			I (0–5) (n = 9)		II (6–10) (n = 5)		I (0–5) (n = 9)		III (>20) (n = 8)	
	Number	%	Number	%	Number	%	Number	%	Number	%
			PPR	(95% CI)	PPR	(95% CI)	PPR	(95% CI)	PPR	(95% CI)
Neck	20	83	7	78	3	100	5	71	5	100
			0.93	(0.88–0.97)	1.2	(1.09–1.27)	0.86	(0.74–0.97)	1.2	(1.03–1.36)
Shoulder	21	88	9	100	3	100	4	57	5	100
			1.14	(1.02–1.26)	1.14	(1.02–1.25)	0.65	(0.57–0.69)	1.14	(1.03–1.22)
Elbow	5	21	1	11	0		0		4	80
			0.53	(0.47–0.59)					3.84	(3.26–4.98)
Wrist/hands	20	83	7	78	3	100	5	71	5	100
			0.93	(0.84–1.04)	1.2	(1.13–1.29)	0.86	(0.67–0.98)	1.2	(1.12–1.24)
Upper back	17	71	8	89	1	33	7	100	1	20
			1.25	(1.11–1.29)	0.47	(0.45–0.51)	1.41	(1.33–1.47)	0.28	(0.26–0.31)
Low back	5	21	2	22	0		0		3	60
			1.07	(1.02–1.18)					2.88	(2.71–3.04)
Hip/thigh	0	0	0		0		0		0	
Knee	15	63	4	44	0		6	86	5	100
			0.71	(0.67–0.75)			1.37	(1.23–1.45)	1.6	(1.35–1.92)
Ankle/shank/feet	3	13	0		0		2	29	1	20
							2.29	(2.14–2.65)	1.6	(1.43–1.76)
Awkward posture	24	100	9	100	3	100	7	100	5	100
			1	(0.96–1.05)	1	(0.96–1.04)	1.00	(0.98–1.04)	1.00	(0.98–1.05)
Physical exhausting	10	42	3	33	1	33	6	86	0	
			0.8	(0.68–0.93)	0.8	(0.73–1.02)	2.06	(1.94–2.21)		
Extensive work	5	21	0		1	33	2	29	2	40
					1.6	(1.42–1.74)	1.37	(1.22–1.45)	1.92	(1.71–1.98)
High work speed	4	17	0		0		2	29	2	40
					0		1.71	(1.59–1.88)	2.4	(2.17–1.56)
Too many job tasks	0		0		0		0		0	
Colleagues' support	12	50	7	78	1	33	2	29	2	40
			1.56	(1.36–1.72)	0.67	(0.46–0.73)	0.57	(0.396–0.79)	0.8	(0.68–1.02)
Supervisors' support	4	17	1	11	1	33	1	14	1	20
			0.67	(0.63–0.72)	2	(1.88–2.16)	0.86	(0.72–1.03)	1.2	(1.14–1.32)

* Multiple answers were possible

Results displayed in Table 2 show that painters mostly complain of discomfort in the neck (83%), shoulders (88%), at the base of the hand (83%) and upper back (71%). After work, 63% note pain and discomfort in knees as well. These problems occur more in younger painters (24.22 ± 7.84), whose length of service in the related profession is from 0 to 5 years (PPR 0.93–1.25; CI 0.88–1.26). In our study it could be related with physical and psychological unpreparedness for work load. It is also proved by information obtained in interviews with painters. Similar complaints appear also among older painters (66.60 ± 5.86), whose length of service in the profession is >20 years (PPR 2.8–1.2; CI 2.78–1.24). Older employees (100%) complain of discomfort in knees as well (PPR 1.6–1.37; CI 1.35–1.92). The employees whose length of service in the profession is 17.29 ± 3.64 complain mainly about discomfort or pain in knees (PPR 1.37; CI 1.23–1.45), upper back (PPR 1.41; CI 1.33–1.47), in the area of the hand (PPR 0.86–0.93; CI 0.67–0.98), neck and shoulders (PPR 0.86–0.65; CI 0.74–0.69).

It may be explained by great length of service in the profession, amount of work affecting hands and upper back, work in bent position, rather often on knees, and fluctuations of microclimate parameters in work premises. It also conforms to the results of other authors' studies which claim that WRMSD are affected not only by physical load, but also by other risks of work environment [25]. Analyzing painters' complaints about work postures, it should be noted that 100% of the participants complained about work in awkward posture. About physical exhaustion at work complained 42% of painters, mainly those with length of service 17.29 ± 3.64 (PPR 2.06; CI 1.98–1.04). Support from colleagues is received by 50% of painters, mainly younger ones from the age group 24.22 ± 7.84 with length of service 0–5 years (3.22 ± 1.39). Supervisor`s support is received by 17% only from different age groups. As to high work speed and too many job tasks, there are practically no complaints. Acquired results allow us to conclude that essential significance in WRMSD origin belongs to interaction between physical load at work and psychosocial risks, and that employees' age and length of service are also significant. Similar conclusions have been made also by other authors [26].

Statistical data presented in Table 3 show that 65% of tilers complain about pain in their neck, 55% - shoulders, 68% - wrist/hands, 48% - low back and 42% - knee. All (100%) of younger employees (21.00 ± 1.73) with length of service in the profession 0–5 years complain about pain in the neck and shoulders, the same refers to employees of age group 49.36 ± 12.48 having length of service 11–20 years (PPR 1.03–1.22; CI 1.01–1.25). About pain in knees and legs more complain older employees (PPR 1.19–2.58; CI 1.13–1.63) with length of service more than 20 years, and 50% of employees whose length of service is 11–20 years (PPR 1.11–0.69; CI 1.10–0.75). Comparing with painters' complaints, it should be noted that 48% of tilers, mainly older ones, acknowledge pain in the lower back (PPR 1.38–0.78; CI 1.35–0.82), but they practically do not have complaints about pain in the upper back. It may be explained by specifics of tilers' work, frequent load on legs and knees, work in crawling position, irregular load on these parts of the body. Statistical data reveals that 100% of tilers in all age groups admit work in awkward postures, 77% complain about physical exhaustion, 55% about work at high speed. This category of employees receives bigger support from colleagues and supervisors than painters: support from colleagues is received by 68% and supervisor`s support by 39% of tilers. About physical exhaustion more have complained tilers whose length of service in the profession is 11 to 20 years (PPR 1.03; CI 0.98–1.03), and above 20 years-older employees (PPR 1.29; CI 1.23–1.35). The employees whose length of service is 11–20 years have admitted work at high speed (PPR 1.03; CI 1.397–1.49), and this group of tilers has also received the greatest support from colleagues and supervisors in their direct work (PPR 0.98–1.02; CI 1.11–1.78). It shows that work load is not divided evenly, and in order to satisfy client's needs, rather often, direct supervisors join the work process. Together with this, rest pauses are not taken, tilers work with physical and mental overload, which significantly affects development of WRMSD.

Table 3. Distribution of persistent complaints in different parts of the body, psychosocial conditions of tilers, prevalence proportion ratio (PPR) and 95% confidence interval (CI), compared with joint group (n = 31).

	Tilers* (n = 31)		Reference groups (length of service, years)							
			I (0–5) (n = 3)		II (6–10) (n = 5)		III (11–20) (n = 15)		III (>20) (n = 8)	
	Number	%	Number	%	Number	%	Number	%	Number	%
			PPR	(95% CI)	PPR	(95% CI)	PPR	(95% CI)	PPR	(95% CI)
Neck	20	65	3	100	3	60	10	66	4	50
			1.55	(1.48–1.61)	0.93	(0.88–0.95)	1.03	(1.01–1.06)	0.78	(0.69–0.82)
Shoulder	17	55	3	100	4	80	10	66	0	
			1.82	(1.73–1.87)	1.46	(1.42–1.51)	1.22	(1.17–1.25)		
Elbow	5	16	0		1	20	3	20	1	13
					1.24	(1.21–1.25)	1.24	(1.22–1.28)	0.78	(0.71–0.83)
Wrist/hands	21	68	0		4	80	12	80	2	25
					1.18	(1.14–1.20)	1.18	(1.15–1.23)	0.37	(0.28–0.45)
Upper back	8	26	0		0	0	7	47	1	13
							1.81	(1.75–1.83)	0.48	(0.46–0.54)
Low back	15	48	0		2	40	10	67	3	38
					0.83	(0.81–0.88)	1.38	(1.35–1.42)	0.78	(0.72–0.81)
Hip/thigh	0	0	0		0		0		0	
Knee	13	42	0		2	40	7	47	4	50
					0.95	(0.89–0.98)	1.11	(1.10–1.15)	1.19	(1.13–1.24)
Ankle/shank/feet	3	1	0		0		1	7	2	25
							0.69	(0.68–0.75)	2.58	(1.56–1.63)
Awkward posture	31	100	3	100	5	100	15	100	8	100
			1.00	(0.98–1.05)	1.00	(0.96–1.03)	1.00	(0.95–1.06)	1.00	(0.96–1.05)
Physical exhausting	24	77	0		3	60	12	80	8	100
					0.78	(0.74–0.85)	1.03	(0.98–1.03)	1.29	(1.23–1.35)
Extensive work	7	23	1	33	1	20	3	20	2	25
			1.48	(1.42–1.54)	0.89	(0.85–0.92)	0.89	(0.86–0.92)	1.11	(1.08–1.14)
High work speed	17	55	1	33	2	40	12	80	2	25
			0.61	(0.58–0.64)	0.73	(0.70–0.79)	1.46	(1.37–1.49)	0.46	(0.42–0.51)
Too many job tasks	10	32	2	67	2	40	3	20	3	38
			2.07	(2.02–2.14)	1.24	(1.19–1.26)	0.62	(0.60–0.63)	1.16	(1.14–1.19)
Colleagues' support	21	68	0		1	20	12	80	5	63
					0.30	(0.25–0.37)	1.18	(1.11–1.31)	0.92	(0.90–1.01)
Supervisors' support	12	39	0		1	20	10	67	1	13
					0.52	(0.48–0.55)	1.72	(1.65–1.78)	0.32	(0.28–0.36)

* Multiple answers were possible

In our study on WRMSD reasons the acquired results conform to studies of other authors showing that construction employees, actually, perform heavy manual work and are employed in awkward postures, they lift and move heavy weight. Health condition of painters and tilers is also affected by other risks of work environment, for example, work in unsuitable microclimate, noise, as well as work at high speed, which in long-term period can cause WRMSD [24–27]. The health and well-being of workers are greatly influenced by exposures not only to occupational hazards in organizational context, but also by risks associated with individual health behaviours [28]. It corresponds with data acquired in our study revealing that painters and tilers spend their leisure time using alcohol and smoking.

4 Conclusion

Results of our study allow us to conclude that causes of WRMSD in painters and tilers, employed in construction, are not only physical risks at work (awkward postures, heavy manual work, load on the back, etc.), but also psychosocial risks (work at high speed, lack of support from colleagues and supervisors), as well as individual attitude towards one's own health. This study reveals that there is no relationship between the increased level of pain or discomfort in body parts with age or length of service. The study will be continued in order to analyze interaction of physical load and psychosocial risks in tillers and painters.

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Ultraviolet Radiation in Sunlight and Artificial Lighting Systems: Are They Alike?

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Abstract. Nowadays, we are urged to avoid the sun to avoid the UVR (ultraviolet radiation) especially since the data indicate that the growing cases of melanoma and cataracts occur due to it. So, we stay out of the sun. Moreover, artificial light has UVR and, even though the amount of UVR under artificial light is much less than under sunlight, the truth is that the time that we spend indoor, with the lights on, is way too much. The light has a great impact on our visual and non-visual requests. These facts are responsible for many of our health complaints. Still, what are the differences between the natural UVR (sunlight) and the artificial UVR (artificial light)? The objective of this paper is, through literature review, examine the way we balance our needs and how we can promote our health and wellbeing.

Keywords: Artificial light · Visual and non-visual · Workplace · Ultraviolet radiation · Vitamin D

1 Introduction

In order to better understand how UVR affects our wellbeing, we start by defining vitamin D. Secondly, we summarise the ranges of UVR and their impacts on our skin, eyes and circadian system. After that, it is important to distinguish between UV production and UV destruction. Then information about UVR in artificial lighting systems is exemplified. However, there are filters for lamps and for windows. Lastly, we discuss about the UVR impact on indoor and outdoor workers.

2 Literature Review

2.1 Sunlight & Vitamin D

Since the beginning of life on Earth, sunlight has followed human evolution, and that is the main reason why we are adapted to the complete solar spectrum; it is an archetype of natural and healthy light [1, 2]. Sunlight has both protective and detrimental impact on human health, and when exposure is low it can cause seasonal affective disorder (SAD), rickets, and too much exposure can cause melanoma (skin cancer), cataract

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(opacity in the lens of the eye) and other eye diseases [3–5]. But, somewhere in the middle, there is the right amount of human exposure under sunlight. There are many benefits from sunlight, such as the production of Vitamin D, which only occurs when we are exposed to UV-B radiation (between 290 and 320 nm) [6, 7]. It is necessary that the exposure is not for too long so that we do not tan much [8]. In order to promote the production of vitamin D when in times of stress the amount of additional cholesterol increases [7], so it is essential to have cholesterol in our diet [8]. For instance, when in times of stress, the amount of additional cholesterol increases and we deplete our reserves to promote the production of vitamin D. The provitamin D7 is transformed into pre-vitamin in the outer skin, and in the liver and kidneys the bio-form D3 (Fig. 1) is formed [2]. This phenomenon was found by Adolf Otto Reinhold Windaus who received the Chemistry Nobel Prize in 1928 for his discovery of vitamin D3 [9]. In addition, the most food and supplements produce D2, which is a different type of Vitamin D. Therefore, the UVR is very important. Vitamin D (under UV-B) have a protective effect on health in diagnostics as depression, cancer, cardiovascular disease, influenza, diabetes, skin diseases (psoriasis, atopic dermatitis, vitiligo but it is also associated with a higher risk of such scourges as multiple sclerosis, tuberculosis and many forms of cancer, liver spots, actinic keratosis and solar elastosis [3–5, 10, 11]. Furthermore, it is essential for a healthy skeleton to consume calcium and phosphorus. UV-A is responsible for photo ageing, bone disorders, immune-suppression of the skin, immune system and potential enhancement of the negative effects of UV-B exposure [12, 13]. In order to produce 25.000 international units of Vitamin D the skin have to be exposed to sunlight for about 20 min. Even though, there are some conditions that can foster production of vitamin D, such as being young, not obese, for instance, have light skin, when it is summer, in the middle of the day, a greater percentage of skin exposed to the sun and not all parts of the body produce the same quantities of vitamin D (hands and face almost do not produce vitamin D, and chest is the body part that produces the most), when we are lying down (like at the beach), if we are without sunscreen and if we are near the Equator [8, 14]. However, sunscreen with factor 15, for instance, reduces solitrol (Vitamin D) production by 99.9% [20]. Women aged between 20 and 55 years living in a polluted area (urban) have a higher risk of developing vitamin D deficiency [15]. Those who are obese may require two to three times more production of vitamin D in order to satisfy the minimum requirements [9]. Also, as we age the skin loses production capacity of synthesize vitamin D [15]. Exposure to UV-B is very important for our health because there are very little food contains natural D3 and food that is fortified do not fulfil the vitamin D requirements [16, 9]. Moreover, in winter months (November to February), no production of vitamin D3 is found, at latitudes of 42°N, and the same happens at latitudes of 52°N from October to March. It is not easy to get the right quantity of vitamin D (Fig. 2) [5]. In nature bright blue light always comes with UVR. The hypothalamus has to coordinate different hormone concentrations and adapt them to the environmental conditions. There is one very important hormone that is not excreted by a gland but produced directly in the skin under the influence of ultraviolet radiation with wavelengths between 290 and 320 nm: the so-called Vitamin D.

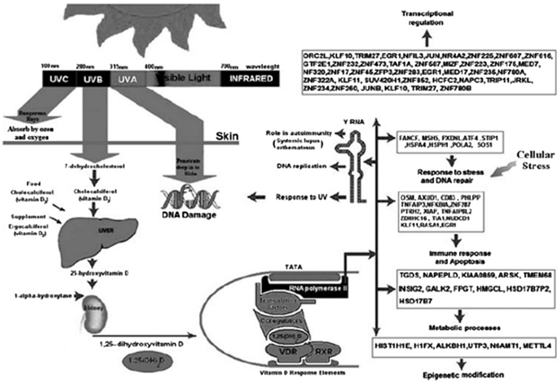

Fig. 1. Biological functions for genes whose expression levels were altered after 2 months of vitamin D3 supplementation. After receiving vitamin D3 supplementation were identified 291 genes whose expression was significantly decreased or increased. Some of these genes influence several pathways that are involved in response to stress and DNA repair, DNA replication, immune regulation, epigenetic modification, transcriptional regulation and other biological functions. In addition, vitamin D3 supplementation influenced the expression of Y RNA and CETN3 that are involved on DNA repair in response to UVR exposure [9].

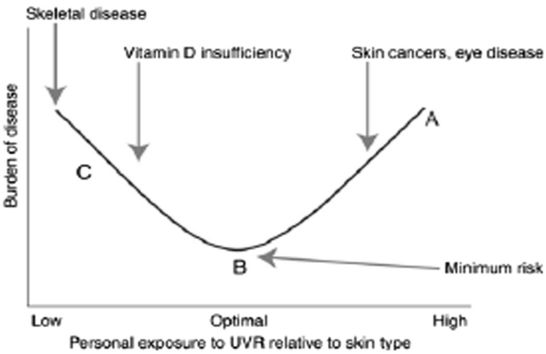

Fig. 2. Schematic diagram of the relation between UVR exposure and the burden of disease. Points A and C represent inappropriate UVR exposure. Fair-skinned populations in Australia with high outdoor UVR exposure typify point A. Point C represents people with insufficient UVR exposure, whose dietary vitamin D intake will also be important in determining their vitamin D status. Point B represents optimal UVR exposure: a person with correct UVR dose for skin type [5].

In order to enlighten the several impacts on our body and mind, let us begin with the definition and distinction of different wavelengths.

2.2 Ultraviolet Radiation

The solar radiation (SR) is composed of ultraviolet radiation (UVR), visible radiation (light) and infrared radiation (IR). UVR (Fig. 3) is often divided into 3 wavelengths:

UV-A (315–400 nm) - the weakest, UV-B (280–315 nm) and UV-C (100–280 nm) - the strongest, like proposed by the Second International Congress on Light in 1932 [2, 5, 10, 11] However, dermatological and environmental photo biologists use values slightly different. Visible radiation (380–780 nm) and Infrared includes IR-A (780–1400 nm), IR-B (1400–3000 nm) and IR-C (3 µm–1 mm) [2].

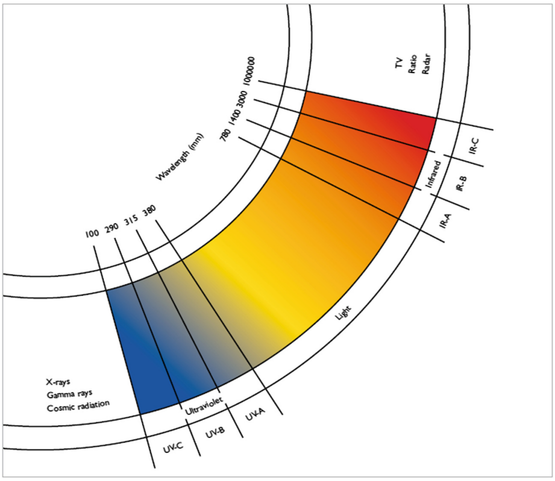

Fig. 3. Spectrum of the Sun [2].

Only 60% of the UVR are responsible for driving life on Earth, the remaining 40% is reflected back into space. Ultraviolet (UV) radiation (R) is produced mainly by the sun, and almost (95%) of the UVR that reaches the Earth is in the UV-A range, and a smaller amount (5%) is UV-B [11, 17]. There are many factors that UVR depends on, such as the time of day (a third of the daily UVR is produced from 11 a.m. to 1 p.m. and the other three-quarters between 9 a.m. and 5 p.m.) [15, 17], season of the year (UV rays are weaker in winter time) [17] (Fig. 4, on the right), distance from Equator (latitude 0°, as we get further away from the Equator the weaker the UVR is) [9], altitude (UVR increases with altitude, by 6–8% per 1000 m) [14, 5, 17]. In fact, in the summer at noon, the UV is more intense due to a shorter distance between the Sun and the Earth´s surface, and the UV-B is more intense (two-three times more) in Equator, when compared with northern Europe (Fig. 4, on the left). In addition, direct and scattered (diffuse) are the components of the solar radiation, where direct is characterized by the rays from the sun that passes through the atmosphere and the scattered is diffuse by air molecules and depends on the wavelength [17]. Another factor that contributes for this effect is the weather conditions, such as a cloudy day (a clear sky have higher UVR, although at certain conditions clouds could enhance UVR) [10, 14, 17], whereas on days with scattered clouds we have to spend more 10% of time exposure, on broken clouds we need to stay more 27% of the time and, finally, beneath overcast it is advisable to spend more 68% of time [8]. In addition, we have to count with reflections from surfaces, such as grass, soil, water (less than 10%) snow (80%), and sand (25%) [10, 17]. Also, we must realise that the ozone layer filters completely the UV-C radiation [8] and absorb UV-B which it is the reason for the annual variation, compared with the UV-A, conversely the ozone depletion lead to a UV-B radiation increase [10, 11, 14]. Pollution, also, filters out UVR [11, 15]. In addition, the different UVR ranges have different impacts on humans, the UV-A, for instance, can alter the structure of collagen and elastin fibres, cause skin-ageing (wrinkles) and can cause indirect damage on DNA. UV-B, are the main responsible for direct damage to the DNA, can cause sunburn and thought to cause most skin cancers. UV-C, is filtered by the ozone layer, but it can be present in some man-made artificial light, such as arc welding torches, mercury lamps, and used to be present in the sunbeds [10, 11].

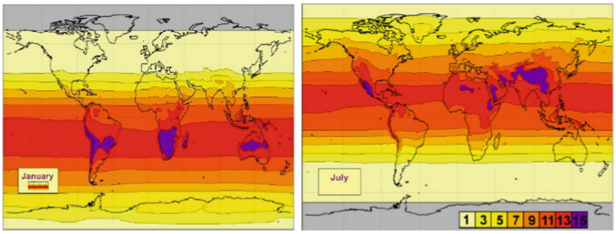

Fig. 4. Estimation of global geographical distribution of the UV Index in the winter (January) and summer (July) months at noon, for clear day [11].

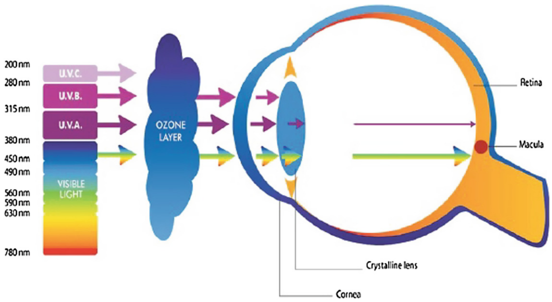

Fig. 5. Absorption and transmission of solar radiation in the eye. The cornea and crystalline lens filter out UV-B and most UV-A, so that the most energetic light reaching the retina is short wavelength blue-violet light [19].

Nevertheless, there is more into it, the light has great impact on human health, which can be divided into three ways: the radiation exposure can damage the eye and the skin, on photochemical and thermal systems, and the visual and the circadian systems [4, 12]. The eyes and the skin are the organs more exposed to UV rays [11]. At the eyes it can cause many conditions, such as the formation of cataracts (opacity of the lens), photo keratitis (snow blindness) photo retinitis (also called blue-light hazard) [4] and pterygium (tissue growth on the surface of the eye) which can lead to impair vision [10, 11, 16]. UV-C exposure of the eyes, for instance, can cause DNA damage, lead to cataract formation and retinal damage [18]. Fortunately, the eye has some mechanisms of defence (Fig. 5). Some of the damages can be repaired although the repair mechanisms become less effective with age [4]; moreover, damages can be accumulated over lifetime. Sunglasses with UV-A and UV-B filters are very important for children [11] under 9 years of age, when their retinas are less protected.

Besides the impact at the eyes, there is, also, the impact on the skin. However, we must keep in mind that UVR is also dependent on the sensibility of the individual [11]. As a matter of fact, a skin type I, produces six-times more vitamin D than a skin VI [14]. Even though, the skin has protective mechanisms such as the production of melanin (tan) [11]. The darker the skin, the less will be affected by radiation [2]. The skin is the largest organ of human body, and it is, constituted by the dermis, which contains the collagen fibres, gives the skin its elasticity where the skin-aging is a result of elasticity decrease (Fig. 6). The UV-A reaches the epidermis [6], but UV-A only reaches the dermis, the capillary layers and the blood vessels [6]. Some of the biological effects of UV-A to skin are: it generates free radicals and causes indirect DNA [2, 9, 18] damage (malignant melanoma), due to the fact that UV-A penetrates deeper which contribute for the damage of the collagen fibres, destroys vitamin A [2, 18], reduces skin and blood antioxidants [16]. Whereas skin exposure to UV-B causes erythema (sunburns), malignant melanoma, although it has positive effects, also, such as the moderate doses induce the production of vitamins D and K [18]. Melanin, is a natural protection of the skin that is produced in response to UV-B exposure, and acts as an antioxidant and reduce the damage on the cells by free radicals [21]. Cloths such as hats and sunscreens are a protective measure of the UV negative effects [5, 14] as well as Mediterranean diet [2, 15, 16]. Also, monosaturated fats in our diet, such as almonds, will help to increase bio-availability of vitamin D from the UV-B radiation [8]. Another protective factor is the Omega-3 characterised by fatty acids [16] and Vitamin D may also reduce damage in the skin induced by UVR [16], even though UV-B exposure showed no significantly increase in the risk of skin cancer [2].

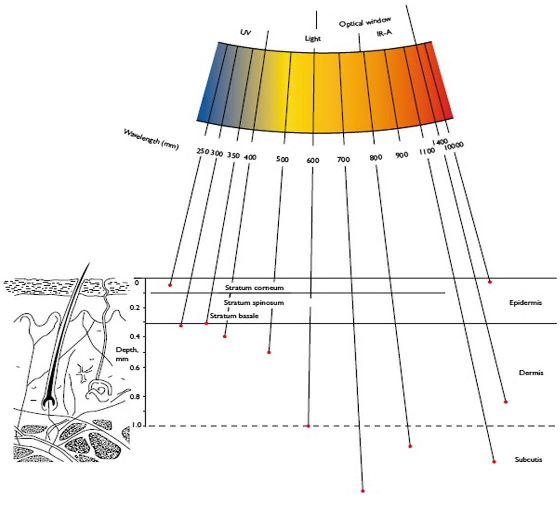

Fig. 6. Skin penetration depth of optical radiation [2]

As far as the impact of light on the circadian system [4] is concerned, the light received by the eyes is transmitted through the optic nerve and reaches the pineal gland, which is connected to the hypothalamus. The synchronization of circadian rhythms is related to the hormonal system, and the result is perceived by the alertness fatigue, and emotional levels (Seasonal Affective Disorder, SAD) [13]. As stated above, sunlight regulate various body functions, and it is a great disappointment that western society gives more attention to the negative effects of UV [2]. Even if with an UVR exposure equal to zero some of the diseases still occur, without vitamin D this situation gets worse. For instance, the pituitary gland and pineal are antagonistic organs in the brain, which regulates the endocrine and the circadian systems, respectively, and at the same time react to light through the eye and skin. The pituitary is of extreme importance since it induces the stress hormones production (like cortisol) and the pineal gland is responsible for melatonin production. In addition, it is important to juxtapose what could be the results of UV and how it impacts in our physiological system.

2.3 UV Production vs UV Destruction

In spite of that, vitamins are by definition substances which the body cannot produce independently, Solitrol (Vitamin D) is antagonistic to melatonin, whereas melatonin concentration is higher the risk of cancer is lower. Furthermore, while UV builds up Solitrol (Vitamin D) in the capillary layers of the skin, other hormones like steroids are destroyed under the influence of this radiation. This endocrine reduction is compensated by the activation of retinohypothalamic tract, which promotes the new hormone production [6]. One of the main reasons of this paper construction, is to point out that the UV contained in the man-made artificial light do not have the same behaviour. The artificial light, especially with high colour temperature tells to the brain through the eye the amount of UV outside that it is time to build stress hormones, but Solitrol does not come, and the stress and sex hormones are not destroyed (Fig. 7). This happens because there is no UV-B, or not enough, in the light and, in addition the skin is

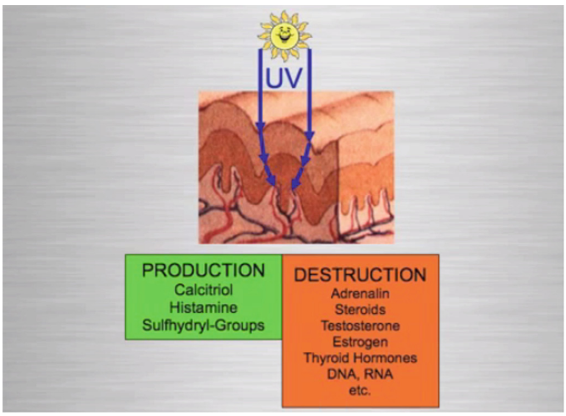

Fig. 7. Dermal photo transduction: photochemical skin reactions [20].

covered by clothes, which when in long term conditions can lead to cardiovasculatory diseases and hormone-dependent cancers, such as breast cancer [6]. So, it is important to understand the UVR presence in the artificial light.

2.4 Artificial Light

UVR and infrared are present in artificial light, which means that some lamps produce significant infrared and ultraviolet radiation. A side effect is that we are exposed to UVR at indoor environments - such as workplace - without knowing [4, 12]. Fortunately, the infrared radiation repair the oxidative damage caused by blue light and UVR (Fig. 8) [1] but incandescent lamps, which are mainly red light, are no longer produced or available for consumption. UVR is produced mainly by gas discharge lamps (low pressure mercury), fluorescent lamps (and compact fluorescent lamps - CFL) and light-emitting-diodes (LEDs) [11].

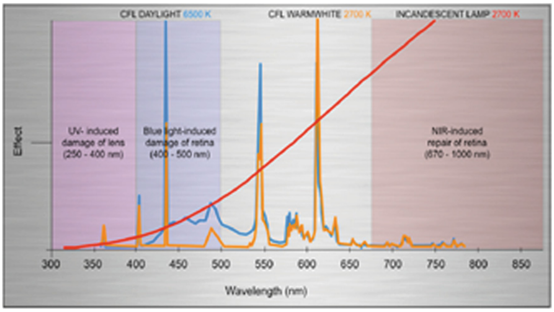

Fig. 8. Spectral ranges responsible for retinal damage and repair correlated with spectral energy distribution of different lamp types [1].

The incandescent lamp produces clean light without modulation frequencies and flicker [6]. Incandescent light sources avoid unwanted hormonal malfunction [1]. However incandescent lamps are no longer available since they have been discontinued. Tungsten halogen lamps are used at home and at workplaces, and when unfiltered they can cause injury at short distance, as for example, task lights [4, 12, 16]. The problem is that they have been recently discontinued also. So, there are only two lighting systems left: Fluorescent and LED. Fluorescent lamps are commonly used at workplaces. Although these lamps emit small amounts of UV the exposure to it accumulates over the day, which could cause some risk to skin and at the eyes. Besides, UVR emission, fluorescent lamps contain mercury vapour [6]. And, this is an issue that it is worthy to clarify, since mercury is a toxic substance which is very difficult to eliminate and the body deposits it in tissues with a low metabolic activity so we can find it in the neuronal myelin sheaths of the brain [6], Myelin wraps axons then are responsible for the communication between neurons, i.e. synapses. Another fact is that in the past the human was attuned to sunlight, but nowadays man is attuned to mercury, so this is a real problem and most of us do not realise it. In addition, the discharge on the mercury atmosphere produces UVR [13]. This being stated, let us get back to UVR presence in fluorescent lamps. So, in the UV-B range there are TL/01 and TL/12 lamps, which are mainly used in phototherapy and, in the UV-A region there are TL/09 and TL/10 used in photochemotherapy and phototherapy [2]. Moreover, UVR is used for cosmetic treatment of the skin [11]. So, all fluorescent lamps emit some UV. Typical fluorescent lamps, including CFLs (compact fluorescent lamps), emit very low levels of UV. Depending on the mercury vapour pressure we can have: low-, medium- and high-pressure mercury lamps [2]. Whereas low-pressure mercury (254 nm, UV-C range) is used for sterilization, disinfection (water and waste, for example) [2], the medium-pressure mercury lamps emit the same UV power but can be made more compact [11]. And, high-pressure mercury lamps emit more radiation below 215 nm (UV-C range) [11]. Like traditional tube-style fluorescent lamps, CFLs contain a small amount of mercury as already stated. Typical household CFLs contain less than 5 mg of mercury (size of the tip of a pen). Though CFLs do not emit mercury as they operate, only when the outer glass tubing that contains the mercury breaks [21]. LEDs spectrum is above 400 nm, which is not within the UV light wavelength but, instead is in the blue light range. The output of a UV LED, is in the 368-nm range [11], so relatively pure blue light from the LED has almost no UV [21]. However, exposure for long periods of time will have some impact. At outdoor environments, we can find sodium vapour lamps which are used essentially in street lights. The sodium-vapour bulb is extremely efficient, producing large amounts of yellow light with little electricity and it contains virtually no UV [21]. Furthermore, we must have in mind, that there is a large and increasing number of fluorescent light sources in our environment which produce high amounts of photooxidative potent light, such as mercury vapour lamps with high colour temperature, like for instance the backlight of TFT computer screens and TV sets [1]. So, it is important to understand how, and if there is that possibility, we can avoid the downside of UV-A and, maybe, increase UV-B exposure, when indoors.

2.5 Filters

As for filters, there are some ways to avoid UVR. Let us begin with the luminaire and afterwards we will discuss about windows filters that can be used. For instance, UVR from tungsten halogen lamps can be reduced by using a glass cover [4]. CFLs should not be allowed for more than 60 min at distances less a 0.30 m [4]. Dyes can absorb UVR. HID (High intensity discharge) lamps emit significant amount of UVR and like tungsten halogen can be minimized with a UV filter [12]. The glass used in CFLs already provides a UV filtering effect. In addition, any additional glass, or plastic, or fabric used in lighting fixtures that is between the individual and the CFL will act as additional UV filters and by increasing the distance between individual and any radiation source, will also reduce the small level to a lower level [21]. On the other hand, there are also window filters such as UV-filtering window films which are flexible films that adhere to glass and block UV and visible light. Films that filter mainly UV light are clear (usually with a slight yellowish cast when viewed on edge), while to filter visible light the film must be tinted or coated. The majority of films available now nearly eliminate UVR, elimination of UV light is typically stated as 95–99% or better in the range of 200 to 380 nm. Window films are usually laminated polyester film layers modified with material that absorbs, scatters, or reflects UV and visible light. Most often films are impregnated with dyes or carbon particles or coated with a layer of magnetic sputter vapor deposited metal to accomplish the desired results. Metallic coatings, usually aluminium, will reflect incident light, thereby reducing the transmission of UV and visible light and can also create a reflective mirror-like surface from the exterior. There are non-reflective/metallic options that can also reduce glare on the interior. The UV absorbers can be built into the film base, coated on the film, or applied in the adhesive. They can be applied to interior windows, storm glass, or used as roller blinds. Often window films are applied to the interior window surface. Films made for exterior application are more expensive and guaranteed for about half the amount of time, because they are prone to peeling due to exposure to the elements. Interior films are generally guaranteed for 10–15 years. Films can be removed with solvents, such as paint strippers, ammoniated solutions, or odourless thinners. Besides, window film can, in summer, cuts down heat within the home, reducing air conditioning expenses, and in winter, some films reflect interior heat back into the house, reducing heating costs and it helps keep sunshine from fading upholstery and home furnishings [22, 23]. Filters can be very important since chronic exposure to UV-A rays through windows may accelerate skin aging by 5 to 7 years. More than 90 percent of skin cancers and the visible signs of skin aging, are caused by the sun [23]. So, what is better for us, to stay indoors or to go out?

2.6 UV Indoor versus UV Outdoor

There is some contradiction when we compare workers working in indoor and outdoor environment. Although, outdoor workers are exposed more time to UVR than indoor ones, there are an increased incidence of malignant melanoma for indoor workers. UV-A radiation passes through windows, which can break down vitamin D3 formed after outdoor exposure. So, production of the provitamin D3 only happens under sunlight. Vitamin D3 can be converted to its most hormonally active form, calcitriol, which kills melanoma cells in vitro and reduces tumour growth in vivo. Therefore, indoor workers may be at a higher risk of malignant melanoma. Besides, UVA window exposures can cause negative biological effects such as photo-aging among others. In addition, indoor workers are exposed to minor amounts of UV-A and UV-B from fluorescent lights [24].

3 Discussion

Presently, many dermatologists and physicians strongly recommend us to avoid sunlight as a countermeasure to melanoma formation. The melanoma, particularly the malignant cases are increasing worldwide, as the other immune diseases. So, they are suggesting that we spend, more time indoors, especially between 11 a.m. and 16 p.m., which is when the UV-B radiation is at its peak. The simple fact that the present society spend 90% of their lifetime indoors, where the mainly light available is artificial and the only way that we receive UVR is from the windows and from artificial light sources itself, although this last fact is unknown for the most the indoor workers, it isn´t the best answer. Because of the fear of skin cancer people continually avoid sunlight, and what is worse is that they think that before and after this UVR time, there is no risk of melanoma, but, it is the opposite that is true. Our windows glass and lamps could help us to decrease UV-A and to increase UV-B but as already stated the impact on our endocrine system can never be ignored. So, how can we balance our needs? Well, it seems that the best solution is have an access to outdoor environment of some kind. If we think in our workplace it can be hard to fulfil our needs, on the other hand if we change our way of conceiving spaces we might achieve the equilibrium. If we start to think of indoors environments with a place where we can be outdoor for pauses for instance, then we begin to have some answers to our needs. Spaces like patios, indoor gardens, where we simply can get some sun we will have a more balanced vitamin D production, we will not endanger our endocrine system, not so much at least, we will promote our health which will improve our wellbeing and help us to achieve a better performance at work. So, what are we waiting for? Let begin to change our way of thinking and of conceiving spaces for a "sustainable self" and not be concerned merely with energy costs.

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Ergonomic Risks of Physical Load on Administrative Workers in a Higher Education Institution 2015-Cartagena

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Abstract. In this paper, we identified ergonomic risks of physical load on a group of administrative workers of an Institution of Higher Education, Cartagena, Colombia, through a descriptive study conducted between July and December 2015. A questionnaire usage to collect the information that had into account demographic variables, working conditions and ergonomic risk factors of physical load; results were analyzed with Excel 2.5 tools. Most of the population belong to the female gender (70%) in the age range of between 20 and 29 years; with a type of fixed-term contracts (57%); the most relevant ergonomic aspects were: work in sitting posture more than 8 h (34%), poor postural hygiene (88%) no active breaks (89%) and lumbar muscle discomfort (89%). In conclusion, poor postural hygiene, absence of active breaks and lumbar muscle discomfort were the most important occupational characteristics in this study.

Keywords: Lumbar pain · Human-ergonomics · Health at work

1 Introduction

Ergonomics according to the International Association of Ergonomics (IEA) is the "scientific discipline that deals with interactions between humans and other elements of a system, as well as the profession that applies theories, principles, data and methods to the design, In order to optimize the well been of the human being and the overall result of the system" [1].

One of the subjects of study of Ergonomics is the workload, which are all the psychophysical requirements to which the worker is been exposed during its working day.

The physical workload are all those factors or physical requirements that the worker performs during his work environment and that involves the use of the skeletal and cardiovascular muscle system. These factors are Postures, Strength and Movements; and only represent a danger when the individual's responsiveness is been exceeded or there is no adequate biological recovery of tissues.

Continuous exposure to physical overload can lead to injury to the musculoskeletal system, resulting in musculoskeletal disorders, which the World Health Organization says, "are multifactorial problems involving physical environment factors, work

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organization, psychosocial factors, Individual and sociocultural and lumbar pain is part of these work-related disorders" [2].

A systemic review by the National Institute of Occupational Safety and Health (NIOSH) concluded that lumbar pain is within the group of "work-related musculoskeletal disorders caused by occupational exposures. For which there is strong evidence and are heavy physical work, lifting of loads, forced postures of the spine, flexion movements and trunk turns, static postures, vibrations and organizational and psychosocial factors" [3].

Same as the National Institute of Occupational Health and Safety, a study by Gómez-Conesa and Méndez Carrillo "determined that the causes of the origin of lumbar pain are related to the work environment, where the muscular structures, ligaments and bones of the spine Vertebral are exposed to a physical overload of work" [4].

The report on occupational diseases (2001–2002) in Colombia concluded "that musculoskeletal disorders can be studied from two perspectives: firstly, from the analysis of the consequences of adopting a state policy of labor flexibility. On the other hand, from the perspective of musculoskeletal injuries associated with intensification and densification of work" [5].

The progressive increase of this type of lesions could be notice on the evolution of the professional disease in Colombia [6]. The same report presents, among other data, the indicators related to the disorders that affect the musculoskeletal system in workers affiliated to the risk prevention system in Colombia; There is evidence that during the year 2004, 15% of the diagnoses corresponded to these pathologies.

Unlike the carpal tunnel syndrome, lumbar pain presented an increase, going from 12% to 22% in 2001 to 2003, although its incidence decreased in 2004. In addition, it is established that during 2004, the five the most frequently identified occupational pathologies in men were lumbar pain (27%), carpal tunnel syndrome (SCC 13%), intervertebral disc disorder (TDIV 12%), Hearing Loss Neurosensory (SNS 11%) and rotator cuff syndrome 6%). These pathologies accounted for 69% of all pathologies diagnosed in men during that year [7].

In the Executive Report of the Second National Survey of Occupational Safety and Health Conditions "occupational risk factors of posture, repetitive movements and load manipulation, proved to be the agents with the highest reports in the evaluated work centers and injuries Skeletal muscles were the occupational diseases with greater attention in the managers of occupational risks" [8].

This leads to the analysis that the mostly of the population of Colombian workers become ill due to exposure to these factors, indicating that effective plans and greater management in prevention in the field of occupational hazards are still needed, designing healthy work environment.

Likewise, the International Labor Organization, the World Health Organization and the Secretary General of the Ibero-American Social Security Organization "make reference to the fact that in Latin America the economic impact due to accidents and occupational illness correspond to 10% of the region's GDP, 3.5 times more than in Europe and the United States. It is a high cost in these developing economies, which implies developing policies that help curb the economic impact that is currently generate by the lack of strategies to prevent occupational diseases" [9].

Non-specific back pain or non-specific low back pain (ICD 10: M54) is defined as localized pain or discomfort between the lower limit of the ribs and the lower limit of the buttocks, the intensity of which varies depending on posture and physical activity. It is been usually accompanied by painful limitation of movement and may or may not be associated with referred or irradiated pain. The diagnosis of non-specific low back pain implies that the pain is not due to fractures, trauma or systemic diseases (such as spondylitis or infectious or vascular, neurological, metabolic, endocrine or neoplastic conditions) and that there is no proven root compression or indication of surgical treatment. The average duration of symptomatic episodes is 4 weeks with or without medical treatment.

Several epidemiological studies that have investigated the causal relationship with different exposure factors, so many physical, organizational and psychosocial [10]. Physical and biomechanical factors include lifting loads, heavy physical work, twists and turns (forced postures), performing repetitive movements, static working posture, whole body vibration, environments with inadequate thermal environments.

Organizational and psychosocial risk factors includes: jobs with high psychological demands, lack of control over tasks, low autonomy, low level of worker satisfaction, monotonous and repetitive work. In the individual factors or associated to the worker's own characteristics are personal history, age, sex, obesity [11].

The administrative staff of the companies are predisposed to suffer musculoskeletal injuries mentioned above. It because during the performance of their work are present movements such as: flexion or rotation of the neck, abduction or shoulder flexion, shoulder lift, flexion of elbow, wrist extension or flexion, ulnar or radial deviation of the wrist, finger extension or flexion, highly repetitive movements, movements with a force component and inadequate postures. In addition to those indicated in the dimensional aspect of the workplace [12].

Posture at work is an important element to consider; the development of sedentary activities is been deeply linked to the cultural and technological patterns of this civilization. It can affirms that the sedentary posture is the most frequent body position, taking into account the number of hours that we spend sitting during the day in the means of transport, in the workplace, or in leisure activities.

We carried this work out in an Institution of Higher Education in the city of Cartagena.

The administrative processes done by the workers are admissions, credit and portfolio, academic secretaries, dean secretaries, human talent, quality, among others. Normally it works in the schedule of eight of the morning to six and a half of the afternoon of Monday to Saturday; In the process of enrolment the work might extended until seven or eight at night.

The study focuses mainly on a group of administrative employees, approximately 30 people, and with them, we intended to demonstrate how their demographic characteristics, working conditions and the ergonomic risk factors of physical load to which they are exposed are, leading to come out of musculoskeletal disorders, in this case, occupational lumbar pain.

2 Materials and Methods

The research was kind descriptive and was carried out in a Higher Education Institution in the city of Cartagena during the period July-December 2015 and the sample consisted of 30 administrative workers. The selection criteria were age, sex, seniority level, physical effort, work timeframe, among others. The 30 workers (100%) got into the study by simple random sampling [13], from the general population of workers who are in the administrative area.

The group of researchers carried out a sensitization that the workers understood the reason for the investigation, in order to be clear about the objectives of the investigation. A questionnaire was applied that contained questions about demographic characterization variables, working conditions and physical risk factors; In addition, the Nordic Kourinka questionnaire was used as a guide for the analysis of musculoskeletal symptoms, in which its ask about of muscle discomfort [14]. The results tabulated and analyzed using Excel tools.

2.1 Demographic Characteristics of Workers

Tables 1, 2, 3 and 4 shows the results of this variable; it was possible to show that 70% are female and the other 30% is male. These gender distinction as results allowed focus the questions of the questionnaire. The age range that showed the highest proportion is between 20–29 years, with 54% of the population surveyed, followed by the 30–39 year interval with 36%; In terms of height to the range of 150–160 cm corresponded 66% while for the weight the most representative range was 61–70 kg (43%). It was possible to show that the population of workers is young, both men and women and is the most vulnerable to this problem and have a healthy body mass index (BMI) [15].

Table 1. Distribution of gender

Age	Number of people	Percentage
Male	9	30%
Female	21	70%
Total	30	100%

Table 2. Distribution according to age range

Age	Male	Female	Percentage
20–29 years old	4	12	54%
30–39 years old	4	7	36%
40–49 years old	1	2	10%
Total	30		100%

Table 3. Distribution according to height

Height	Male	Female	Percentage
150–160 cm	4	16	66%
161–170 cm	5	5	34%
171–180 cm	0	0	0%
>180 cm	0	0	0%
Total	30		100%

Table 4. Distribution according to weight

Weight	Male	Female	Percentage
De 50–60 kg	0	8	26%
De 61–70 kg	1	12	43%
De 71–80 kg	4	1	17%
>80 kg	4	0	14%
Total	30		100%

2.2 Labor Conditions

Table 5 describes this variable. Fixed-term contracting accounted for 57%, followed by the type of labor contract (36%), and finally the indefinite rate (7%).

Table 5. Distribution according to type of contract

Age	Male	Female	Percentage
Undefined	1	1	7%
Fixed term	4	13	57%
By work	4	7	36%
Total	30		100%

2.3 Ergonomic Risk Factors of Physical Load

Table 6 shows the distribution according to gender and posture at workplace, in both genders is predominant on people who do not have a good posture. Mostly people, from both genders, are more than 8 h at the job site in a seated position (Table 7). On the other hand, the majority of men (56%) and women (52%), reported to be expose to the same posture (Table 8). Regarding postural hygiene, the majority of women (67%) and men (88%) reported not knowing the correct way to sit/stand up (Table 9); Both males (56%) and females (71%), frequent backstroke was the predominant physical effort followed by bending (19% in females and 33% males. In both genders, there was also a predominance of people with lumbar muscle discomfort (89% men and 71% women). In addition, 66% of men reported to have an illness in the lumbar zone as compared to 57% of women. 66% and 89% of women and men respectively, do not take active breaks at the workplace; (44%) followed by dancing (22%) and no activity (22%), but in the female gender, on the other hand, the largest fraction did not play any Activity (42%), while dancing was practiced by 33% (Tables 10, 11, 12, 13, 14).

Table 6. Distribution according to the position at workplace and gender

Good posture in the workplace	Male	%	Female	%
Yes	4	45	9	43
Not	5	55	12	57
Total	9	100	21	100

Table 7. Distribution according to exposure time in sedentary position and gender

Exposure time in sedentary position	Male	%	Female	%
From 1–3 h	2	22	3	14
4–6 h	2	22	5	24
De 6–8 h	2	22	6	29
>8 h	3	34	7	33
Total	9	100	21	100

Table 8. Distribution according to exposure to the same posture and gender

Exposure to the same posture	Male	%	Female	%
Always	5	56	11	52
Frequently	3	33	9	43
Sometimes	1	11	1	5
Total	9	100	21	100

Table 9. Distribution according to postural hygiene and gender

Postural hygiene	Male	%	Female	%
Yes	1	12	7	33
Not	8	88	14	67
Total	9	100	21	100

Table 10. Distribution according to the frequent physical effort and gender

Physical effort	Male	%	Female	%
Getting up frequently	1	11	2	10
Bending down frequently	3	33	4	19
Turning back frequently	5	56	15	71
Any	0	0	0	0
Total	9	100	21	100

Table 11. Distribution according to lumbar muscle discomfort and gender

Lumbar muscle discomfort	Male	%	Female	%
Yes	8	89	15	71
Not	1	11	6	29
Total	9	100	21	100

Table 12. Distribution according to frequency of lumbar pain and gender

Frequency of lumbar pain	Male	%	Female	%
Always	6	66	12	57
Frequently	2	22	8	38
Sometimes	1	12	1	5
Total	9	100	5	100

Table 13. Distribution according to practice of active pauses and gender

Practice of active pauses	Male	%	Female	%
Yes	1	11	7	34
Not	8	89	14	66
Total	9	100	21	100

Table 14. Distribution according to extra-labor activities and gender

Extra-labor activities	Male	%	Female	%
Walking/jogging	1	12	2	11
Play soccer	4	44	0	0
Dance	2	22	7	33
Gymnastics	0	0	3	14
Any	2	22	9	42
Total	9	100	5	100

3 Discussion

The findings show that the study is in the age range in which, according to some authors, lumbar pain is more frequent [16, 17]. Therefore, the institution where the study was performed must consider this factor, in order to generate plans that favor the health of workers.

Among men, lumbar pain was as frequent as among women, with a higher number in males; this could be in agreement with the work done by other authors [18, 19].

Stature is another factor necessary to consider in the population studied, to apply preventive measures, because most of them oscillate in the range where other authors have demonstrated that the highest frequency of lumbar injury found [20]. Although the association between obesity and lumbar pain, it is supported by different investigations by Feldestein et al. [21] in work personnel, according to Helliovaara [22], Weight ratio does not have relationship to lumbar pain because it is not present in a high percentage of obese workers.

Exposure time (age at the workplace) also proved to be an important variable in the onset of lumbar pain. Workers with more than 15 years of work had a higher possibility than those with less time. This is most evident in the case of workers over 25 years of age compared to those who only had 5 years or less in their position. The possibility is 1.5 times greater in the first case and twice in the second. According to Stubbs [23], there is reasonable evidence to associate back symptoms with the following work factors: work physically heavy, static work postures, frequent trunk flexes and turns, powerful lifts and movements, repetitive work and vibrations.

According to the European Agency for Safety and Health at Work [24], occupational risk factors for which there is evidence, at different levels, about their association with the occurrence of lumbar pain are heavy physical labor, lifting heavy loads and force posture at column level. flexion and trunk rotation movements, exposure to whole body vibration, static postures, psychosocial and work organization factors.

In another study about lumbar pain and its relation to work [25] the results show the association and interactions between invalidating lumbar pain and labor variables such as: work position, job posting, physical exertion, lifting loads, quantity of weight that rises and actions of flexion, extension and/or rotation of the back and very interesting results come out. Such as, that the lumbar pain is 2.5 times greater in those workers in whose position they were exposed to loads and loads Physical and/or forced positions compared to administrative, services and technical and professional positions that are subject to lesser physical demands. More than eight times higher than those who do not lift. In relation to extra-occupational activities, the results obtained are consistent with the findings of Svensson et al. [26] (more than 50% usually practice a sport).

4 Conclusions

Mostly of the sample surveyed stated that they did not have good posture habits in the work place, despite the fact that the majority work more than 8 h a day in a mainly seated position, most of them lack a correct posture hygiene probably as a result of a poor health and safety at work program that guides them to make good decisions in their body kinetics, not only in the lumbar region but also in other body segments, thus reducing the onset of muscle disorders Skeletal. Another relevant aspect is that most people are unaware of the importance of active breaks or rest periods that increase muscle flexibility and body movement, release pressure zones, reduce stress and improve work climate and performance [27]; It should be noted that in the performance of extra-labor activities, the masculine gender showed a greater preference for physical activities, in contrast to the female group that showed poor preferences for them.

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Movement and Balance

What are the Major Risk Factors for Falls Among Community-Dwelling Korean Older Women?

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Abstract. Falls are a major cause of death and disability in older people. This study aims to examine the prevalence of falls and associated major risk factors among community-dwelling Korean older women. Total 189 subjects participated in this study. Their fall history and 18 fall-risk related variables covering demographic information, physical performance, gait ability, body strength, and cognitive performance were collected. Results showed that 39.7% of participants had fall experience, 40% of fallers were injured. Five major categories of risk factors were identified from factor analysis: impaired balance and mobility, large body mass but weak grip strength, poor cognitive function, limited joint flexibility, and weak lower limb strength. Logistics regression further showed that poor cognitive function is the most critical fall risk factor. These findings could not only provide guidelines on choosing/developing appropriate fall risk assessment tools, but also help prioritize effective interventions to prevent the falls for Korean older women.

Keywords: Ageing · Falls · Risk factor · Risk assessment · Fall prevention

1 Introduction

Around one third of older adults aged 65 or over experience at least one fall each year [1–4]. The risk of falls increases dramatically with age and about half of older adults aged 80 or older fall each year [2]. Falls are a leading cause of death and disability in elderly [3, 4]. Falls also pose a serious threat to elderly's psychological well-being, inducing suffer from post-fall syndromes like social isolation or fear of falling [5, 6].

Many studies have investigated fall risk factors in older people [7–9]. The commonly identified significant risk factors for falls were historical falls, gender, age, diseases and the use of medications, physical and cognitive impairments [8, 9]. In addition, some studies have attempted to identify dominant factors out of those commonly reported risk factors [10–12]. For community-dwelling elderly having experience of at least one injurious fall or multiple falls, people with impaired physiological function, impaired execution function, and poor dynamic balance had a high risk of falling [10]. Hung et al. investigated older men with experience of recurrent falls living in veteran's community and reported that depression was the most critical fall risk

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factor for single fallers. For multiple fallers, urinary incontinence was the first and depression was the second most important factor [11]. Dhargave and Sendhilkumar conducted an experiment for older people living in the long-term care home and found falls in the previous year as the most critical risk factor of falling, followed by fear of falling, imbalance, vertigo, and walking with a cane [12].

Even though there are many studies on fall risk factors of different older populations (predominantly in western countries), the data about Korean older population is very limited [13–15]. Considering Korea is now facing a major challenge on population ageing and the substantial health problem among the elderly population from falls, it is important to investigate the prevalence of falls and risk factors associated with falls for Korean elderly. Previous studies with Korean older populations mainly focused on socio-demographic characteristics through surveys [13, 14], or with very limited quantitative items from cognitive measurements [15]. In addition, there is a lack of studies that seek underlying latent fall risk variables (factors) that could be reflected in the observed variables. Identification of major underlying fall risk factors will not only allow us to gain insights about elderly fall risks, but also could provide us a guideline on choosing/developing appropriate fall risk assessment tools. The primary goal of this study is to investigate the prevalence of falls and major risk factors associated with falls for community-dwelling Korean older women. The outcome of this study is expected to provide health professionals with some basic information on fall prevention for community-dwelling elderly in Korea.

2 Methodology

2.1 Sample

Participants for this study were a convenience sample of volunteers recruited from three social welfare centres in the city of Ulsan (South Korea) who have lived in communities for most of their lives. There were three inclusion criteria in the recruitment, (1) aged 65 or older, (2) female, and (3) able to walk independently without any assistive device in the daily living. Only female participants were recruited to avoid the potential gender effect on the prevalence of falls [16]. A total of 189 community-dwelling older Korean women participated in this study. All participants were given information about the study prior to inclusion in this study. Each participant provided the informed consent on a protocol approved by the university institutional review board.

2.2 Study Design and Data Acquisition

A retrospective study design was used to examine the prevalence of falls and associated risk factors. This study mainly consisted of three sessions. The first session was to record basic demographic data (age, height, weight, BMI) of each participant. Various physical, cognitive and functional tests were performed in the second session to measure 14 fall-related test variables and the details are described in the following paragraphs. The third session was a face-to-face interview for fall data in the past 12 months (frequency of falls, their locations, reasons, and injuries). A fall was defined as "inadvertently coming to rest on the ground, floor, or lower level, excluding intentional change in position to rest on furniture, wall or other objects" [17]. An injurious fall was defined as a fall that results in receiving any form of medical treatment [18].

Five fall risk assessments including Berg Balance Scale-BBS [19], Short Physical Performance Battery-SPPB [20], Functional Reach Test-FRT [21], Timed Up and Go-TUG [22], Sit to Stand Five times-STS5 [23] were first conducted for assessing various physical performances. The participant's walking speed was also measured during the test of SPPB. The knee range of motion was measured using Xsens inertial sensors (Xsens Technologies BV, Enschede, Netherlands). When subjects conducted this test, they wore Xsens sensors on the lower extremity, and they laid on front on a bed. From this posture, an experimenter flexed their knees as much as possible without pain, and the flexed angle was measured (Fig. 1A). Each participant's hand grip strength and the strengths in the ankle dorsiflexion, knee extension and flexion were measured afterwards using a modified Baseline® Hydraulic Dynamometer. In measuring strength of the ankle dorsiflexion, subjects laid their backs and they maintained a plantar flexion posture. When the dynamometer was placed on their right insteps, subjects waited a few seconds and flexed their ankles as hard as they can, keeping the posture for few seconds. Measuring strength in the knee extension and flexion had a similar mechanism. In this case, each subject laid on the front and bent their knees to 90°. For the knee extension task, the dynamometer was put on a lower part of a right shin, and subjects extended their knees as hard as they can. In the knee flexion, the dynamometer was placed on a lower part of a right calf, and subjects flexed their knees as hard as they can. In measuring the hand grip strength, subjects sat on a chair, and bent their right arm 90° and kept their elbow close to their body. By keeping this posture, they held the dynamometer as strong as they can (Fig. 1B, C, and D). Figure 2 shows a modified dynamometers utilized for measuring different types of strength in this study.

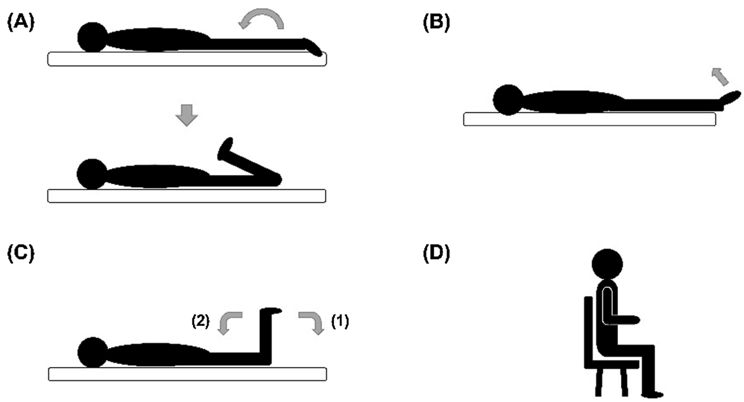

Fig. 1. Participant's postures for measuring (A) the knee range of motion, (B) strength in ankle dorsiflexion, (C) strength in knee extension (1) and knee flexion (2), and (D) hand grip strength.

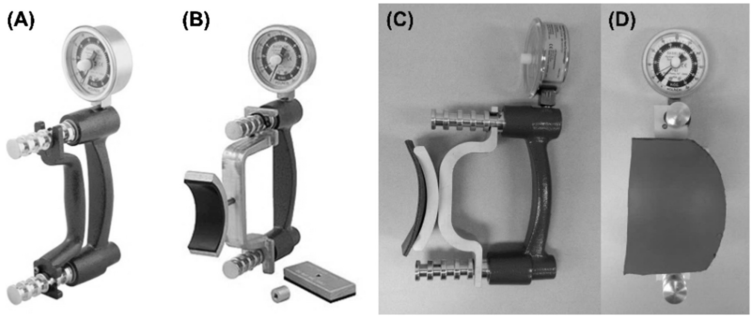

Fig. 2. Hand dynamometer for measuring body strengths. (A) is the original hand dynamometer for measuring hand grip strength and (B), (C) and (D) show a modified dynamometer equipped with a manual muscle testing conversion kit for measuring lower limb strengths.

A smart device reaction test App was used to measure information processing speed [24] and questionnaires of Shorten version of Fall Efficacy Scale (SFES) [25] and Shorten version of Geriatric Depression Scale (SGDS) [26] were used to assess participants' fear of falling and geriatric depression. Questionnaires in Korean were used for the tests to help older Korean women have a better understanding [27, 28].

2.3 Statistical Analysis

Two sample t-tests were conducted to remove insignificant test variables for two groups comparison (fallers versus non-fallers), and the remaining significant variables were grouped into major categories of fall risk factors based on factor analysis. Each significant variable was standardized (rescaled to have a mean of 0 and a standard deviation of 1) for factor analysis because variables have different scales [29]. The number of factors was determined by Jolliffe's criterion which recommends retaining factors above 0.7 [30]. The varimax rotation was applied for the factor rotation, and if the communality for each variable was less than 0.4, the variables were excluded, and the factor analysis was conducted again [31]. Through the factor analysis, if one variable had communality over ±0.5 for a specific factor in a factor loading matrix, it was expected that this variable has a significant correlation with that factor. Factor scores were obtained by Bartlett's approach, which has an advantage that it produces unbiased estimates of factor scores [29]. After the factor categorization, odds ratio (OR) from univariate logistic regression was used to determine the relative importance of those identified categories of fall risk factors. Minitab® 16.1.0 (Minitab Inc., State College, US) was used for the statistical analyses at a significance level of 0.05.

3 Results

Table 1 provides a statistical summary of 18 test variables for both faller and nonfaller groups. Among all 189 elderly participants, 75 participants (39.7%) had at least one fall during the last year, and 45.3% of fallers experienced recurrent falls (at least two falls).

Injurious falls accounted for 40% (30 participants) among total falls (Fig. 3), and lower extremity (45%), upper extremity (32%), and head/neck (9%) were the most frequently injured regions (Fig. 4). Results of two sample t-tests (Table 1) showed that BMI, SFES, BBS, SPPB, TUG, SGDS, hand grip strength, information processing speed, strength in knee extension, strength in knee flexion, STS5, and knee range of motion were significantly different between faller and non-faller groups ($p < 0.05$). The faller group had higher values on BMI, SFES, SGDS, TUG and STS5 than the nonfaller group, with lower values on information processing speed, hand grip strength, strength in knee extension, strength in knee flexion, knee range of motion, BBS and SPPB.

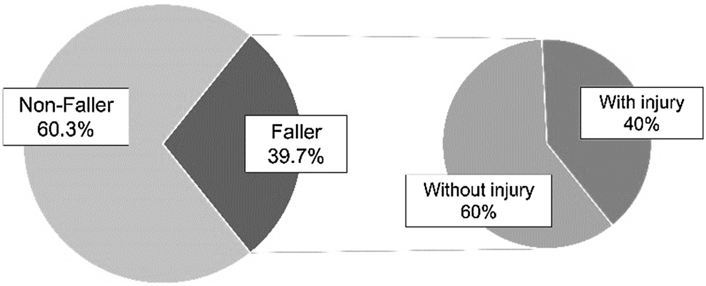

Fig. 3. Total fall (left) and injurious fall (right) rates

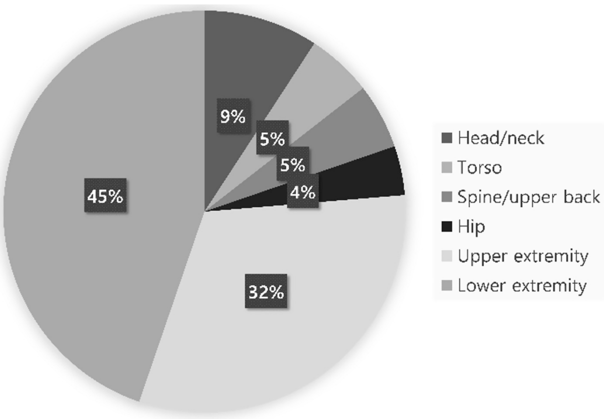

Fig. 4. Injured body regions from falls

Table 1. Comparison of descriptive statistics (mean, standard deviation in bracket) between faller and non-faller groups. p-values less than 0.05 showing significant group differences are bolded.

Fall risk variables (unit)	Faller (N_1 = 75)	Non-faller (N_2 = 114)	p-value
Age (years)	72.04 (4.95)	72.05 (4.33)	0.985
Height (cm)	154.83 (5.47)	154.49 (4.80)	0.669
Weight (kg)	60.23 (7.41)	58.26 (6.85)	0.070
BMI (kg/m^2)	25.25 (2.76)	24.32 (2.26)	**0.019**
Shorten Version of Fall Efficacy Scale-SFES score	14.59 (5.41)	9.15 (1.74)	**0.000**
Berg Balance Scale-BBS score	53.52 (2.30)	54.53 (1.60)	**0.002**
Short Physical Performance Battery-SPPB score	10.86 (1.29)	11.55 (0.63)	**0.000**
Functional Reach Test-FRT (cm)	25.38 (7.17)	26.76 (5.88)	0.170
Timed Up and Go-TUG (s)	11.93 (1.61)	11.15 (1.46)	**0.001**
Shorten Version of Geriatric Depression Scale-SGDS score	3.99 (2.97)	2.55 (2.61)	**0.001**
Hand grip strength (m^2)[a]	0.84 (0.12)	0.89 (0.17)	**0.032**
Information processing speed (bit/s)	5.87 (1.22)	6.92 (1.29)	**0.000**
Strength in ankle dorsiflexion (m^2)[a]	0.44 (0.14)	0.49 (0.15)	0.164
Strength in knee extension (m^2)[a]	0.56 (0.17)	0.66 (0.19)	**0.001**
Strength in knee flexion (m^2)[a]	0.24 (0.10)	0.28 (0.11)	**0.011**
Sit to Stand Five Times-STS5 (s)	11.06 (2.81)	9.91 (1.99)	**0.003**
Knee range of motion (degree)	126.3 (11.5)	131.5 (11.5)	**0.004**
Walking speed (cm/s)	83.8 (15.0)	84.1 (12.9)	0.859

[a] The strength related variables are normalized by BMI, thus the units are in m^2.

The number of factors in the factor analysis was determined to be five since the leading 5 factors explained 75.1% of total variance. All the variables used in factor analysis had acceptable communalities (>0.5). Factor loadings in the significant variables were summarized in Table 2.

In the factor loading matrix, the first factor had high correlations with BBS, SPPB, TUG, and STS5, and the second factor had high correlations with BMI (positive correlation) and grip strength (negative correlation). The third factor was strongly associated with strength in knee extension and flexion, and the forth factor was highly correlated with SFES, SGDS, and information processing speed. The fifth factor had a strong relation with the knee range of motion. The names of each factors were decided based on commonality of included variables in each factor. Components in the first factor were BBS, SPPB, TUG, and STS5, so it was named 'balance and mobility' [32].

Table 2. Factor loading matrix of 12 significant fall risk variables and 5 named factors generated from the factor analysis. Cells shaded by gray indicate highly correlated variables with each factor.

Fall risk variables	Factor 1- Balance and mobility	Factor 2- Body mass and grip strength	Factor 3- Lower limb strength	Factor 4- Cognitive function	Factor 5- Joint flexibility
BMI	-0.046	0.827	0.072	-0.021	0.300
SFES score	-0.482	0.325	0.009	0.570	-0.284
BBS score	0.768	-0.342	-0.139	-0.083	0.115
SPPB score	0.845	-0.080	-0.223	-0.021	-0.035
TUG	-0.802	0.141	0.242	0.056	0.144
SGDS score	0.099	0.009	0.139	0.866	0.029
Grip strength	0.197	-0.733	-0.323	-0.099	-0.024
Information processing speed	0.327	0.035	0.027	-0.593	-0.415
Strength in knee extension	0.240	-0.160	-0.842	-0.133	-0.166
Strength in knee flexion	0.271	-0.174	-0.812	-0.018	0.177
STS5	-0.779	-0.102	0.136	0.091	0.295
Knee range of motion	0.139	-0.365	0.012	-0.066	-0.777

The second factor contained BMI and grip strength, and this factor was called 'body mass and grip strength'. The third factor comprised of strengths in knee extension and flexion, so it was named 'Lower limb strength'. The forth factor was composed of SFES, SGDS, and information processing speed, and the factor name was 'cognitive function'. Lastly the fifth factor included the knee range of motion, so it was named 'joint flexibility'.

After factor analysis, the univariate logistic regression was conducted using factor scores for deriving corresponding odds ratios. Poor performance in each factor indicated high risk of falling in community-dwelling Korean older women. 'Poor cognitive function' had the highest odds ratio (=2.65), followed by 'large body weight but weak grip strength' (odds ratio = 2.16), 'impaired balance and mobility' (odds ratio = 1.79), 'weak lower limb strength' (odds ratio = 1.44), and 'limited joint flexibility' (odds ratio = 1.33) (Table 3).

Table 3. The odds ratio of fall occurrence for different fall risk factors in community-dwelling Korean older women.

Fall risk factors (from factor analysis)	Components	Odds ratio (95% confidence interval)
Impaired balance and mobility	BBS score, SPPB score, TUG, STS5	1.79 (1.27–2.51)
Large body mass but weak grip strength	BMI, grip strength	2.16 (1.40–3.36)
Weak lower limb strength	Strengths in the knee extension and flexion	1.44 (1.08–1.92)
Poor cognitive function	SFES score, SGDS score, information processing speed	2.65 (1.86–3.77)
Limited joint flexibility	Knee range of motion	1.33 (0.86–2.05)

4 Discussion and Limitations

4.1 Discussion

Previous studies reported significant risk factors associated with occurrence of falls. In Western populations, physical and mobility impairments, impaired mental health like fear of falling and depression, weak grip strength or feet strength were identified as significant fall risk factors [8–10, 33], same with this study. Imbalance and poor cognitive function were also identified as major fall risk factors in Asian populations [12, 14, 15], so the factors mentioned above seem to be common critical risk factors of falling regardless of population. However, considerable differences in fall risk factors also exist among different studies, even using the same Korean population. For example, Kim, Yang and Park found that for community-dwelling Korean older people, arthralgia was the most important fall risk factor, and dizziness, use of assistive device, living alone, low education level, fear of falling, fall efficacy, and quality of life were also major fall risk factors [14]. However, poor gait performance, impaired muscle function, reaction time, and flexibility were reported as major factors for fall risks in Korean elderly based on Kim, Park and Lee's study [15], which was largely consistent with our study. Aforementioned differences could be due to different sampling methods, inclusion of different fall risk factors and utilization of different data analysis methods.

This study found 5 major fall risk factors, and poor cognitive function which including fear of falling, depression, and slow information processing speed was the most critical fall risk factor in community-dwelling Korean older women. Older people with fear of falling have a negative impact on physical function by decreasing balance confidence, restricting activities, resulting in reduced stability and increased fall risk [34, 35]. Older people with fear of falling have 'stiffening strategy' on their behavior, which reduces the range of motion of their center of mass, causing reduced range of motion and angular velocity in the lower limb extremity. This adaptation is an intuitive strategy in accommodating potential destabilizing, but it is not effective during walking which requires interactions with environments in complex and dynamic motions [36].

Depression has a significant bidirectional relationship with falls. It directly promotes falls by causing insomnia and deficiencies in vitamin D as well as cognitive deficits, affecting attention, executive function, and processing speed which are associated with increasing fall risk [37]. The slow information processing speed can delay the sensory integration process and the selection of an appropriate response, and results in falls [24].

Large body mass but weak grip strength was the second most important risk factor of falling. Usually people with a high BMI have high fall risk because of poor coordination, body instability, and dizziness [38]. People with a low BMI also have increased fall risk due to low muscle mass and strength, which is related to physical disability [39]. If high body mass and weak strength are combined, it should increase the risks of falling.

The impaired balance and mobility are fall risk factors already verified by a lot of published studies. Good balance and mobility allow humans to identify orientation with respect to gravity and make automatic postural adjustments to maintain posture and stability in various conditions and activities [40]. Around 50% of falls occur during some forms of locomotion, most of them happen with problematic walking systems such as vulnerability in initiating and terminating gait, turning, avoiding obstacles, or bumping into people and objects [41].

Lower limb strength and joint flexibility were also significant fall risk factors even though joint flexibility was not significant in the discriminative test in this study. Weak leg muscle strength is related with gait variability [42]. A previous study also suggested that only joint flexibility is not likely to be significantly related to fall risk as well as static balance [43]. Because human maintains the balance under the condition that various systems interact each other, which including sensory system and integration with motor system, it may be not easy to identify high risk of falling with lower limb strength or limited joint flexibility only [40].

4.2 Limitations

This study has several limitations. Firstly, this study used history of falls to classify faller and non-faller groups. Therefore, it cannot be concluded that the identified major risk factors are predictors for future falls. Secondly, fall-related risk variables in this study are not fully representative. Some important risk variables such as environmental hazards and the use of medication were not studied. Last but not least, only limited Korean older women were recruited in this study, so the study findings may not be generalizable to the male populations.

5 Conclusion

This study investigated the prevalence of falls and discovered major risk factors of falling in community-dwelling older women in Korea. 39.7% of participants experienced at least one fall in the past 12 months, 40% of them were injured from falls and received medical treatments. Five major categories of fall risk factors were identified from factor analysis on 18 test variables: impaired balance and mobility, large body mass but weak grip strength, poor cognitive function, limited joint flexibility, and weak lower limb strength. Logistics regression further showed that poor cognitive function is the most critical fall risk factor (OR = 2.65), followed by large body mass but weak grip strength (OR = 2.16), impaired balance and mobility (OR = 1.79), weak lower limb strength (OR = 1.44), and limited joint flexibility (OR = 1.33). The identified major fall risk factors and their relative importance from this study could provide a guideline on choosing or developing appropriate fall risk assessment tools for screening older individuals at high risk of falling. In addition, it could be helpful for prioritizing effective interventions to prevent the falls for community-dwelling Korean older people.

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Acupuncture/Acupressure for Knee Osteoarthritis (OA) Relieving in the Elderly: A Review

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Abstract. The prevalence of knee osteoarthritis (OA) is quite high among the elderly and significantly influence their mobility which is quite relevant to functional independence and health-related life quality. Acupuncture and acupressure are increasingly popular in treating many diseases including some musculoskeletal and connective tissue disorders such as the knee OA. This paper aims to review the previous published researches on acupuncture and acupressure therapy for knee OA regarding the treatment mechanisms, effectiveness and characteristics to summarize and give therapeutic recommendations on knee OA in the elderly. Future directions will be provided for symptom management and functional maintenance in knee OA in order to improve the mobility and life quality of the old knee OA sufferers, so that the personal, societal, medical and financial burdens will then be correspondingly reduced.

Keywords: Knee osteoarthritis · Physical therapy · Traditional Chinese Medicine · Acupuncture · Acupressure · Elderly

1 Introduction

Osteoarthritis (OA) is the most common type of arthritis and was defined as a degenerative joint disease caused by inflammation, breakdown, and eventual loss of the cartilage [1–3]. This kind of disease could occur in almost any joints on human body including hands, shoulder, spine, hips, etc. [2]. However, the knee, the largest joint to bear the whole body stress while twisting and turning, is the most common prone to osteoarthritis [4]. The knee OA affects more than one third of the elderly aged over 65 years old with the presenting symptoms of stiffness, pain, physical function decrease that significantly cause the mobility limitation in the elderly and highly influence their life quality [5]. It is reported that nearly 80% of the elderly knee OA patients have mild or severe movement limitation problems, and nearly 25% of them have difficulty in performing basic daily activities while 11% of these knee OA patients even need personal care to support their daily life [1]. Moreover, elderly who suffer from knee OA are easier to get mental or cardiovascular diseases because of less social participation

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and sedentary lifestyle and even have a higher risk of falls which may cause a higher rate of mortality [6].

To treat for the knee OA, although a variety of treatments are available such as pharmacologic, and non-pharmacologic treatments or surgical therapies, considering the general health condition and medical history of the elderly, there still remains some major issues related to untoward effects, complications and rehabilitation. Thus, physical therapies including some Traditional Chinese Medicine (TCM) modalities could be suitable for this group of people. Acupuncture and acupressure are increasingly popular in treating many diseases including some musculoskeletal and connective tissue disorders and were reported to have good therapeutic effectiveness on knee OA treating [7]. Many knee OA sufferers who have not adopted any western therapies find symptom relief from acupuncture or acupressure [8]. For those who receive western therapies such as pharmacological treatment or surgeries usually use acupuncture or acupressure as an effective and safe adjunctive therapy [9]. In this paper, published academic papers and clinical trials of acupuncture and acupressure for knee OA will be reviewed as a preliminary study of developing promising therapies for knee OA relieving in the elderly considering human factors.

2 Acupuncture/Acupressure

Acupuncture, a form of non-pharmacologic therapy (also known as a form of alternative medicine/physical treatment), belongs to Traditional Chinese Medicine (TCM) which insert fine needles into human body to achieve acupoints stimulation across meridians. Acupressure is a non-invasive variant of acupuncture which based on the similar philosophy and TCM meridian theory to that of acupuncture. In contrast to acupuncture, acupressure use fingers, hands, elbow, or various devices to apply pressure stimulation on acupoints instead of needle invasion. However, acupressure is safer and more convenient due to its non-invasive nature making it more suitable for the elderly. Furthermore, acupressure can not only achieve meridian stimulation as acupuncture dose, but also help to promote relaxation, decrease tissue adhesion, increase parasympathetic nervous activity, increase regional blood circulation, etc. [10].

3 Acupuncture/Acupressure Mechanisms for Knee OA Treating

3.1 The Traditional Chinese Medicine (TCM) Theory

The TCM mechanism states that the flow of vital energy (called Qi) is regulated by certain channels called meridians in the human body. Unbalance of the vital energy (Qi) may cause the inharmonious relationship of Yin Yang therefore lead to health problems. Acupoints stimulation could help to correct imbalanced Qi flows through the meridian channels to achieve physiological functions improvement of the body system and human internal organs [11]. Main concepts in the acupuncture/acupressure TCM mechanism are explained below.

Yin and Yang. The concept of Yin and Yang holds that everything in the universe consists of two opposite but mutually dependent forces that complement and supplement each other in order to keep the balance. In china, they are originally regarded as two basic root intuitions. Yin represents cold, darkness, tranquility, quiescence and passiveness while Yang usually associate with warm, bright, stimulation, assertiveness and dynamic potential. As a part of the universe, human beings were believed to maintain a healthy status by balancing the Yin and Yang forces inside body. In the Traditional Chinese Medicine system, basic and fundamental theory of Yin and Yang is widely applied in diagnosis, pathology, physiology and treatment. Continuum of vital energy flows in human along meridians between the two opposite poles of Yin Yang. Any disturbance in the balance of Yin and Yang to break their interdependent relationship may result in illness [12, 13].

Qi. In the TCM system, Qi is the vital energy circulating throughout the whole human body with myriad forms. Qi could be classified into two types within our bodies. The first one is the congenital Qi which we born with. This type of Qi associate to our basic health conditions with a limited amount and quality. Correspondingly, acquired Qi is another type of Qi which could be obtained from the external environment through food, air, exercises, etc. Unbalance of the vital energy (Qi) may cause health problems. Acupuncture or acupressure is an efficient way to help people get the acquired Qi.

Meridians and Acupoints. Meridian is a translation of the Chinese term-Jing Luo while “Jing” means to pass through and “Luo” represents the net or connection. In the TCM system, meridians are main channels connecting with organs for the passage of Qi flow through the body. There are 12 standard meridians also known as Principal Meridians running through the whole body. All of these 12 main meridians are divided into Yin and Yang groups. The Yin meridians include the Liver, Spleen, Kidney, Heart, Lung and Pericardium meridians. The Small Intestine, Triple warmer, Large Intestine, Stomach, Bladder, and Gall Bladder meridians belong to the Yang meridian group. As for acupoints, they are specific points located on meridians closest to the skin surface of our human body where to apply the needling or pressure stimulations by acupuncture or acupressure therapy. To note that acupressure and acupuncture used the same acupoints based on the same fundamental theory. Acupoints on different body parts presents various sensations such as pain or soreness when receiving external stimulation. Moreover, acupoints stimulations on different body parts are able to treat for different health problems [14].

3.2 Gate-Control Theory

The Gate-control theory was put forward by Melzack and Wall (1965) which identified that some stimulation input may close the “gate” to painful input thus prevent the ordinary pain signals traveling to the central nervous system [15]. Such stimulation will be effective in pain relief. To note that stimulations by acupuncture/acupressure will be converted into impulses to the brain with the frequency four times faster than ordinary pain signals. These continuous impulses are able to shut the “gate” in the central gelatinous substance of spinal cord and stop the ordinary pain signals such as knee pain from reaching the brain. Moreover, in addition to endogenous pain relief function, acupuncture/acupressure stimulation benefits for the primary somatosensory processing and regulating maladaptive neuroplasticity [14].

3.3 Neurohumoral Theory

Biochemical mechanism explained that acupuncture/acupressure stimulation on points causes some neurohormonal responses [16]. Acupuncture or acupressure stimuli on acupoints lead to the icon channel activation. Concentrations of K^+, Na^+, Ca^+, etc. may change among the sensory neuron network [17] which may cause the hypothalamic pituitary adrenocortical axis activation. Thus, cortisol level will be balanced to form a relaxation response, more endorphin and serotonin will be secreted by hypothalamus and pituitary gland to suppress the pain perception therefore the general physical performance of the knee OA sufferers will be improved [18]. Cortisol is a steroid hormone, in the glucocorticoid class of hormones. It is quite related to the metabolism, memory, sleep, stress, etc. of human body which plays an important role in both mental and physical performance. Endorphin and serotonin are neurotransmitters in the analgesia system. Endorphin was reported to have significant analgesic effect [19] while serotonin was known to contribute to producing happiness, relaxation, feeling well and achieving psychomotor balance [20]. Moreover, according to the neurohumoral theory, some endogenous, analgesic effective substances will also be produced such as enkephalins and dynorphins together with some neurotransmitters (e.g. aspartate in the central nervous system) and neuropeptides like β-endorphin, encephalin, and leucine as a result of acupuncture/acupressure in order to achieve pain reduction, physical function improvement and other symptoms relief of knee OA [21, 22].

3.4 Nitric Oxide (NO) Theory

Nitric oxide (NO) is one of the few gaseous signaling molecules which acts as biological messenger in a variety of organisms including human being. It is the key regulator of metabolism and local blood circulation. Nitric oxides (NO) on the inner lining (endothelium) of blood vessels have the ability to send message to smooth muscle surrounded making it relaxed therefore achieve the vasodilation and increase the blood flow. However, along with the aging process, the autocrine ability of NO declined. Even in our 60's and beyond, we may lose about 85% of our ability to make NO. The decrease of NO content may gradually lead to thickening arteries, inflammation plaque buildup, stiffening wall calcium buildup and finally, rupture. Some research finding suggested that acupressure or acupuncture stimulation on acupoints or areas along meridians could affect nitric oxide (NO) level in human body. This stimulation has been proved to promote the NO autocrine to increased local blood circulation, prevent local inflammation and relief local pain condition. Moreover, increased NO level caused by acupuncture or acupressure can also mediate signal to suppress fatigue inducing molecules in the blood then be able to improve physical performance [14, 23, 24]. Thus, this NO theory could also be applied in the knee OA treating by acupressure especially among the elderly patients.

3.5 Magnet Therapy

Acupoints on human body have been found to have a lower electrical resistance than surrounding areas [25]. Specifically, skin on normal condition has an electrical resistance of 200 Ω while the acupoints only have the resistance of 50 Ω [21]. This resistance difference on skin and energy flow (Qi) inside body through meridians may create electromagnetic field [26]. If the acupuncture/acupressure therapy was conducted by using magnetic devices, there will be an internal and external magnetic fields interaction to achieve magnetic acupuncture/acupressure. The static magnet field could decrease the firing rate of c-type chronic pain neurons and change the enzyme reaction rate in order to relieve knee OA pain and cure joint inflammatory [27]. Actually, there are already some products in the market such as the acupressure insoles adopting the magnets as the massage beads matching the acupoints on the feet. Although few types of research could be found on magnetic acupressure therapy, some studies have already proved the therapeutic effectiveness on knee OA and similar diseases with the suitable magnet strength ranging from 800 Gauss to 2000 Gauss [28–31].

4 Trial Review Result and Discussion

4.1 Basic Characteristics

To get a better understanding of the acupuncture/acupressure therapy for knee OA treating from the perspective of clinical practice. A total of 12 randomized clinical trials of acupuncture and acupressure for knee OA have been reviewed and summarized in the Table 1 below. All these researches were conducted among the target group of middle-aged and elderly people who are 40 years old and above. Specifically, more than 80% of the clinical trials were conducted in the elderly who aged 55 years old or above. And about 67% of the researches had the subjects aged over 60 years old with the mean age of 65. Sample size of these trials ranged from 30 to 1039 with the mean of 230.5 while 67% of these studies had the sample size within the range of 30 to 150. The treatment period of these 12 clinical trials ranged from 4 weeks to 12 months. For those long lasting trials such as Trial 9, 10, 11, 12, measures were usually recorded in different stages of the whole trial [32–35]. For instance, the Trail 10 carried by Foster et al. (2007) totally lasted for 12 months and the outcome measures were recorded at week 2, week 6, month 6 and month 12 [33]. As for the measures, the WOMAC (Western Ontario and McMaster Universities Osteoarthritis Index) was most widely adopted as a measurement for knee OA research (83%). To measure the knee pain, stiffness, physical function of patients, items in the WOMAC were divided into these 3 subscales: (1) Pain: during walking/using stairs/in bed/sitting or lying//standing; (2) Stiffness: after first waking/later in the day; (3) Physical Function: stair use/rising from sitting/standing/bending/walking/getting in or out of a car/shopping/putting on or taking off socks/rising from bed/lying in bed/getting in or out of bath/sitting/getting on or off toilet/heavy household duties/light household duties.

Table 1. Clinical trials of acupuncture and acupressure for knee OA treating

Trail	Design	Sample size	Age	Period	Measures	Intervention
1	RCT	150	>65 years AVG.73	8 weeks	-WOMAC -Physical function -self reported	-Verum acupressure group -Sham acupressure group -Usual care group
2	RCT	30	>50 years	8 weeks	-WOMAC -SF 36	-Experimental group -Control group
3	RCT	30	40–70 AVG. 58	4 weeks	-KOOS	-True acupuncture group (high dose acupoints) -True acupuncture group (low dose acupoints) -Sham acupuncture group
4	Quasi-CT	90	45–60 AVG.52	3 months	-WOMAC	-Isometric exercise group -Acupressure group -Control group
5	RCT	214	AVG.60	12 weeks	-WOMAC	-True acupuncture group -Sham acupuncture group
6	RCT	30	40–70 AVG:57.5	4 weeks	-MASS -KOOS	-True acupuncture group (high dose acupoints) -True acupuncture group (low dose acupoints) -Sham acupuncture group
7	RCT	120	AVG.61.8	8 weeks	-WOMAC -SF-36	-True acupuncture group (with Etoricoxib), -Sham acupuncture group (with Etoricoxib), -Control group (only Etoricoxib),
8	RCT	68	AVG.65	5 weeks	-WOMAC -VAS -EQ-5D	-True acupuncture group -Sham acupuncture group
9	RCT	1039	>40 years AVG.63	26 weeks	-WOMAC	-True acupuncture group -Sham acupuncture group -control group
10	RCT	352	>50 years AVG.63	12 months	-WOMAC	-True acupuncture group -Sham acupuncture group -Control group
11	RCT	570	>50 years AVG.65.5	26 weeks	-WOMAC -SF-36	-True acupuncture group -Sham acupuncture group -Control group
12	RCT	73	>50 years AVG.65	12 weeks	-WOMAC	-Acupuncture group -Control group

RCT: randomized controlled trial; CT: controlled trial; WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index; SF-36: 36-Item Short-Form Health Survey; MASS: Massachusetts General Hospital Acupuncture Sensation Scale; KOOS: Knee injury and Osteoarthritis Outcome Score; VAS: Visual Analogue Scale for pain; EQ-5D: EuroQol five dimension questionnaire; AVG.: Average

4.2 Effectiveness

83% of the acupuncture/acupressure trials indicated the therapeutic effectiveness on knee OA treating. Specifically, clinical trials 4, 6, 8, 9, 11 and 12 conducted by Sorour et al. (2014), Spaeth et al. (2013), Jubb et al. (2008), Scharf et al. (2007) and Berman et al. (2004), Berman et al. (1999) respectively have proved that acupuncture and acupressure have a significant improvement in knee pain, stiffness or function but on different level [8, 10, 32, 34–36]. Sorour et al. (2014) noted that compare to the control group, acupressure group acted better on pain reduction while isometric exercise group had more improvement in stiffness and function [10]. Jubb et al. (2008) reported that the true acupuncture improved the knee OA resulted pain, stiffness and function problems when comparing to sham and control groups and the pain decline is more significant than stiffness and function improvement [8]. Although the effectiveness of acupuncture/acupressure for knee OA treating was not clinically significant in the trial 10 of Foster et al. (2007), this technique can still achieve some pain relief but shortly existed [33]. These results may indicate that acupuncture/acupressure is an effective treatment especially for pain relevant diseases. Analgesic effect could be the main and first achievement of acupuncture/acupressure in the knee OA treating process therefore patients will be more willing to move their lower libs due to less pain and correspondingly improve the stiffness and mobility limitation. Moreover, acupuncture/acupressure was also noted as a good adjunctive therapy for pharmacological treatment in Trial 7 that helps to achieve a higher therapeutic effectiveness [9]. The feasibility investigation research of Li et al. (2016) in Trial 1 showed that such Traditional Chinese Medicine therapy especially the acupressure is safe, effective and tolerable for older adults with knee osteoarthritis [37].

However, the research of Jubb et al. (2008) reported that acupuncture gave a symptomatic improvement for knee OA in both the true and sham groups in week 5 comparing to the baseline but the therapeutic effectiveness decline or even disappear since week 9 [8]. Similarly, Berman et al. (1999) noted that the total WOMAC score (including pain, stiffness and function) of the treatment group decreased by 34% at week 4, 42% at week 8, but obtained a slight increase in week 12 which may due to some treatment cessations since week 8 [35]. Thus, periodic treatment design may be more suitable for acupuncture/acupressure in order to relax and rest the acupoints, meridians and human body in order to receive a maximum therapeutic effect. According to the reviewed clinical trials, 4–8 weeks could be recommended as a suitable acupuncture/acupressure treatment period. Moreover, acupuncture/acupressure should be adopted continuously within a certain treatment period to ensure the therapeutic effectiveness.

4.3 Acupoints

Results in Trail 3 and 6 showed that true acupuncture whether high dose or low dose acupoints could achieve therapeutic effectiveness on knee OA [36, 38]. This may because core acupoints were included in both high dose and low dose groups which worked efficiently for knee OA treating. To select the core acupoints for true treatment in future research, all the acupoints used in true groups of those reviewed trials were presented in Table 2. To summarize, the most recommended and frequently appeared acupoints are XiYan, SP9 (YingLingQuan), GB34 (YangLingQuan), ST35 (DuBi) and ST36 (ZuSanLi) concentrating on the lower limbs. Correspondingly, sham point were set up by some trials in their sham acupuncture/acupressure group to minimize result bias. There were two types of sham acupoints. The first type of sham acupoints are located at the same position as the true acupoints but use nonpuncturing needles to creating an illusion of insertion. The second type of sham acupoints are non-acupoints which located a distance from those true acupoints. Sham acupoints used in sham treatment group are usually set up about 1.5–3 cun (a traditional Chinese unit of length used in TCM) away from the true acupoints avoiding the main meridians [32, 36, 38]. It could be noticed that in some studies such as the trial of Scharf et al. (2007), both the true and sham acupuncture/acupressure groups obtained a good consequence in knee OA treating with the success rate of 53.1% and 51.0% respectively but had little effectiveness difference between the two groups [32]. This may because the sham points are still within the true acupoints' effective area or sham points were located on effective meridians.

Table 2. Acupoints used for knee OA treating

Trial	Author (year)	Acupoints
1	Li et al. (2016) [37]	Yintang, Anmian, HT 7, SP 6, KI 3
2	Appleyard et al. (2016) [39]	ST35, Ex-LE5, ST36, GB34, SP9, ST34, SP10, GB33, LR7, LR8, Ex-LE2
3	Chen et al. (2014) [38]	ST35, Xiyan, GB34, SP9, GB39, SP6
4	Sorour et al. (2014) [10]	ST34, ST35, ST36, SP9, SP10, GB34, EX-LE2, EX-LE4
5	Chen et al. (2013) [40]	GB34, SP9, ST36, ST35, Xiyan, UB 60, GB39, SP6, KI3
6	Spaeth et al. (2013) [36]	GB34, GB39, ST35, Xiyan, SP9, SP6
7	Mavrommatis et al. (2012) [9]	ST36, SP9, SP10, GB34, Ex-LE2, Ex-LE5, LI4, KI3, ST40, SP6
8	Jubb et al. (2008) [8]	LI4, SP10, Xiyan, SP9, GB34, ST36, LIV3, BL40, BL57
9	Scharf et al. (2007) [32]	ST34, ST36, Xiyan, SP9, SP10, GB34
10	Foster et al. (2007) [33]	SP9, SP10, ST34, ST35, ST36, Xiyan, GB34, LI4, TH5, SP6, LIV3, ST44, KI3, BI60, GB41
11	Berman et al. (2004) [34]	GB34, SP9, ST36, ST35, Xiyan, BL60, GB39, SP6, KI3
12	Berman et al. (1999) [35]	GB34, SP9, ST36, ST35, Xiyan, BL60, GB39, SP 6, KI3

5 Limitations and Recommendations

However, although some clinical trials have reported positive results of acupuncture/acupressure treatment for knee OA, there still remain some limitations that need to pay attention to. Firstly, relevant academic publication of high quality is limited. Secondly, when recruit participants, the history of other interventions such as drugs have not been recorded that might have some impacts on the results. Third, core acupoints selection theory were not usually stated by trials. Few studies only noted that they choose local acupoints based on previous research. To accurately select core acupoints in the future, both TCM theory and practice experience should be considered. Besides, there remained methodologic limitations, insufficient sample size for each separate subgroup analysis, a lack of placebo group or control group (33% of the trials) and inadequate assessment of long-term treatment effectiveness (more than 50% of the trials) which may lead to a research bias. Future research on acupuncture/acupressure based therapy with a well-designed methodology for knee OA relieving is highly needed.

To develop acupuncture/acupressure into a more promising method for knee OA symptom management and functional maintenance in the elderly, therapeutic recommendations are presented as follows:

- For those who have severe knee OA that must take pharmacological treatment could also take acupuncture/acupressure as an adjunctive therapy to relief pain.
- For those who take acupuncture/acupressure as main therapy could also adopt isometric exercise (e.g. Static stretching, strengthening, resistive exercise) to improve stiffness and function thus promote the virtuous cycle of acupuncture/acupressure therapy.
- Acupuncture/acupressure could be developed into magnetic acupuncture/acupressure by using magnetic needle or device to achieve a better therapeutic effect. Magnet strength should be 800–2000 Gauss.
- Acupoints of XiYan, SP9 (YingLingQuan), GB34 (YangLingQuan), ST35 (DuBi) and ST36 (ZuSanLi) are the most effective acupoints for knee OA treating. It is better to confirm them with acupuncturists who are experts in practice.
- It is better to adopt acupuncture/acupressure treatment periodically in order to receive a long term therapeutic effectiveness. 4–8 weeks are recommended as a period for receiving acupuncture/acupressure therapy.
- It is better to adopted acupuncture/acupressure treatment continuously within a certain treatment period to ensure the therapeutic effectiveness.
- Acupressure is safer and more convenient than acupuncture due to its non-invasive nature. Self-acupressure could be conducted by knee OA sufferers themselves by using fingers, hands, elbow or other devices under correct guideline in order to receive immediate treatment when needed.
- Wearable acupressure devices could be developed matching specific acupoints on human body to provide continuously treatment for the knee OA in the elderly.

In addition, more research with high quality randomized controlled trials are needed in the future to evaluate the feasibility and effectiveness of acupuncture/acupressure based therapy for knee OA treating. Well-designed methodology including true acupuncture/acupressure group, sham acupuncture/acupressure and control group is necessary to minimize the research bias. Sample size need to be scientifically calculated to ensure the sufficiency of subjects in each sub-group. Demographic and health history of each participant should be investigated before the trial to make a careful screening of the subjects. The WOMAC (Western Ontario and McMaster Universities Osteoarthritis Index) could be taken as a main measurement for analysis. Moreover, it is important to choose appropriate sham points which usually about 1.5–3 cun away from the true acupoints avoiding the main meridians. Last but not the least, feedbacks from participants referring to whether physical or psychological aspects should be recorded and considered carefully to ensure effectiveness, safety and comfort.

6 Conclusion

Although there are numerous normal and tradition treatments for knee OA, consider the particularity of the elderly, the drug dependence consequence and drug side effects of pharmacological treatment, a high medical risk of surgery, the nonpharmacological treatment of acupuncture/acupressure is more suitable for knee OA treating in the elderly. Due to its safe, effective, convenient, side-effect free and cost-effective nature, the Traditional Chinese Medicine treatment of acupuncture/acupressure has a tremendous potential to be widely accepted by patients and significantly support the home treatment which is highly urged by the elderly. This human factor based treatment may not only provide promising methods to relieve knee OA and improve mobility but also give future directions for symptom management and functional maintenance in knee OA in order to improve the life quality of the old knee OA sufferers, so that the personal, societal, medical and financial burdens will then be correspondingly reduced

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Effect of Motion Type and Inclination on Muscle Activity and Edema

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Abstract. The purpose of the study was to assess the lower limb muscle activity and the leg volume changes associated with different motion types and inclination. Participants were asked to run and walk at two different inclinations on a treadmill to quantify the muscle activity with EMG. The corresponding lower limb volume changes were recorded with a foot volumeter. Results found that running conditions led to a significant volume increase and a significantly greater muscle activity. The greatest increase in leg volume appeared in running with bigger inclination. However, walking with great inclination resulted in reduced leg volume. The research will provide invaluable insights in rehabilitation, fatigue prevention, prosthetics and sport shoes design.

Keywords: Edema · EMG · Muscle pump · Venous return · Dynamic tasks · Aerobic exercises

1 Introduction

Loaded positions such as standing, walking or running places the lower legs in a dependent position where the weight of the body is borne by the lower legs. In a loaded static standing position or orthostasis, the absence of any significant lower leg muscle action to pump blood to facilitate venous return, can lead to pooling of blood in lower extremities following a prolonged exposure [1]. This results in an increased foot volume [2–5]. However, in the case of loaded dynamic tasks such as walking and running, calf muscle pump is thought to have an effect of maintaining a steady state of venous return nullifying the effect of gravity in pooling blood in the distal lower limbs [6]. However, this effect of calf muscle pump in maintaining venous return and thereby contributing to leg volume regulation has not been very conclusively established and has not been apparent in several studies. Some loaded dynamic tasks such as walking and running has been even found to lead to an increasing leg volume proposed to be due to an increase in blood circulation to the exercising limbs [7, 8] while some have reported no changes at all [9, 10].

The formation of lower extremity swelling due to fluid accumulation is subsequently manifested as dependent edema. Over time, this condition can lead to chronic edema or venous insufficiencies. Edema in lower extremities is an indicator of peripheral vascular diseases or developing circulatory insufficiencies. In the long term, persistent edema

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formation of lower limbs put people under greater risk of varicose veins, thrombosis and pulmonary embolism [11]. Athletes, patients with CVI (Chronic Venous Insufficiency) and individuals in standing work may be at higher risk of dangerous levels of foot swelling and edematic limbs.

This study aims to highlight how lower limb muscle dynamics influence the regulation of foot volumetry and to find the volume changes of lower legs associated with walking, running and gradients to help understand the mechanism of edema formation. This research can contribute to the existing body of knowledge on venous dynamics and can help aid the development of exercise and treatment methods without risk of edema formation.

2 Literature Review

Foot volume was found to decrease following walking which could mean the effect of musculo-venous pumping counteracting the increased blood flow to the exercising muscles by helping in venous return from the lower extremities [6]. Skeletal muscle pump plays an important role in preventing edema in lower legs [15]. The musculo venous pumping could have an effect of pumping the fluid out of interstitial areas, decreasing the foot volume [3, 10, 6, 16]. Apart from the muscle pump forcing blood out from the lower extremities, it was found that due to a dynamic muscle activity, an enhanced lymph flow and a reduced venous pressure develops [4]. Reduced venous pressure develops due to the muscle pump mechanism wherein the venous compression induced by the contracting muscles quickly empty the veins. The venous valves prevent the backward flow of blood (reflux) to the lower legs ensuring an upward unidirectional flow [17]. The closed venous valves have an effect of reducing the pressure of venous sections locally along segments this in turn lead to a reduction in blood pressure at venous sections of capillaries, lowering the filtration pressure and brings down the filtration of fluid to the interstitial space [18]. The low venous pressure drives down the capillary filtration pressure thereby aids in overall limb volume reduction [6].

However, foot volume was found to be increasing after walking using a Lucite foot volumeter although the increase in volume was not as pronounced as in running [7]. Another research validated this finding having observed a significant increase in foot volume with walking [8]. The observations where the dynamic activities such as walking or running have resulted in increased edema is supported by the findings of increased blood flow to the exercising muscles of lower extremities and the subsequent shift of capillary fluid to the interstitial space [6, 7, 10].

This increase in foot volume due to dynamic activities can be as high as 8% [10]. Research has also supported the claims of increased interstitial and extracellular volume related to workload and subsequently resulting in swelling of lower limbs [4]. However, there have been a lot of conflicting findings as well such as in the case of an intense bout of volleyball activity [10] and pedaling [19].

3 Method

3.1 Participants

Seven healthy male participants with ages ranging from 22 to 38 years (M = 25.33/SD = 3.07), weights from 61 kg to 98 kg (M = 73/SD = 12.91) and stature from 165 cm to 183 cm (M = 174.33/SD = 7.20) volunteered to participate in the study. The subjects did not report any prior incident of lower leg disorders. All participants were provided with written, informed consent form.

3.2 Equipment

The experiment was conducted on a treadmill (Trackmaster TMX425C) and an EMG apparatus (Biopac MP150) and foot volumeter (North Coast Medical Inc.) were used *to measure the physiological and biomechanical responses of the lower leg* (Fig. 1).

Fig. 1. Foot volumeter (left) and EMG equipment (right)

3.3 Independent and Dependent Variables

- Independent variables included the type of motion (walking and running) and the angle of inclination (0° and 3°).
- Dependent variables included the foot volume change and the lower leg muscle activity (% MVC) at Tibialis Anterior (TA) and Gastrocnemius (GA).

3.4 Experiment Task

The experiments were performed on a treadmill (Fig. 2). For running, the participants followed a normal gait involving an aerial or a flight phase in which all feet are above the ground. For walking, the participants followed a normal gait involving a foot always in contact with the ground and the center of gravity arching over the stance leg in an inverted pendulum model. Each of the motion was experimented at two different inclinations of 0° and 3° for a duration of 5 min. Walking and running speeds were set at 2.5 miles/h and

5 miles/h respectively. The experiment was a 2 × 2 factorial within-subjects design. The four conditions were randomly assigned to each participant in the experiment.

Fig. 2. Treadmill at 0° incline (left) and treadmill at 3° incline (right)

3.5 Procedure

After reporting to the lab, the participants initially lied down supine on a flat table for 20 min following which they shifted to a sitting posture. The baseline of foot volume was measured using the volumeter and the skin was prepared according to SENIAM guidelines. The electrodes were attached at skin over GA and TA and the ground was given at prepared skin over the talus. The transmitter was attached to the participant's ankle with a velcro strap firm at a minimal pressure. The participant performed the task on treadmill according to the random assignment.

The amplified raw EMG data was collected during the final 30 s of the experiment at a sampling rate of 2000 Hz and the signals were band-pass filtered at 20 Hz–500 Hz and full wave rectified to remove motion artefacts.

The peak and RMS EMG signals recorded were normalized with respect to the Maximum Voluntary Contraction (MVC) for each muscle. To exert GA, the participants plantar flexed their foot against a certain fixed resistance sitting on the floor and leaning against a wall in a gradual and continuous 2-second buildup of effort culminating in a 2-s maximal effort. For TA, participants dorsiflexed their foot against a fixed resistance applied at the metatarsals while standing. The participants were verbally encouraged during the process. A 500 ms window during the maximal exertion was used for all amplitude normalizations.

The readings were collected using Acknowledge 4.3 software and analyzed using SAS software. At the end of the session, the electrodes were detached and volumetry was performed to measure the change in foot volume. 24 h gap was allowed between all testing days to ensure that the physiological variables returned to their baseline values.

4 Results

ANOVA was conducted to analyze the effect of motion type and inclination on the leg volume change and EMG activity. Table 1 illustrates the significant effect of motion type and inclination.

Table 1. Significant effect for performance measures

Dependent variable	Effect	*F*-value	*P*-value
Leg volume change	Motion type	6.80	0.0402
TA muscle activity	Motion type	24.58	0.0026
GA muscle activity	Motion Type	9.65	0.0209

4.1 Foot Volume Change

The analysis revealed a significant effect of motion type on leg volume change ($F_{1,6} = 6.80$, $p = 0.0402$) with a decreasing leg volume for walking ($M = 6.78$, $SD = 17.67$) and increasing leg volume for running ($M = 9.92$, $SD = 14.44$). The inclined surface tend to elicit a reduction in leg volume ($M = 1.42$, $SD = 17.82$) and level surface tend to lead to an increase in the leg volume ($M = 4.57$, $SD = 18.28$). However there was no statistical significance ($F_{1,6} = 0.94$, $p = 0.3706$) or interaction effect ($F_{1,6} = 2.06$, $p = 0.2008$). A reduction in leg volume was observed only for inclined walking while all other conditions led to at least some degree of leg swelling. The largest increase in leg volume was observed for incline running while the least increase was found for level walking.

4.2 EMG Activity at Tibialis Anterior (TA)

There was a significant effect of motion type on TA activity ($F_{1,6} = 24.58$, $p = 0.0026$). Post hoc analysis revealed that muscle activity on TA for running ($M = 0.77$, $SD = 0.29$) was significantly bigger than that for walking ($M = 0.37$, $SD = 0.18$). However, the level of inclination did not alter the TA EMG activity significantly ($F_{1,6} = 0.01$, $p = 0.9238$) nor was there an interaction effect ($F_{1,6} = 2.21$, $p = 0.1878$). The highest EMG activity was identified for incline running followed by level running. The least EMG activity was identified for incline walking.

4.3 EMG Activity at Gastrocnemius (GA)

GA muscle activity was significantly affected by the motion type ($F_{1,6} = 9.65$, $p = 0.0209$). Post hoc analysis revealed that muscle activity on GA for running ($M = 0.68$, $SD = 0.27$) was significantly bigger than that for walking ($M = 0.59$, $SD = 0.31$). Although the level of exertion was higher for inclined surface, the effect was not significant ($F_{1,6} = 0.94$, $p = 0.3690$). There was also no interaction effect ($F_{1,6} = 1.18$, $p = 0.3191$). Incline running had the highest EMG activity followed by level running. Level walking had the least EMG activity.

5 Discussion

5.1 Effect of Motion Type

For running condition, the leg volume tend to increase which agrees with several previous findings [6, 8, 20]. This could be due to the increased blood volume shift to the lower legs due to the intensity of the task and the subsequent inability of the lower leg musculature to maintain a constant rate of venous return [10]. During steady bouts of loaded dynamic activities such as running, a drop in venous pressure at the saphenous vein as high as 80 mm of mercury can hinder a steady rate of venous return aggravating edema [16]. The significantly high intensity of muscular exercise for running conditions could be evidenced from the EMG activity at TA and GA.

Foot volume was found to decrease for walking which agrees with the previous research [6]. This could be due to the musculo-venous pumping offsetting the relatively lower blood volume shift to the exercising lower leg muscles. Also, the drop in venous pressures had been observed to be much lesser in walking [6] which means it could not be significantly hampering an efficient venous return unlike running. The GA EMG activity was the lowest for both walking conditions and could have been sufficient to pump the fluid out of interstitial spaces [10] and ensure a steady venous return thereby controlling the overall foot volume.

5.2 Effect of Inclination

It has been suggested that strong muscle contractions may lead to a fluid accumulation in the working muscle [22]. An increased rate of trans-capillary filtration due to the increased blood flow to the exercising muscles can also result in the formation of interstitial edema. Incidentally, the highest TA and GA EMG activity, which was recorded during incline running, had also resulted in the greatest leg volume increase.

Walking gait has been found to be more efficient than running at minimizing leg volume change. This could be probably due to the characteristic muscle dynamics of or the way the muscles are contracted during walking gait. More studies need to be performed to assess how the differences is muscle dynamics between walking and running affect muscle pump. It could be inferred that for inclined walking condition, which had a higher GA EMG activity than in level walking, the musculo-venous pumping could have not only been sufficient to counteract the increased blood flow to the exercising muscles by aiding venous return but also had quite interestingly, been strong enough to elicit an actual leg volume reduction. This could conclusively show the effect of calf muscle pump in controlling foot volume and incline walking as the most effective means to reduce leg volume.

6 Conclusion

Four different combinations of motion types and inclinations were compared for participants on a treadmill to study the effect of motion type and inclination on EMG activity at lower leg muscles and the leg volume. The relationship between the muscle activity levels of lower leg and the corresponding volume changes were studied and interpreted from a physiological standpoint. Running conditions led to a volume increase and had a greater TA and GA muscle activity. The greatest increase in foot volume was identified for incline running which also had the highest EMG activity at both muscles. Walking conditions had been shown to reduce leg volume and had the least EMG activity. Only incline walking showed a reduced lower limb volume post activity and might be the best combination of activity-inclination to reduce leg volume.

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Applied Ergonomics in Fashion Design and Sports Technology

Women's Clothing Choices are Being Inhibited by Poor Fit

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Abstract. Clothing is expected to conform to our body shape, to fit closely, and deform in synchronization with our body movement [1]. Although ergonomics with regard to fashion is still little discussed, it is understood that this scientific discipline is of fundamental importance in the design and development stage of a project, since it makes it possible to ensure clothing meet the different demands of users [2]. This study will test the hypothesis that introducing bra cup sizes as an additional independent measurement into the standard sizing model will markedly improve the fit of the clothing, and lead to an increase in comfort and consumer satisfaction. The focus will be on fitted clothing, made from non-stretch fabric, where the pattern cutting of the garment needs to conform to body anthropometric data and the ergonomics of movement.

Keywords: Close fitting garments · Experimental pattern cutting · Bust cup grading · New sizing system

1 Introduction

Clothing is one of the larger retail sectors, representing £30 billion (42 billion) in the UK, and US$173 billion in the USA in 2004. Experts estimate that global textile and apparel consumption reached US$984 billion in 2002. There are many challenges in this sector. One is a long-term shift of influence from producer to consumer; another is the high level of garment returns [3]. The inability of many consumers to find good fit in mass-produced clothing has long been recognized as a major problem in providing quality apparel products to consumers. Many retailers export their clothing in the same sizing ranges as produced in their home countries, without the consideration of ethnic body shape deviations. In the last decades, the apparel industry perceives the world as a global market: global competition among global companies for global customers [4].

Fit, proper fit, is not about size or measurements; it's all about shape. The body is three-dimensional and when clothing patterns are developed that actually represent the three-dimensional shape of real human bodies, the odds that clothing will fit increase sharply [5]. The average size for women has been increasing; consequently, their body shapes have changed as well [6]. The British Standards Institute, (BSI) reported in 2003 the average British size 12 women measures 88 cm bust, 72 cm waist and 96 cm hip [7]. According to Size USA 2004, the average American female is 163 cm in height and weighs about 73.94 kg. She has a bust measure of 108.6 cm, and hips, which measure

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112.4 cm [8]. Even though consumers may have similar body measurements, their body shapes may be different. The differences in body shape often determine how a garment will hang on a figure, how comfortable the garment feels, and ultimately how that garment is perceived to fit by the consumer [6]. Fit of a garment is defined by the relationship between its dimensions and those of the human body.

Most clothing is designed for the ‘anthropometric’ position; that is, for a person standing squarely with feet slightly apart and arms at the sides. Yet we spend relatively little time in this static position; we generally are in constant motion [9]. Measurement charts are published as a guide to apparel sizing, but, there are no international relegations surrounding how a brand must label its sizes or if the size must relate to actual body measurements. In anthropometric studies, which are used to create sizing charts, the bust measurement is seen as a total girth body measurement, without the consideration for a woman’s bust cup size. I hypothesise that an optimised sizing system can be developed which would better fit the female population, a sizing system which respects the contours of a woman’s body, creating sizes within sizes, and in so doing will generate new knowledge that will benefit the consumers and the fashion industry. This research will focus on fitted clothing made from non-stretch clothing where the pattern cutting of the garment needs to conform to body anthropometric data and the ergonomics of movement. Clothing should be ergonomically designed, in accordance with the dynamic anthropometric conditions of use and functionality, while still allowing wearing comfort and a high degree of free movement, as well as uninterrupted and safe work activities [10].

2 Consumer Expectations and Satisfaction

Consumers increasingly expect their garments to have functional properties that match the specific end-use conditions under which the garments are to be worn. Therefore, everyday garments are no longer expected to merely satisfy the basic and traditional requirements of everyday wear such as basic comfort, adornment, modesty protection and fashion, but also to satisfy other performance requirements and functionalities including anti-wrinkling, breathability, waterproofing, physiological and psychological comfort, etc. [11]. Fit is one of the first things that individuals consider in evaluating a garment. It is also the number one customer complaint and reason for clothing returns [12]. Human performance can most certainly be impaired by poor fit. Restricting factors such as range of motion, reach, and manual dexterity [13]. An understanding of dress in everyday life requires understanding not just how the body is represented within the fashion system and its discourses on dress, but also how the body is experienced and lived and the role that dress plays in the presentation of the body/self [14]. The root of the fit of clothing can be traced to a lack of communication between ergonomics and designers of clothing. It is important that ergonomists collect and present their scientific data in a suitable format while the designers should be ready to interpret and apply it to design of products [15].

According to Rasband [17] garments should fit the predominant girth measurements – bust, waist and hipline in the following manner –

1. Bust or chest. Shirts and blouses should have 1 to 2 inches of ease on each side, jackets 3 to 4 inches of ease and coats 7 to 8 inches, without closures hanging straight and smooth.
2. Waist. The waistband should be comfortably snug and level with the floor when standing, yet remains comfortable when sitting.
3. Hip area. Skirts and pants should have 1 to 2 inches of ease on each side and drop half to one inch below the crotch. Skirts and pants should fall straight down below the abdomen and hipline, rather than cupping the abdomen, buttocks or thighs [16].

3 Bust Size Increases, Bra Technology and Design

The global lingerie market is estimated to be around US$30 billion, with a projected growth of perhaps 9% over the next five years [17]. The average national bra size has increased by three-cup sizes over the last 30 years, according to a new study by Intimacy. The lingerie retailer reported an average of 34DD. This compares to the 34B bra-size average in 1983. Average American bra sizes are at an all-time high, increasing from 34B to 34DD over the past 30 years, new research has revealed [18]. Not only have bust sizes increased, women are making the most of their growing assets with sales of cleavage enhancing bras up from 36% in 2010 to 70% [19]. In recent years, the average British bra size has increased from 34B to 36D, which means that while women's backs have grown one size, breasts have jumped up two. The technology in bra design can also enhance a woman's cup size by more than two sizes with additional padding. The bra can lift, enlarge, support, confine, flatten, and modestly covered women's breasts. Additional to women's natural breast size and bra technology, there is also a demand for cosmetic surgery to enhance bust sizes. Female consumers regularly explain their desire for cosmetic surgery in terms of re-creating a "genuine" body lost to physical changes [20]. The American Society for Aesthetic Plastic Surgery (ASAPS) published in their 15th annual statistical report that there was an increase of 213.2% in procedures from 1997 to 2011, being the second rated aesthetic surgical procedure after liposuction in 2011 [21].

For women with a small bust size, padding can increase confidence and self-esteem and enable them to wear fitted clothing, showing a full bust line. An investigation of two online retailer's bra styles showed 69% of designs have additional padding. The average DD cup woman now has less choice of non-padded bra styles so could be persuaded to purchase a padded bra, increasing her cup size to an E cup. As the intimate apparel industry and the apparel fashion industry operate as two independent fields, from fashion education to designers in industry, there is no correlation or cross over of information on women's body sizes. When lingerie retailers develop the technology, and padding to increase the bra cup and a woman's cleavage they do not consider the clothing that has to fit over the top. The clothing retailers seem to be unaware of the bust cup size increases, natural, cosmetic and through technology as they still produce clothing to a B cup bra.

4 Industry Sizing of Apparel

The lack of standards in the high-street sizing of clothing is contributing to customer dissatisfaction over the fit and comfort of their garments. An investigation of 47 high street retailer's online data was collated in 2015, women's bust, waist and hip measurements; across three sizes - small, medium and large (UK 10, 12 and 14). An analysis was made over the average, smallest, largest and the difference in measurements between the largest and smallest garment with the same size label. Figure 1 shows a difference of 12 cm in the bust measurement for clothing, which has the same size label.

(47 retailers) 2015 data	SMALL - UK10/ US6			MEDIUM UK12/US8			LARGE - UK14/US10		
	Bust	Waist	Hip	Bust	Waist	Hip	Bust	Waist	Hip
Average Size	86.5	68.4	93	91.4	73.2	97.9	96.8	78.6	103.2
Smallest Size	80	62.5	87.5	88	67.5	92.5	92	73.75	97.5
Largest Size	92	75	102	94.5	80	106	100.5	87.5	106.75
Difference Small to Large	12	12.5	14.5	6.5	12.5	13.5	8.5	13.75	9.25

Fig. 1. Retailers analysis of sizing data

Problems with garment fit may arise from the current industry practice of setting sizing systems, namely sizing up and down the measurements of a garment fitted perfectly to a single person, called a fit model, by applying the grades of a standard body-sizing system. Factors that influence garment fit in this scenario include the fit model, who essentially sets the starting point for the size scale and might not be representative of the target population, and the body size grades, which might not be appropriate for the targeted population [22]. The human body does not grow proportionally as suggested in size charts that guide grading practices. As a result, grading practices contribute to fit problems [23]. Schofield and LaBat (2005) compared current pattern grade rules with an anthropometric sizing database and determined that grade assumptions were not supported by body measurement data. They found a mismatch between grading practices and the body measurements of intended consumers [24]. Upper body garments are typically sized by segmenting bust circumference (primary dimension) in regular 5-cm intervals to create "sizing tables", the main tool used by pattern makers [25]. However, bust sizes are not accounted for in any type of pattern grading. The base size model in the fashion industry is commonly a size UK10, 34B cup bra. This is proportionately graded as mentioned. An average bra cup size difference is 2.5 cm, with the average grade of the bust line being 5 cm. A C cup woman, is 2.5 cm larger than the standard size at the bust line so would have to purchase the next clothes size up, just to fit her bust correctly. DD, and E cup bust would need to buy two clothes sizes larger to fit their bust line measurement.

Anthropometry is aimed at providing the correct body dimensions required to provide a good fit of the product to the user. It helps the designers to understand and appreciate the variability that exists in human body dimensions, proportions and shape [15]. At the core of clothing anthropometrics are therefore three key issues: (1) how to measure the body adequately, (2) how to analyse the vast data into efficient size charts and (3) how to use the size charts in marketing in order to create customer satisfaction with clothing [26]. Although ergonomics with regard to fashion is still little discussed, it is understood that this scientific discipline is of fundamental importance in the design and development stage of a project, since it makes it possible to ensure fashion products and clothing meet the different demands of users [2].

5 Bust Cup Sizing in Woven Apparel

To test the hypothesis that introducing bra cup sizes as an additional independent measurement into the standard sizing model will markedly improve the fit of the clothing, and lead to an increase in comfort and consumer satisfaction a four-part experiment was conducted.

1. An online survey was launched online, targeting women with a bust cup size bigger than a B (current high street sizing size). The survey received 116 responses, with 41 complete, which were used for analysis. (https://myacs.polyu.edu.hk/utils/mysurvey/index.php/838438/lang-en)
2. Two garments were purchased from three global retailers to analyse the pattern construction, size, fit and grade between sizes.
3. An experiment to create a bust cup grading formula into a basic bodice block was performed; a sample was made and fitted to a dress form.
4. A group of 12 women were selected covering a diverse age range, body size and bust cup size, called pilot testers. The bust cup formula was used to create a made to measure panel line dress for each participant.

The survey results clearly showed dissatisfaction with the availability of high street clothes sizing and fit. When questioned on clothes fit and comfort, 76% said no they did not meet expectations. Asked if clothes are tight over their bust 78% said yes, with 85% saying they did not purchase clothes due to the bust line not fitting comfortably. 75% of respondents said they had to purchase clothes in a larger size just to fit their bust size.

In January 2017 two items of clothing were purchased from a selection of retailers to cross analyse the sizing, grading, and create a pattern from the garment to analyse the construction. They were purchased in stores in Hong Kong SAR. The ideal garment was a fitted shirt, to show armhole shape and sleeve width. However, it was increasingly difficult to find such items in store. Many retailers have less and less fitted woven apparel, opting for stretch jersey fabrics for fitted styles. Woven styles predominantly had a semi fit, often with no bust shaping using a bust dart. They were looser fitting, flat over the bust, with the same measurement front and back bust line. Zara had the closest item to a fitted shirt, which has a loose waistline, with back darts only reducing waist girth at the back, and no bust dart. In H&M and Marks and Spencer's it was impossible to fulfil the criteria of a fitted shirt with none in stock, therefore, a fitted woven dress was purchased in both retailers instead.

A paper pattern of the garments was made, noting bust line, waistline, and hipline, and cross front and back positions. These girth measurements were approximated due to the shaping of the garment. Bust line measurement was taken as 2.5 cm under armhole for sleeved garments. The garments would have had ease of movement added into the pattern cutting. Dove (2013) shows a minimal ease of movement to be 4 cm bust line, 2 cm waist line and 4 cm hip line [27]. The following chart shows the original garment measurement, reduction of ease and cross comparison to the retailers sizing displayed on their live websites. Size small was used for the cross comparison (Fig. 2).

Measurement Location In centimetres	Online 08/15 S UK10	XS UK8 (32)	S UK10 (34)	M UK12 (36)	Minus ease movement	Difference
H&M fitted dress. 98% Polyester, 2% Elastane						
Across Front.			28.5cm	30cm		
Bust dart			2cm	2cm		
Bust Line	84cm		75cm	80cm	71cm	- 13cm
Waist Line	68cm		64cm	68cm	62cm	- 6cm
Hip Line	92cm		88cm	90cm	84cm	- 8cm
Body length.			39cm	40cm		
Zara Denim Shirt - 100% Cotton						
Across Front.		31.5cm	33cm			
Bust Line	86.5cm	85cm	90cm		86cm	+ 0.5cm
Waist Line	69cm	77cm	82cm		80cm	+ 11cm
Hip Line	96.5cm	90cm	96cm		92cm	- 4.5cm
Body length.		40cm	41cm			
Marks and Spencer's dress. 95% polyester, 5% elastane						
Bust and waist dart was combined as a French dart						
Bust Line	84.7cm		91cm	96cm	87cm	+ 2.3cm
Waist Line	68cm		77cm	82cm	75cm	+ 7cm
Hip Line	92.5cm		95cm	100cm	91cm	- 1.5cm
Body length.			41cm	42cm		

Fig. 2. High street garment sizing analysis

The H&M dress was significantly smaller than the advertised bust waist and hip measurements on their website, with the sizing label indicating the European bust sizing of 34 and 36 inches respectively. The Zara shirt hipline was 4.5 cm smaller than the advertised measurement, the waist of the design was made to be larger than the body and the bust was the same as advertised. Marks and Spencer's had larger bust and waist, with a smaller hip size than advertised online.

A cluster analysis was performed of women's under and over bust sizes, based on data collected from the online survey, and pilot tester measurements, a total of 48 measurements. The red diagonal dotted line shows the high-street sizing of apparel where the over bust is an average of 10 cm larger than the under bust. For smaller framed women, UK sizes 8 and 10 they appear on or slightly over the high-street standard. However, a majority of women measuring a UK12 are over 5 cm larger in bust size than the standard. The image has the addition of cup sizes, based on a 2.5 cm grade per cup band. Based on the high-street sizing of a B cup model, the cup sizes are vertically up from the dotted red line (Fig. 3).

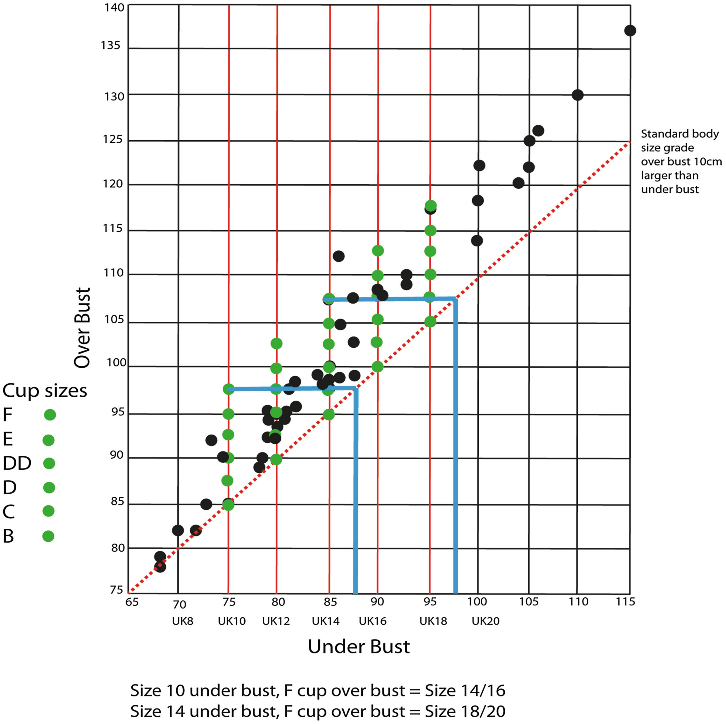

Fig. 3. Cluster analysis of 48 women's over and under bust measurements

The blue bold line shows an example of an F cup woman, size 10 and size 14 where the increase in cup measurement meets the high-street sizing (red dotted line) 2.5 sizes up. Resulting in size 10 body frame women, with an F cup bust, having to wear between a UK size 14 and 16 in fitted apparel.

6 Bust Cup Grading Formula

A dress form, missy 12 was used as the base of this experiment. The form was measured net, then with a B and a D cup bra placed over the form. A drape of the torso was also taken to analyse the difference in bust cup dart width with the two different bra cup sizes. The dress form was taped for key girth, width and height placement, with the D cup bra for this experiment. A made to measure bodice block was created for the dress form, using the below formula to add the bust cup size D into the block. The front block being created smaller than the back, with increased bust dart width and raised front neckline (Figs. 4, 5, 6).

Bust cup dart width at shoulder seam	2cm grade per cup size – experimental calculation
Front bust line at side seam front	1.25cm grade per cup size (half a cup size)
Front panel line	Moving to side seam by 0.5cm per cup
Bust line position	Raised by 0.5cm per cup
Cross front position	Raise by 0.5cm per cup – default of bust line position
Shoulder line and front neck drop	Raised by 0.5cm per cup – default of bust line position

Fig. 4. Bust cup grading formula

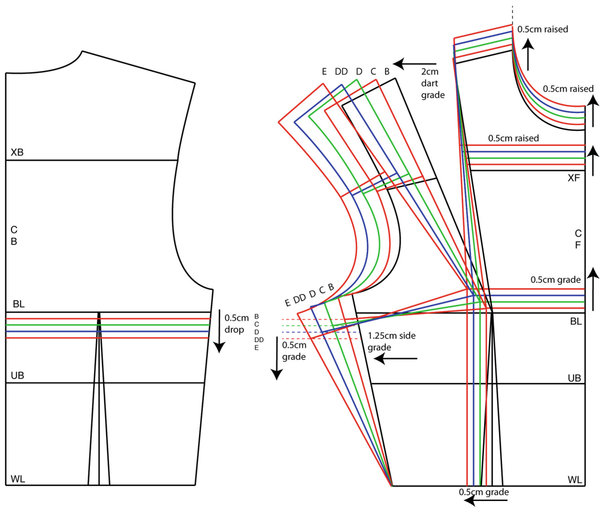

Fig. 5. Bust cup grading formula diagram

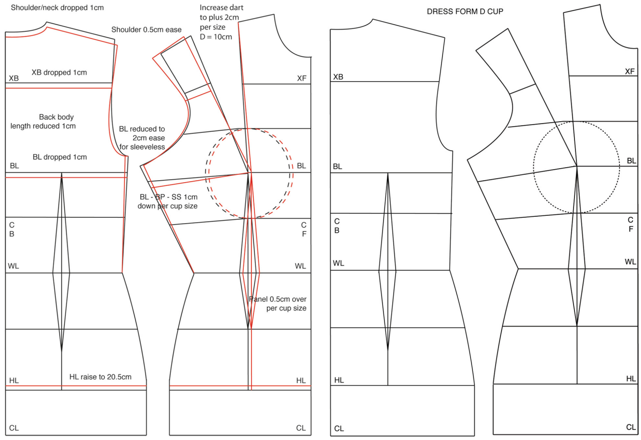

Fig. 6. Dress form bodice block created with a D cup bust line at the front

A small group of 14 women were selected to perform the same experiment of bust cup grading, aged 18–67 with bust cup sizes from a C cup to an E cup. Two women withdrew from the experiment after being measured. The panel line dress experiment was used to create a panel line sleeveless dress for the participants. The dress was made to measure from their body measurements, with the bust cup grading formula added into the bodice block. The objective of the pilot tester experiment was to ascertain if the bust cup grade is an accurate formula to provide an improved fit and customer satisfaction. A panel line dress was created from the bodice block and a sample with lining made, fitted on the participant and photo recorded. Participants also completed a post-fitting questionnaire while conducting a one hour wearer trial (Fig. 7).

			E					
			E					
			E					
			DD					
			DD					
	D		D	D				
	C	DD	D	C			DD	E
UK SIZE	10	12	14	16	18	20	22	24

Fig. 7. Participants body and bust sizes

The participants bust cup size was analysed by three methods, the pilot testers own bra size worn, the over/under bust analysis and using a bra cup tape measure. Seven of the participants fell within a size UK14 range, using a base size, with a 5 cm body grade to calculate an approximate size range. Pilot testers were also categorised in different heights, five were within the petite height range, the majority, seven participants, falling in the average height range, with only two in the tall range.

7 Dress Fit Analysis Conclusion

The initial dress fit on the dress form was acceptable for the D cup construction method. The bust fitted the form with ease of movement. The waist fit was shapely, the hip slightly large with 4 cm ease of movement. The pilot testers completed a questionnaire during a wearer trial, with results showing that 10 women felt the dress was a significantly improved fit over their bust line, with 2 feeling the bust was still tight; and these being two of the E cup women. All women felt very comfortable in the dress, with the waist and hip fitting receiving 100% satisfaction. The armhole positioning, side seam and ease of movement was all analysed, receiving positive feedback on fit and form. From a technical capacity, the evaluation of this pilot test was very successful. There are still improvements that can be made in the fit of a bust cup grade within the body, specifically the grading of larger cup sizes.

An experimental sizing chart was subsequently calculated to show how bust cup grading could be implemented within a sizing system. Figure 8 shows the over bust girth being the base, size UK 10 with a 4 cm body size grade. Additional measurements for C, D, DD, E and F cup sizes were calculated, increasing the bust girth without altering the under bust, waist or hip measurements (Fig. 8).

UK Body size in centimetres	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**	**22**
Over Bust Girth B cup	76	80	84	88	92	96	100	104	110
C (2.5cm cup grade)	78.5	82.5	86.5	90.5	94.5	98.5	102.5	106.5	112.5
D	81	85	89	93	97	101.5	105	109	115
DD	83.5	87.5	91.5	95.5	99.5	104	107.5	111.5	117.5
E	86	90	94	98	102	106.5	110	104	120
F	88.5	92.5	96.5	100.5	104.5	109	112.5	106.5	122.5
Under Bust girth	60	65	70	75	80	85	90	95	100
Waist girth	59	63	67	71	75	79	83	87	93
Hip Girth	82	86	90	94	98	102	106	110	114

Fig. 8. Experimental sizing system for bust cup grading

This research has shown an inconsistency in clothing sizes, across pattern publications, retail outlets, from clothing to bras. International and national standards are in place, but not used. Retailers believe they cater for their customers in their sizing, yet clothing returns and bad fit are commonplace. The objective of this research is to develop a sizing system that fits the three-dimensional contours of a woman's body, by adding in bust sizing into the current system, improving customer satisfaction, fit and function. Given all of the difficulties of creating sizing systems for ready-made clothing, it seems that it would be impossible to provide good fit for everyone in the population, and indeed the difficulties increase, as more people are included in the target market for a firm. Therefore, most apparel companies create their sizing systems by defining their target market in a way that gives them a loyal following of customers, who appreciate the styles, fit characteristics, level of quality, and cost provided by the company [28]. This exploratory grading system requires further experimental work using participants with a variety of figure shapes and bust sizes. The fashion industry could select sizes for their specific target consumers from the chart, not being expected to cater to all body and bust size. In the past ten years, the apparel and retail industries have come a long way in terms of understanding fit, its relation to body shape, and the critical role both play in the success of every retailer and brand. While companies will continue to explore new, innovative technologies trying to solve the fit frustration that many consumers face on a regular basis, there is no 100% solution [5].

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Reading Task Investigation of the Kindle app in Three Mediums

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Abstract. E-textbooks are often considered the future of textbooks but the current capabilities and implications of app-based textbooks and their corresponding technology are not well outlined. The goal in this study was to understand the effects of the change in medium on the academic reading task, student perception of the devices and components, and identify issues surrounding two in-app components. Students completed four reading tasks in three different size mobile devices and a paper control. The experiment also consisted of a between-subject study where students were asked to use the highlighting or annotation component while reading. Results showed that the devices and components actually changed the way the students interact with their reading. Also, students were generally unhappy with the in-app components and smallest sized device. This information is useful to identify the effects of e-textbook apps on reading behavior, which can be applied to improve the design of future e-textbooks.

Keywords: Electronic textbooks · Textbook design · Interface design · Kindle app · Experiment

1 Introduction

Education is slowly shifting to new practices, especially when it comes to textbooks. While some universities across the world are hesitant to move to electronic textbooks, others are moving forward with electronic textbook adoption [1]. McFadden predicts that within the next few of years, tablets will take the place of other forms of personal computers to become the primary computing platform in academia [2]. Some of the new mobile devices are attempting to straddle this line with their marketing and technology, such as the iPad Pro, Microsoft Surface, and the Lenovo Yoga.

This shift leads us to the core research question, which drove this study. What effect does screen size of the most frequently used mobile technology have on student academic reading behavior? Past research has given us some insight into this area, but leaves much to be desired in information on some important aspects such as an investigation into how supporting activities, such as highlighting and notetaking, change.

Research based on leisure reading in electronic forms do not necessarily apply to academic reading because academic reading requires higher levels of concentration and

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the ability to infer and deduct the proper aspects of the text so that material may be fully comprehended and recalled later [3, 4]. This recall is vital to the task of academic reading because of the academic performance measures such as papers and exams [5]. It is also important to remember that students do not tend to read for school without any supporting activities, such as highlighting and notetaking.

Past research has told us that moving to the electronic form of textbooks does not have a negative impact in comprehension, but some aspects resulting from the switch to the digital medium such as sentence splitting may in fact negatively influence comprehension [6]. Since working memory is limited, the complexity of the learning task will increase the cognitive load on the working memory and thus impeded the student's learning of the material [7]. It is vital to acknowledge cognitive load as there is a correlation between working memory and academic achievement [8]. Research has also shown that the visual demands of electronic texts, especially hypertext, increases cognitive load [9]. Past research has found the different types of e-readers did not have an effect on students' learning of the material [10]. In fact, teachers have reported benefits in some of the different functionalities available through electronic textbooks, such as the ability for students to take notes they can refer back to and the built in dictionary components [11].

While research showed that there is little difference in student comprehension of the material, student behavior has been shown to change. Woody, et al. found that students are more likely to use certain aspects of the physical textbook, such as reading summaries or answering questions, than those included in electronic textbooks [12]. And several studies have found that students spend more time with an electronic textbook than the printed counterpart [13, 14]. Yet, this same finding regarding time spent reading is discounted in other literature [15].

Many of the studies listed above compare only a physical textbook to an electronic addition or various e-readers to each other. For example, apps such as the Kindle app has been studied before, but in relation to other reading applications [16]. So, this study evaluates one electronic textbook on the Kindle app using three mobile devices commonly used by students at the university and paper control which was the same size and format as the largest mobile device. In addition, two of the commonly used supporting activity components, the highlighting and annotation components, were also investigated to identify any changes in study behavior.

2 Method

2.1 Participants

A total of 92 students participated in this research. 51 of those students were female while 41 were male. The average age of participants was 25 years old.

There were a total of three qualifying factors for participation in the experiment. First, the participant had to be a current student at the university. Students were chosen as experiment participants because of their familiarity with academic texts. Second, students were required to have normal or corrected vision. Finally, students were required to have a native language other than English and pass a pretest. Non-native

English speakers were chosen as the target group for the study as current research on electronic textbooks does not always take into account non-native language users of the books. With more and more students studying abroad and universities offering courses in languages other than the native language their students use, this is an important user group. Education level was not considered a qualifying factor for this experiment as a student's reading level did not necessarily coincide with their education level. Instead, groups were balanced by pretest results. If a student performed too poorly on the pretest, they were disqualified from participating in the experiment.

2.2 Equipment

An iPhone 6s, iPad mini, and iPad were used during this experiment (see Table 1). The three forms of mobile devices used were chosen based on the prevalence of usage within the university. All devices used the same operating system so as to have the least amount of differences within the app and subsequent interactions. All three devices had the text size, brightness, and layout preset so the conditions were the same across devices. Devices were also presented to students on a stand and they were not allowed to hold the devices or alter the state of the devices except to change the page, take notes, or highlight depending on group assigned.

Table 1. Screen sizes and resolutions of mobile devices.

Display features	Mobile	Mini-tablet	iPad
Screen resolution	1334 × 750	1024 × 768	1024 × 768
Screen size	4.7 inches	7.9 inches	9.7 inches

The Kindle app was chosen as the application, which the textbook would be presented. This was because of ease of access across the devices and previous research into students at the university showed a general familiarity with the app. The textbook chosen for the students was written in English by professors at a foreign language speaking university to be used in their classrooms. Four individual chapters were chosen from the textbook and educational reading experts deemed appropriate for the experiment, as they were similar in length and reading level.

A Sony HDR-PJ440 Handycam was also used to video record the students interacting with the mobile devices during the reading sessions. The video camera was placed on a tripod located behind the left shoulder of the participants.

2.3 Experimental Design

The findings presented in this paper were discovered during a mixed factorial design experiment, which used four settings. The four settings were using different devices including mobile phone, mini-tablet, normal sized tablet, and a control group who used paper. The paper control was the same size as the normal iPad so as to identify if changes in task behavior were based on the change in medium without confounding factors such as layout and size. The chapter students were asked to read was randomized. Participants read a chapter on all three of the mobile device sizes and the paper.

In addition, participants were separated into three different groups. 31 Students were in Group A and completed the readings with the three different screen sizes and paper in the four conditions. 31 students in Group B completed the same process but were requested to use the built in highlighting function or to highlight directly on the paper. And the 30 students in Group C also completed the same process but were requested to use the annotation tool while using the devices and take notes directly on paper when using paper.

Each session ranged from one hour to one and a half hours based on the individual's time spent reading. Participants were paid for their time.

2.4 Procedure

Participants were briefed on the experimental procedure and signed a consent form. After taking a reading comprehension and recall pretest, students were assigned to one of the three groups. Before the students began reading, they were briefly shown how to use the app and any functions they were required to use. They also had the opportunity to try navigating in the book and opening the annotation tool or using the highlighting function.

The student then began the reading assigned to the condition. After each condition, a rest period of three minutes was completed and students filled out a questionnaire regarding their experience during the reading task. Then they were given a post reading test. Following that, the next condition began. After all conditions were completed, students were asked to compare their experiences in all the conditions and report their general impressions and any issues they found.

3 Results

3.1 Time Spent Reading

Before analysis began, normality of the data was assessed. To ensure the normality of the data, outliers were removed. This left 26 participants in Group A, 31 participants in Group B, and 28 participants in Group C. All results related to time spent reading were based on data from these participants.

This study showed that time spent reading changed not only between the paper control and the various mobile device sizes, but also between groups. Table 2 shows the average time spent reading for each condition in words per minute (wpm).

Table 2. Average time spent reading in Word Per Minute for each group and device.

Groups	Paper	iPhone 6s	iPad mini	iPad
A	118	109	121	117
B	96	99	106	104
C	95	98	107	103

In Group A, where users were only required to finish the readings in each condition, the iPad mini was shown to afford the fastest time for completion of reading but the changes in time spent reading were not as pronounced between the mini, iPad, and paper control. The difference between the least time spent reading and most across all four conditions was 12 wpm. The full-size iPad and the paper control were the same size and format and the time spent reading in these two conditions only differed by 1wpm.

Groups B and C included a supporting task, highlighting and note taking respectively, during the reading sessions. Conversely to the findings of Group A, the paper control had the longest time spent reading while the iPad mini continued to afford the shortest time spent reading. Once again, the difference between the iPad and the iPad mini was a decrease of less than 4 wpm. While Group A showed a difference of more than 12 wpm between the iPhone and the iPad mini, this large difference in time spent reading was reduced in Groups B and C. Instead, there was a 7 wpm decrease in Group B and 9 wpm decrease in Group C when using the mobile phone.

3.2 Changes in Reading Behavior

There were changes in the behavior of students when using components, which support their reading. Overall, when moving to the Kindle App, students took less notes and used the highlighting tool less frequently.

Students frequently reported, during the experiment, that the platform did not support their habits. Analysis of paper controls found that 73.3% students in the notetaking group used a more visual notetaking style that is not supported by the app's simple textbook input (see Fig. 1). Also, 16.1% students in the highlighting group used other marks such as circling or starring to help identify the importance of the material in addition to simple highlighting (see Fig. 2).

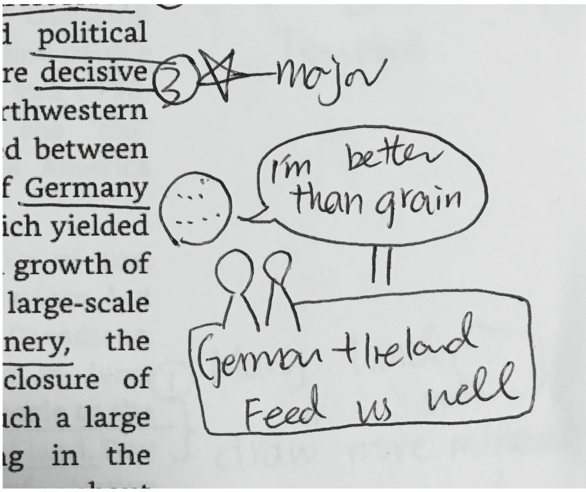
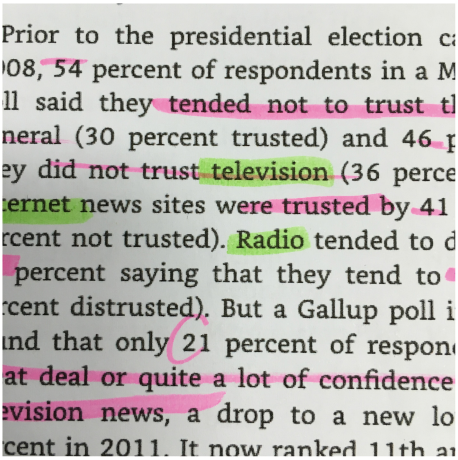


Fig. 1. Example of notetaking behavior not supported by Kindle app.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cent in 2011. It now ranked 11th a

Fig. 2. Example of highlighting behavior that is not supported by Kindle App.

3.3 Issues Identified

Several issues were identified during the experiment through facilitator observation and student report after each task. Some of these were related solely to the specific mobile device and others were found across all of the mobile devices.

Device specific issues were found on the iPhone 6s. This was due to the small screen size. Students frequently reported issues reading the material due to the limited information on the screen. Students also reported difficulties of taking notes and highlighting. The issues of taking notes were related to the small size of the keyboard input. The issues related to highlighting were frequently related to the increased sentence splitting caused by the small screen size. Students would have to highlight text on two different pages and reported this as being difficult and often time consuming.

Issues with the in-app components used in both Groups B and C were reported across devices. Highlighting was reported as difficult for students to complete without using more than one highlighting movement to cover the complete sentence. Similar to what the students reported, the facilitator also observed student issues when they attempted to make an existing highlighted section longer or shorter and at times ended up completely removing the highlighted section and started again. Students also reported that they often went back or forward a page while attempting to highlight a passage.

Students also struggled frequently with the annotation tool. Students reported that the keyboard input was not ideal for inputting their notes. Many students reported frustration with the fact that they could not move the textbox popup so that they could see the text they were referencing. Instead they had to spend more time opening and closing the textbox repeatedly until they could edit their notes to their satisfaction. In addition, the facilitator observed many students getting confused when attempting to access the annotation component. When they would select a word or phrase, students would initially look at the larger dictionary, thesaurus, Wikipedia boxes that pop up bellow the toolbar. Some students even attempted to select those options out of reflex. Students also showed frustration with the way the notetaking icon was represented. Several students deleted the note to try and select a phrase once again to only have the same icon appear. A few of these students then used the highlighting component to identify the corresponding phrase.

4 Discussion

In general, the time spent reading while using physical text in Group A did not change much from the electronic version of the text. Findings from Group A showed that time reading was shorter in paper than most of the electronic mediums, which is supported by previous research [14]. Still, reading was completed faster on the iPad mini, which is supported by contradictory research that found that time spent reading decreased when using the electronic version of texts [15]. This trend of shorter time spent reading in the paper medium was not sustained in Groups B and C where the components were introduced. This discrepancy is possibly related to the increase in highlights and notes that students in those groups took in the paper form. Since students reported struggling with these functions or that the components did not support their habits, the time they saved by using them less frequently is likely the cause of this change in time spent reading.

While past surveys have shown that hundreds of thousands of students wish to be able to take notes or highlight in their electronic textbooks [17], these components are not yet optimized for students in the Kindle app. In fact, these features, which are considered essential, have yet to be perfected in any e-reader [18]. And while all the students in Group B were able to use the highlighting function in this study, although with difficulty, past research found that less than 80% of Kindle app users on an iPad 3 were able to use the highlight function within 1 min [16].

5 Conclusion

The findings from this study showed that student academic reading behavior does change not only when moving from the print to electronic medium, but there are also changes when moving between different sized mobile devices and when using different components of those electronic textbooks. The time spent reading was less for students reading in a print medium in the same size and format as the electronic textbook. Yet, this increase in speed is lost when students begin using supporting activities such as highlighting or notetaking. Students tended to do more highlighting and notetaking in terms of number of words and different styles in paper format. In addition, students struggled to use the functions in general and found them frustrating. There was a marked increase in time spent reading when moving to the mobile phone condition in all groups and students reported the least satisfaction with reading on the device in general due to their greater difficulties in reading the material and using the functions.

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Fashion Education Innovations Based on Ergonomic Design

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Abstract. Technologies are changing the life of the human being. Fashion technology brings forward more and more convenience and comfort to people's life. As the second skin, clothing plays a vital role on daily life. In aspects of art design, fashionable and colorful clothes make people obtain psychological satisfaction. From the ergonomic design, more attention was paid both on the physiological and psychological needs of the human being. For examples, the thermal physiology and compression comfort will directly have impact overall status of the health status of the human being. Especially, with development of functional fabrics and smart bio-medical sensors, functional and smart clothing has been an up-and-coming product for fashion industry and have been gradually accepted by the market. In the near future, with the changing of consumers' consumption psychology, functional and smart clothing with fashionable design will be the mainstream of the market. Considering the fashion education system at present, fashion designers and fashion education will meet new challenges in the near future. Based on ergonomic design, innovative educations should be made accordingly. The research focused on the aspects of fashion education innovations, such as materials, clothing and accessories based on ergonomic design, which laid comprehensive foundations for functional fashion design.

Keywords: Fashion design · Ergonomic design · Education innovation

1 Introduction

With the rapid developing of science and technologies, various aspects of life of the human being is dramatically changed. The same as the fashion areas, the technologies of fashion industry enhance the efficiencies and innovations [1–3]. The functional and smart clothing is under research and development in the global trends. People in the apparel and accessories market have much acceptance with these kind of high technological products, which is raising new challenges to the fashion industry [4, 5]. In the old times, fashion designers mainly emphasis on the aesthetic and fashionable functions from psychological and sociological role of clothing [6–8]. The training and education to fashion designers was surrounded from these kind of disciplines. Especially in mainland China, the startup of fashion education had not long-term history. But with the consistent contributions of the fashion educators, fashion design education has kept up

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with the developing of the fashion technologies. A pilot study of fashion design education based on multi-disciplinary and ergonomic design had been made to strengthen the innovations and creativities of the students and junior designers in this research.

2 The Fashion Design Education in Mainland China

In Mainland China, the developing of fashion design education system had its features in the background, which could be traced from the historical developing process of fashion design education and the challenges of fashion design education.

2.1 The Historical Developing Process of Fashion Design Education

Before 70s, tailors and dressmakers followed the master and apprentice systems. In the middle of 70s, with the construction of labor-intensive garment plant, the master may not satisfy the needs from the industry and apprentice systems, many training organizations had emerged. The universities under the former Ministry of Light Industry and Ministry of Textile Industry of Mainland China started their high education on fashion design. In those times, the faculties of fashioner were consisted from different backgrounds such as industrial technicians and some overseas returnee. The student source had come from fine art disciplines. This was the beginning of academic fashion educations, which mainly focused on aesthetic training to students and could not fully satisfied the raising needs from the industry [8]. The fashion related knowledge hierarchy was not completed and the course offered were not entirely market orientation. The fashion design educators had contributed greatly with the education systems. The textbooks and education systems from Japan, USA and Europe, had gradually been localized in Mainland China in these periods. The needs from the fashion industries had encouraged the fashion educators and students to expand the knowledge systems, especially on garment product developments and branding concepts in 90s and afterwards [8] (Fig. 1).

Fig. 1. Designer: Hong Wu [9]

2.2 The Challenges of Fashion Design Education

The fashion branding trends in Mainland China initiating from 90s challenged the knowledge hierarchy of fashion education greatly. The fashion design process combined with business operation which leading to more division of labor and multi-disciplinary knowledge, such as sales & marketing, product planning, product management, consumer psychology and behavior. With China's accession into WTO, the fashion industry unavoidable faced the international business environments and pressure. The fashion education system had to be adjusted with global field of vision and point of views. Times are changing as well as the fashion design education system. Efforts from generation to generation of fashion educators had constructed the fashion design education nowadays. More fashion designers created works keeping up with the global fashion trends [9]. The knowledge hierarchy is covering the art design, science, technologies and social science at present [7, 8, 10]. For example, the ergonomic design has been listed in the school syllabus to enhance the knowledge of students from science and technologies aspects. The international communication from staffs students are carried on at the same time. The fashion education system is developing with the challenges of the times.

3 Innovations of Fashion Design Education Based on Ergonomic Design

Ergonomic design is a course with science and technology background in fashion design education system. With the fast changing in these areas, the fashion designers need to keep up with the technological trends and make use of it in the design as much as possible. The innovations in science and technology are the inspiration source to the new generations. As fashion design educators, to encourage the students with ergonomic design concept and knowledge will expand the creative activities of the students. A pilot study on innovations of fashion design education based on ergonomic design had been made in the course and the works of the students ranged from material, clothing and accessories, which are full of creativities and imaginations.

3.1 Innovations on Wearable Material Design

In this course, some students made use of existing materials to redesign the texture and structure, which constructed a new fabric. For example, the left one of Fig. 2 designed by Ying Xie, who reconstructed the look of Dupong paper and sized it with color agents. The works of Xueting Wu, see right one of Fig. 2, was decorated with bead tube and white feather. The inspiration of Jiaxin Wang's work was coming from buttons, see the left one of Fig. 3. Each button had different face and mood due to the various thread binding methods. Shiming Zhang's work had tie-dyed and sewn with sequins. The matching of plain weave and white lace presented a particular fabric. The students creatively redesigned the wearable fabrics with common materials from the aesthetic and fashionable point of view. This trial is focused on technical and psychological aspects.

Fig. 2. Left: Designer: Ying Xie. Right: Designer: Xueting Wu. Instructor: Huang Chao

Fig. 3. Left: Designer: Jiaxin Wang Right: Designer: Shiming Zhang. Instructor: Huang Chao

3.2 Innovations on Fashion Design

Kenghong Huang's work named Dyeing & Shining, see Fig. 4 left. The designer utilized linen, LED ribbon lamp and dyeing materials. As a beautiful and traditional skill, tie-dyeing contributes a lot to endow fabrics with new life. Tie-dyed fabrics have decorated the bodies and environments of human being for a long time. With the rapid developing of luminous technology, more and more portable and wearable luminescence material can be used to fashion design. In this work, a fusion of tie-dyeing fabric and LED lamp makes the design present a new look, which is the combination of fashion and technology, tradition and modern. The crossover of tie-dyed skills and luminous technology expresses the fashion design concepts with more technical language.

Deep ocean and water is the work of Lam Hoi Lau, see Fig. 4 right. The designer redesign the fabric with synthetic materials and PVC. The inspiration of this design is from oceans, which occupy about 71% of the whole earth and have great impacts on our life. To understand the ocean and to protect the ocean is a meaningful mission of the human. This design focused on deep oceans and water, using fabric redesign skills based on black synthetic materials and PVC, to reappear the mystery of deep ocean and streaming of water. Deep oceans are quite and never talk, but they are symbiotic with

Fig. 4. Left: Designer: Huang Kenghong. Right: Designer: Lam Hoi Lau. Instructor: Huang Chao

human beings. This design hopes to arouse the concept of ocean protections by means of fashion design expressions.

3.3 Innovations on Accessories Design

Jianmei Kang and Fu Chen's design are both rings. The former had an inspiration from architecture developing a works with combination of art and comfort. The latter was interested in NFC technologies. The designer created a smart ring model with function of wireless payment and can be connected to apps on iOS and Android platform. It also can be used as keys which is quite light and easy to carry (Fig. 5).

Fig. 5. Left: Designer: Jianmei Right: Designer: Fu Chen. Instructor: Huang Chao

The works of Jianheng Tan developed a wristlet for young generation, see the left one of Fig. 6. This work is a combination of art sense and the wearing comfort. Huibao Zhong's wristlet, see the right one of Fig. 6 is braided with yarns, which is adopted with replaceable mosquito repellents. This work is designed to young generation too, which had both aesthetic perception and mosquito repellent function.

Fig. 6. Left: Designer: Jiaheng Tan. Right: Designer Huibao Zhong. Instructor: Huang Chao

3D printing technologies had been used in this pilot study. Wenyi Zhang designed a set of armware and ring with this technology, see Fig. 7. In the time of consumption differentiation, designers should offer humanization, individuation and comfort works to consumers. 3D printing with individual model design based on custom's 3D profile will have optimistic future.

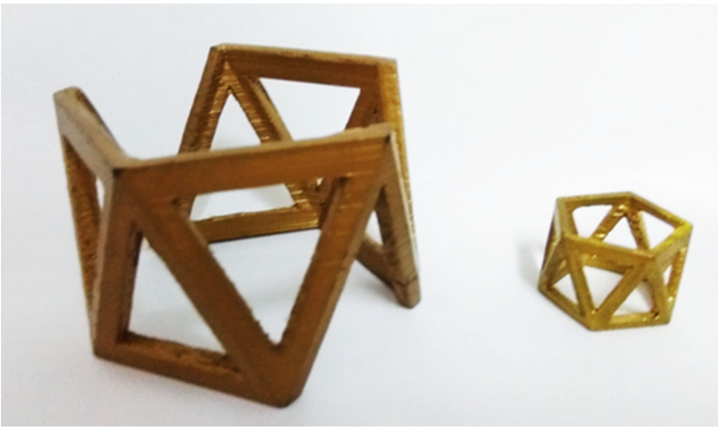

Fig. 7. Designer: Wenyi Zhang. Instructor: Huang Chao

4 Findings and Conclusions

In this pilot study, students had presented favorable manipulative ability and creativities. Though they may not fully utilize the knowledge of ergonomic design, they considered the latest technologies such as LED, NFC and 3D printing; they thought about the needs of comfort of the wearer; they also concentrated on the psychological and physiologic needs of their generations. As fashion design educators, this pilot study is encouraging and would be further extended in the future courses.

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An Explorative Study of Elderly Fashion

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Abstract. Fashion for elderly is not a new concept in the fashion industry, but for Hong Kong market, it seemed much backward when compared to foreign countries. Modification on the new style silhouettes is a critical factor to increase the acceptance in Hong Kong market. This research hoped to demonstrate the new ideas of senior fashion and the new possible style were able to inspired fashion design students or designers to create their own collection with innovation and meaningful collections. Through understanding the senior fashion market, it was anticipated to benefit for the fashion lovers who are getting retired in the next 5 to 10 years. This study developed fashion elements of materials, graphic, embellishment, style and garments design with illustrations and adopted them to questionnaire survey to the elderly fashion in Hong Kong.

Keywords: Fashion design · Elderly fashion · Senior fashion market

1 Introduction

The proportion of over 65 s in the global population has risen from 5.9% in 1980 to 8.0% due to improved health care, higher living standards, better nutrition and increased life expectancy. Compared to the older times, more and more elderly people in this generation have a relatively better education level and financial status especially in developed countries and have greater consumption and spending power for luxuries and non-essentials [1, 2]. The elderly fashion market has growth potentials and need to be further researched for market expansion [3]. In Hong Kong, the fashion industry doesn't pay much attention to this growing market and the products have deficiency on style, size, color, etc., compared to USA and the European market. Insights and creativities are necessary for developing the market in Hong Kong. An explorative study has been made on elderly fashion with innovative design in terms of the senior fashion and investigation of new design to senior fashion market, aiming to provide practical and useful information to the industry.

2 Methodology

In this study, the research method and the exploration of elderly fashion were focused on two steps. The first step is the design developments with elements of materials, graphic, embellishment and style to form the final outfits. In the second step, all of the

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design illustrations were included to questionnaires for further opinions and general acceptance of senior fashion.

3 Design Illustrations for Elderly Fashion

Currently, the fashion products for the elderly in Hong Kong is considerably conservative and insufficient, which is mostly inspired from western countries. To create new design for this generation would be challenging and be of practical significance. Considering the insufficiency of elderly fashion in Hong Kong, design elements of materials, graphic, embellishment and style were concentrated for further elderly fashion design. The explanatory designs of the collection were presented in the following. In this research, illustrations of design were utilized instead of real garments to find out the general acceptance of new image of elderly fashion.

3.1 Materials

The materials to construct the clothing are the foundation for elderly fashion. The requirements for elderly customs are the basic standard on comfort, easy care and wear. Besides, their clothing should be durable and easy to clean.

According to properties of textiles, four kinds of fabrics including cashmere, fur, nylon-quilted fabric, wool tweed fabric were selected for style development, see Fig. 1. The cashmere has good function of keeping warm and soft hand feeling. Fur looks Luxurious and has extremely soft hand feel and smooth texture. Nylon is quite durable and light. The quilted cotton is breathable and with a high insulating ability, which will provide warmness to the elderly. Wool tweed is easy-handled, moisture-resistant and durable [4]. The commonness of these kinds of fabrics is its popularity among the elderly consumers, which is easily to be accepted by them.

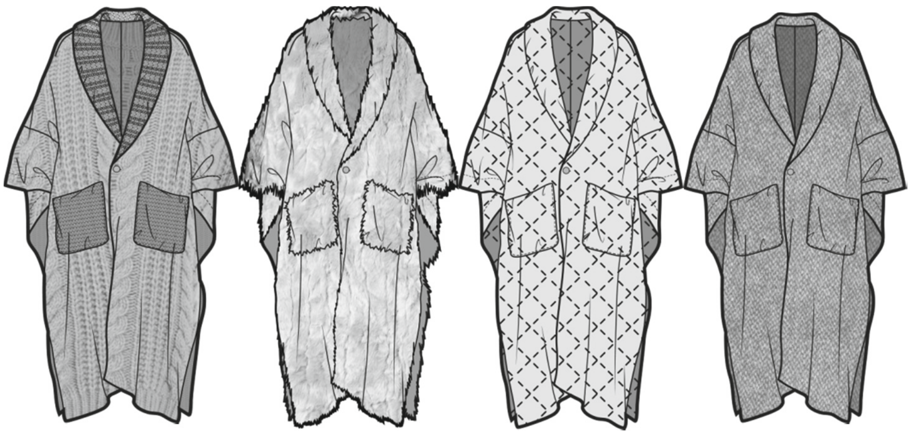


Fig. 1. Materials for elderly fashion. From left to right: cashmere knitwear, fur, nylon quilted fabric, wool tweed fabric

3.2 Screen Print

Screen print is adopted to showing different patterns on the clothing. This technique is a conventional technique, which is particularly suitable for flat fabrics [5]. It has several types with various visual effects differing in printing materials, such as water-based ink, plastisol, expanding ink and flocking etc. Water-based ink is chosen for the design as it is easily to be handled complicated patterns, having amazing visual effects and keeping the original fabrics with relatively comfortable hand feel.

Five patterns including Splash graphic style, Horses print style, Cherry blossoms style, Bolded blossom style and Chrysanthemum pattern style had been developed for screen print, see Fig. 2. Splashing style in pink tone makes elderly look gentle and young. Horses print style in black and white is classic and active. Cherry blossoms are represented as a symbol of spring in Japan presents noble and generous feelings. Bolded blossom print in purple looks noble as purple is distinguished color in China and some western countries. Chrysanthemum is a traditional pattern in Chinese culture. This pattern represents elegance. All of these five patterns were developed from the viewpoint of visual features, psychological acceptance and the background of culture.

Fig. 2. Screen print patterns for elderly fashion. From left to right:Splash graphic style (Splash), Horses print style (Animal), Cherry blossoms style (Small floral), Bolded blossom style (Japan floral), Chrysanthemum pattern style (Big floral)

3.3 Embellishment

Embellishment makes garments look fancy and attractive [6]. Sequins, embroidery, crochet, rhinestone and eyelet are commonly used for clothing decoration, see Fig. 3. Sequins is a twinkling fashion element with wide variety of colors and geometrical shapes. Crochet is a knitting technique with yarns or thread by means of crochet hooks. Rhinestone is a kind of synthetic diamond made from materials such as glass, acrylic and crystal. Eyelet is small ring punched to fabrics with a puncher. Embroidery has a long history and rich expressive performance for clothing decoration. These kinds of various decorative techniques provide the garments with glamorous and modern look, which will satisfy the psychological needs on abundance.

Fig. 3. Embellishment for elderly fashion. From left to right: Sequins, Crochet, Rhinestone and eyelet, Embroidery.

3.4 Style

The mix and match of clothing and accessories such as glasses and handbags makes for various style. Normally the elderly has not much concepts and concerns on it. This study delivered several choices for them, see Fig. 4. Gathers all over details style is cool and innovative. Draw cord asymmetric coat style is a chic look and stylish. Gathered collar

Fig. 4. Style design for elderly fashion. From left to right: Gathers all over details style, Draw cord asymmetric coat style, Gathered collar and pocket details style, Oversized collar jacket style

and pocket details style is dazzling style with elegant hat and fashionable glasses. Oversized collar jacket style is casual and wide adaptation. To help the elderly develop their individual styles is meaningful.

3.5 Garment Design

In this study, the garment design was emphasized on different kinds of coats with the elements previously mentioned. Design illustrations utilizing of various details provided multiple choices for the elderly. There were eight design including Nylon quilted coat, Draw cord coat, Gathered Jacket, Huge collar jacket, Further oversized coat, Fur collar cape, Fringe cape cardigan, Embellishment jacket., see Figs. 5 and 6.

Fig. 5. Garment design for elderly fashion. From left to right: Nylon quilted coat (Design A), Draw cord coat (Design B), Gathered Jacket (Design C), Huge collar jacket (Design D).

Fig. 6. Garment design for elderly fashion. From left to right: Further oversized coat (Design E), Fur collar cape (Design F), Fringe cape cardigan (Design G), Embellishment jacket (Design H).

4 Results

To look into the viewpoints of people for senior fashion, a questionnaire was conducted for quantitative reference. All of the elements design for the elderly, including Materials, Graphic, Embellishment, Style and the Final outfits garment were integrated in the questionnaire design.100 respondents were interviewed in this study. The following is the results of the questionnaire.

From the left one of Fig. 7, half (47%) of the interviewees preferred Fur as the main material for the elderly fashion. In order to save animals there should be imitation of fur materials. Nylon Quilting had only 8% and was the least favorite material. About 60% of the interviewees liked floral patterns including Big floral (31%), Small floral (28%), see the right one of Fig. 7. Animal pattern was accepted with a percentage of 17%. But the Splash and Japan floral seemed not so popular among them both with only 12% preferring it.

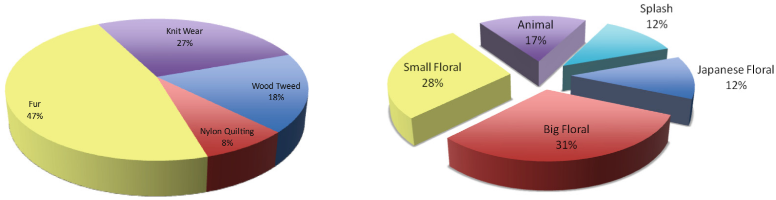
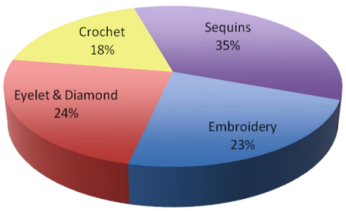


Fig. 7. Favorite materials (left) and patterns (right)

About the embellishment details, see the left one of Fig. 8., the results hadn't great difference. Both sequins (35%), rhinestone and eyelet (24%), embroidery (23%) and crochet (18%) had their markets. Sequins may have a bit more preference than other choices. According to the right pie chart of Fig. 8. The casual and conservative look of Style D would be the most favorite style with a percentage of 38%. Style B was the second one of 28% which was a little casual but more elegant. While the stylish and chic style of Style A (18%) and C (16%) would be not so acceptable for the elderly fashion.



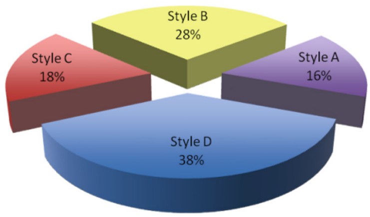


Fig. 8. Favorite embellishment (left) and styles (right)

In general, the interviewees had different interests in the overall garment design from Design A to H, see Fig. 9. Design A would be the favorite one with 19% voting, which is casual and easy to handle but looks fashionable. Design F seemed not popular with only 1%. The design with trousers may not catch the elderly market. For the other design which had mix and match concepts, the results look similar. The needs of wearing casually and elegantly may have the market potentials.

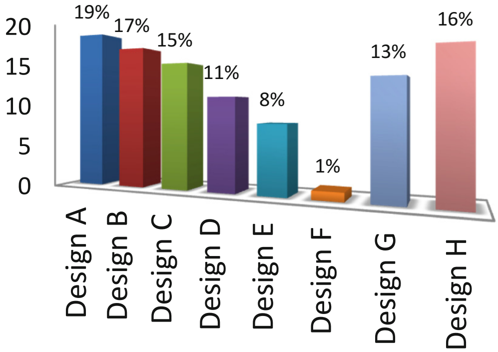


Fig. 9. Favorite garment design

5 Findings and Conclusions

From the results in the study, the elderly fashion in Hong Kong has optimistic potentials as the elderly consumers have their own taste and preference on fashion. The elderly have their own needs from psychological and physiological aspects. For example, warm and light materials may satisfy their needs of keeping comfortable. Big size clothes may be easily worn and handled. Floral patterns make them delighted and looks gentle. The fashion products provided for the elderly in Hong Kong still have a long way to go, such as material selections, pattern development, embellishments, styles and design. Besides, the consumption behaviors of the elderly in Hong Kong need in-depth analysis too. The explorative study on elderly fashion may not fully comprehensive and still has some insufficiency. Further research need to be done to find out the specific directions for the elderly fashion market and actual clothing have to be tested in order to find suitable clothing for the elderly. This research did not consider fit and functional aspect, but all these aspects have to be considered to make elderly practical.

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Old Fashion to New Fashion: The Creative Fashion Design Concepts from Nail Cover of Qing Dynasty

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Abstract. The history of Chinese costume and accessories from different dynasty are charming which has traditional and typical aesthetic appreciation. The beautiful color and handmade techniques of them presents people in nowadays with new fashion concepts. For example, nail cover was a daily accessory of female in Qing dynasty which had special materials, making skills and wearing methods. It has not only its functions to protect the nails but also the satisfaction of aesthetic needs from the female in Qing Dynasty (1644 A.D. to 1911 A.D.). At present, lots of Chinese costume elements attract fashion designers' interests and adopt them to fashion works which becomes a fashion trend for many years. But Chinese old accessories, such as the unique nail cover, would convey more functional and fashionable information which need to be discovered for the creative fashion design concepts. The tracing of old fashion is meaningful to creating the new fashion from function and aesthetic.

Keywords: Nail cover · Qing dynasty · Fashion design

1 Introduction

Nail covers are an ornament usually worn by Qing Dynasty (1644 A.D. to 1911 A.D.) women, but they also function as covers to protect fingernails. The fingernails-keeping habit of Chinese women origins from the aesthetic standard on women's hands: pure white, slender and long, fair nails.

Many words of praise such as catkins, tips of bamboo shoots and spring shallots were given to the fingers of the women in ancient Chinese literature. Book of Odes the Odes of Wei Shuo Ren: "her fingers were like the blades of the young white-grass, her skin was like congealed ointment". It's a description of the hands of the wife of the marquis of Wei: delicate and white as incipient cogongrass shoots. There are also other odes about women's hands. Song of the Washerwoman written by Li Yu, a poet from Southern Tang in Five Dynasties: "her fragrant cheeks lean to one side against her tender hands, for whom glisten her tears undried against the balustrade she stands?" Ode to Hand from Han Wo: "her white wrist and ruddy skin are like jade bamboo shoots, her finger tips can be glimpsed from playing the zither or doing needlework." The original length and shapes of fingers would be very difficult to change, but by growing fingernails long could make fingers visually graceful and slender, therefore ancient women were keen on maintaining their fingernails.

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In ancient China, keeping fingernails is not only a habit for aristocratic women but also for commoners and servant girls. In the ancient novella collection, Amazing Tales:Second Series, it is written of a civilian girl trying to open a shut door, "she never expected that it was fixed by something outside, through dragging her efforts, two or three of her fingernails were together broken". Qingwen, in the novel A Dream of Red Chambers, also had the habit of maintaining her fingernails. In Chap. 71: "wiping her tears, Qingwen puts her hands to her lips, with a screech…she bites her two shallot like fingernails away suddenly". In the Qing dynasty, the custom mainly existed, especially among the Manchu women who lived in luxury. It is recorded that "living an idle life, the Manchu women, who had grown in affluence, were keen on keeping long fingernails to please themselves" [1]. CiXi cared so much for her fingernails that every night, before sleeping, she was used to doing a series of work to perfect them. First, she soaked her fingernails in hot water to soften them, and then improved them with some tool; next she brushed every nook and corner of the fingernails with a small brush; finally, she applied nail polish smoothly by Lingzi tube to protect the nail [2].

2 The History of Nail Covers

As protection covers, nail covers were initially made of bamboo poles and reed tubes, but later with development, made from precious materials such as gold, silver, gems, etc. The earliest nail covers were found in Han Dynasty (226 B.C. to 220 A.D.), during which the nail covers were simply structured: make a nail-like cover with an extremely thin gold piece according to the length of nails and leave a narrow strip of gold at the end of the cover and then bend it to be spiral so that it can be adjusted based on the thickness of fingers. Nail covers have become a splendid ornament which prevailed among women in Qing Dynasty.

Some women kept their fingernails three or four inches long, according to a "sixty-years record of make-up and dresses" by Tianxiao in the time of the Republic of China (1912–1949): "In the past, women considered it beautiful to keep long fingernails which could be so long as three to four inches and as slim as small shallots, pruned from time to time." Such long fingernails were very easily broken, so nail covers played the useful role of protecting them. Worn together, they were like an arch to the upper middle fingers, sharpening the fingers from the base to tip, naturally and gracefully smooth. However, nail covers were not only for protection, but also for their decorative values. They were important precious ornaments for the Manchu women in the Qing dynasty. When Manchu people engaged to be married the gifts the fiancé might give the fiancée could be divided into two kinds: either two sets or four sets. For two sets, they could include a pair of nail covers and rings, while for four sets, a pair of under-worn costume chains and earbobs (or bracelets) might be added [1], from which we can see that nail covers were one of the most essential ornaments of Manchu women. When CiXi was ill, knowing it was not long for her to pass away, she ordered that her most favourite jewellery jade should be placed as sacrificial objects, including "five pairs of nail covers made of gold inlaid with greenstone" [3].

3 The Materials and Techniques of Nail Covers

In the Qing dynasty, nail covers were generally made with expensive materials, mostly gold, silver and copper, as also hawksbill and jade. Two pairs of fingernail covers (Fig. 1) were both made up of entire hawksbill hollowed. Hawksbill, "thirteen scales" as it is known is a kind of large turtle, which got the name because its carapace is made up of thirteen pieces. Its underbelly is bright tan, translucent, smooth and shiny which has been considered as valuable material to be used in ornaments and works of art since ancient times. In the famous Han dynasty poem, "The Peacock Flying to the Southeast", are found the words "wearing silk shoes on foot, and wearing hawksbill on head". A magnificent noble and elegant pair has bodies of soft and translucent yellow hawksbill embellished by the free brown patches. Near the base, the bodies are decorated with small pearls depicting round longevity patterns. The other which is absolutely beautiful, was decorated with three-dimensional flower patterns in the external hawksbill, its curve modelled with a unique sheen of pearls and gemstones.

Fig. 1. Two pairs of fingernail covers made up of hawksbill

Generally, craftworks of fingernail covers include applied kingfisher-feather, treasure inlay, enamel, gold-plating, wirework, openwork and engraving. Kingfisher-feather is a traditional decoration process that is stuck to gold or silver implements to make them more colorful and luxurious without fading and tarnishing for decades (Fig. 2). Treasure inlay is a general craft that sets gems and pearls in the ornaments (Fig. 3). Enamel is to fire the mixture of quartz, feldspar, saltpetre, sodium carbonate, and oxides of lead and tin, and then paint on copper or silver utensils to fire to form enamel surface with different colours, as illustrated Fig. 4. Gold-plating is to mix gold and water into mercury, and then plate on the surface of silver or copper, by heating. The mercury evaporated, gold is adhesive to the surface of silver and copper wares and gives the lesser materials the appearance of solid gold. The examples shown in (Fig. 3) are adopted for gold-plating to increase the gloss of the copper ornament, while open-work not only increases the sense of beauty, but also reduces the weight of the nail cover both by its nature and appearance, as also does wire-accumulating. Wire-accumulating is the most ingenious technique in toreutics, the bending and accumulating to make all kinds of shapes by jointing, with the characteristics of refinement and light (Fig. 5). Openwork is to enchase on the metal to form patterns combining the false and the true Finally, there is the craft called engraving, which is here to use small chisels for shaping some flower patterns on the surface of the objects. Several nail covers unearthed from Qing dynasty tombs utilised this skill.

Fig. 2. Pair of fingernail covers with kingfisher feather and pendants tassel on the base

Fig. 3. Pair of openwork gilt copper fingernail covers with inlaid pearls

Fig. 4. Pair of openwork gilt silver enameled fingernail covers

Fig. 5. Pair of wire-accumulating fingernail covers with decoration of Pangchang

Fig. 6. Pair of gold fingernail covers in Ronglu's graves

In the Beijing collection of the Capital Museum, there is a pair of gold fingernail covers (Fig. 6) unearthed from the grave of Ronglu.

4 The Patterns of Nail Covers

Most patterns shown on the nail covers were auspicious, embodying the pursuit of a better life and its yearning. Such as bat, old money, interlink, Panchang, 寿(longevity), 喜(happiness), and the traditional Chinese plants and flowers. Bat (bian fu) had the partial tone of "blessing" (fu) symbolising good fortune; "endless ten thousand" was the connection of 卐, meaning longevity (Fig. 7); Old money symbolised wealth; Interlink is the constant display of wealth (Fig. 8); Panchang was one of the eight treasures in Buddhism, embodying lasting forever Panchang pattern also meant longevity (Fig. 5); there are both round and square characters for "longevity", with the implication of long life (Fig. 9); the "happiness" pattern represents jubilance, typically for weddings; plum, orchid bamboo and chrysanthemum were four men of honour, showing nobleness. Some nail covers also symbolised more than one meaning with various combinations of patterns with good luck, such as the nail cover in Fig. 10 of old money and longevity, which means enjoy both felicity and longevity. Some nail covers have dangling decoration (Fig. 2), some have pendant tassels from the base, others have over an inch long chain with small adornments such as pomegranate, seed pod and embroidery ball, etc. Most ingenious is that when these small ornaments are hollow, and small beads are put into the internal places, they are like small bells with wonderful sounds when shaken, so the hands of the women wearing these nail covers are more charming.

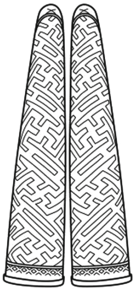

Fig. 7. Pair of fingernail covers with decoration of “Endless ten thousand”

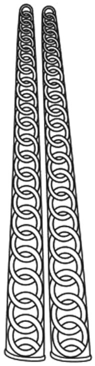

Fig. 8. Pair of fingernail covers with decoration of interlink

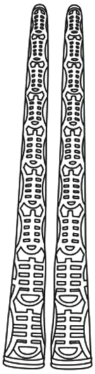

Fig. 9. Pair of fingernail covers with “longevity” character decoration

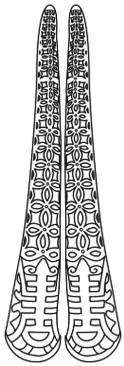

Fig. 10. Pair of fingernail covers with decoration of old money and “longevity” character

5 The Wearing Ways of Nail Covers

There are some customs on wearing nail covers. The book Qing Bai Lei Chao · Costumes compiled by Xu Ke introduced: “gold nails are hand decorations worn by women all fingers covered except thumbs.” It’s also recorded in historical images and other documentation that nail covers are generally worn on the fourth and little fingers. A brothel woman was described in the novel Feng Yue Meng: the fourth and little fingers of the left hand are always covered with silver-patterned nail wraps, about two inches long.” In Chap. 44 of The Witness of the Strange Phenomenon in Twenty years, it is said “it was not known where two gold fingernail covers went” during a prostitute’s tussles. CiXi and other noble ladies also wearing on these two fingers. Because the ring finger and little finger are not used when picking up something, they have the least influence on the action of the hands. It was not necessary to wear symmetrical or identical nail covers. DeLing, female officer of the Imperial Palace, who served CiXi before, recorded in her book: her two-years stay and Record of Qing Palace Life, that when she first met CiXi, she saw her "wearing 3-inch long gold nail covers for right fingers while jade nail covers for two left fingers, both were of the same length". We can see in the photos of CiXi that both her two hands were wearing different fingernail covers.

6 Conclusion

In conclusions, nail wraps were just functional objects for the sake of protecting women's long fingernails. Then it gradually evolves to be a kind of beautiful ornament that both protects fingernails and plays a decorative role and has become a very popular accessory in Qing Dynasty. Its development integrates Chinese cultural spirit and skillfully uptakes traditional Chinese metal working as well, thus making nail wraps gorgeous and comfortable ornaments. Nowadays, the creative fashion design elements, including materials selection, techniques development and pattern design, can also be used for reference from nail cover of Qing dynasty. The tracing of old fashion can bring forward new concepts and inspirations for designers and the whole industry, which is meaningful and practical.

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Investigation on Human Body Movements and the Resulting Body Measurement Variations

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Abstract. This study aimed to develop a new method for better measuring the dynamic human body and analyzing the body dimension variations during motions. Motion capture system, camera combined with 3D body scanner were used to obtain skeleton movement data, photos and body measurement. In the experiment, participants were scanned performing standard standing pose and dynamic postures. At the same time, movements were recorded with motion capture. By analyzing the data derived from both standard and dynamic poses, the measurement variations can be explored. Also, simulated human model generated from motion capture data and photos were examined by mapping with the body scanning data. Results and findings can be beneficial to various areas concerning ergonomics such as apparel, medical rehabilitation, biomechanics, game/film making etc.

Keywords: Human factors · Body motion · Dynamic posture · Body measurement · Body scanning · Motion capture

1 Introduction

An accurate anthropometry data is of great importance for designing comfortable and well-fit products as the products such as helmet, apparel etc. designed based on inaccurate body measurement may lead to negative user experiences. Measurement inaccuracy can be attributed to many reasons. One of reason is human motions, it lead to the stretch and shrinkage of muscle and skin during movements. Kirk and Ibrahim [1] confirmed this cognition by including the body dimension variations during movement as a foundation for later ergonomic studies.

To obtain accurate measurements, researchers have used various methods. Initially, manual taping was widely adopted to collect body measurement [2]. Beazley [3] mentioned manually taping was used to collect the body dimension data for improving the anthropometric survey for example the UK size survey since 1950s. Apeagyei et al. [2] manually measured 30 female participants to study the body cathexis towards fashion products. This method was used to measure the non-standard postures as well, in the work of Gill [4], researchers manually measured dynamic postures separately for lower limbs and upper limbs. While the measurement data collected from manual taping depends largely on the operator and the location of landmarks. Errors may

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generate due to the different measurers even when they are trained in same way and work closely together [5–8].

Instead, emerging new technologies such as 3D body scanning have started to take over. Compared with the manual taping, 3D body scanning can collect a large amount of body measurements within seconds without direct contact with the human body [9]. Brownridge and Twigg [10] have indicated in their research that the scan can produce over 140 measurements in eight seconds after scanning [9]. However, body scanning is not the perfect solution to solve the problem as body scanning can lead to data lost in certain body areas such as under arm and crotch especially when subjects performing dynamic postures.

Based on the background above, developing current method to improving the reliability of body measurement especially dynamic body measurement is of great necessity. To reach this goal, a new method was explored in this research to measure the dynamic human body. The new methods can be included as a foundation for further research on obtaining accurate dynamic body measurement, which have great potential to benefit the areas concerning ergonomics and human engineering.

2 Literature Review

2.1 Static Measurement

Reviewing the previous work in research area of human body measurement, we classified two categories. The first one is static measurement in which measurements are taken when subjects performing various postures and during the whole measuring process subjects need to keep still. Postures in these related researches can be arranged into two kinds: 1. standard standing posture and 2. non-standard dynamic posture.

Standard Standing Posture. Standard standing posture represents one of the most frequent used poses in measuring static human body especially when using body scanning [11, 12]. To perform this pose, subjects need to stand with their feet shoulder width apart, slightly open their arm to around 45° and look straight ahead.

Non-standard Standing Posture. Non-standard pose usually designed by the researchers, for example, raise one's arm upon his head [13]. Data taken from these postures helped researchers to study the possible measurements variations of human body in different motions.

Many researchers have tried to collect measurements from these two kinds of postures. To study the measurement variation of lower body, Tomita [14] conducted a research using moire-topography to collect body measurements. Subjects are required to perform four postures including both standard and non-standard poses for measurement collection. Nam et al. [15] scanned the whole human body in positions of bending and twisting. Some researches focused on specific body parts measurement variations using 3D body scanning. Chi and Kennon [16] studied upper body measurements when subjects' arms lifted in different angles in horizontal plane. Similarly, Shin [17] investigated the measurement variations of upper body in dynamic postures such as stride and swing. Also, there are researches focused on the lower body, Choi and Ashdown [18] took lower body measurements from postures including sitting and knee bending.

2.2 Dynamic Measurement

Skeleton Motion. Another way to obtain the dynamic measurement is taking measurements during the continuous moving. This method is used usually depend on the topic and purpose of the research.

For some research area such as kinematics, bionic-robots and bio-mechanism, knowing the static surface measurements are of less importance. They focus more on the body movements itself, which is the process and regularity of joint movements and the power exertion on body parts during motion. Researchers attached markers on subjects' joints to record the motion process.

Emmerik, etc. [19] recorded the skeleton motion of human body walking process to study the subjects' upper body movement variations among different age groups. With the data obtained from the markers (embed with sensor) attached on subjects' key joints and seven high-speed cameras, researchers analyzed the walking motion from frontal, transverse and sagittal dimensions. Similarly, Zhigailov et al. [20] tended to develop a new method to measure the locomotion parameters of walking motion. Data was collected via inertial measurement units, which provide information in three-axis. Hu, etc. [21] also studied the biomechanical parameters variation during walking motion. An exoskeleton equipment was designed for subject to wear. with the data collected from the markers on the equipment, researchers investigated the inner principle and movement regulation during walking.

Apart from studying the locomotion apparatus, some researches were conducted looking into the power exertion changes during motion. For example, Zijlstra. etc. [22] analyzed the power exertion process during movement of subjects' rising from a chair. Two force plates and makers with sensors were used to collect data.

Surface Deformation. Except from studying the skeleton motion, measuring the skin deformation during continuous movements is another research trend in recent years. In apparel industry especially when designing functional garment, considering the skin surface stretch and shrinkage is of great importance.

Lee, etc. [23] designed several motions such as squatting and knee 90° flexion were design and took the measurement while subjects performing them. To investigate the surface deformation during these motions, subjects' lower limbs were divided into different areas and marked with dots. By analyzing the horizontal and vertical distance of dots during movements, the skin deformation can be known. Result and findings of this research were supposed to improve the lower sportswear's functional ease and fit. In recent decades, with the new technologies development, some new exploratory methods are developed by researches to obtain the skin deformation data. For instance, motion capture system with markers and sensors were adopted to record the body back skin surface deformation in body movements in Sohn and Bye's [24] research. Similarly, distances between attached markers are measured to calculate the skin surface change.

From reviewing the above previous works, we can find the frequently used methods are manual taping, 3d body scanning, motion capture, markers and high-speed cameras. The results and findings can be applied to industries such as clinical medicine, game and intelligence and humanoid. Also, these researches lay a foundation for further establishing the mathematics human model which can be useful to assess patients' condition in treatment or rehabilitation.

3 Method

3.1 Participants

14 male subjects were selected as a convenience sample in Hong Kong Polytechnic University with an average 172 cm heights. Participants are required to wear light-colored tight scan garment during the experiment. They also need to wear a set of elastic strap with Velcro on the scan garment for attaching the MVN motion capture markers. A total of 17 markers are attached on each participant.

3.2 Experiment Design

Postures. Apart from the standard standing posture, participants were scanned in 7 dynamic postures. These dynamic poses are extreme postures which represent exaggerated poses we usually do not perform in the daily life. When performing extreme movements, the body measurement of certain area may change to an extreme extend (Fig. 1).

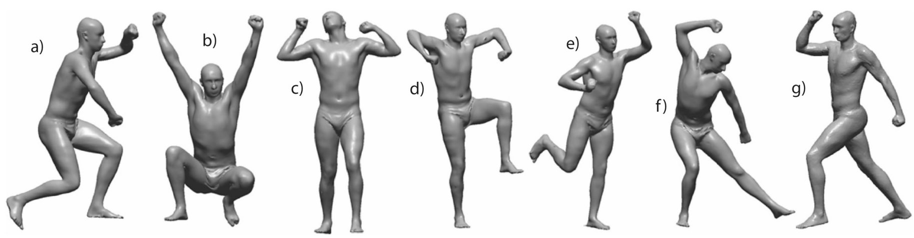

Fig. 1. Experiment dynamic poses

3.3 Process

Phase 1: Each participant was asked to wear tight light color scan garment. After taking photos of three views (front, side and back) in standard pose, participants' shoulder width, arm length, hip height, hip width, knee height, ankle height, foot length and sole were measured manually by tape. Their height and weight were measured by weight scale. Then they were scanned in standard standing posture. After scanning, researchers attached MVN Xsens motion capture markers on the participants' skin. As for the specific position of markers: one was attached at the back of head, one was on the stern above the chest, two were at the back on the position of scapulae, one was at the middle back of waist on the pelvis, two were on the middle side of upper arms, two were on the front of wrists, two were on the hand back, two were on the middle side of thighs, two were on the shin bone just below the knee cap and last two markers were placed on the participants' feet beneath shoe tongues (Fig. 2).

Fig. 2. Markers positions

Table 1. Selected key body measurement

Selected body key measurements		
Upper body	Bust girth	Upper arm girth
	Waist girth	Elbow girth
	Armscye girth	Arm length
	Shoulder length	
Lower body	Max thigh girth	Hip girth
	Knee girth	Crotch length
	Calf girth	

Phase 2: To connect with the motion system, participants need to stand up straight and drop arms to their sides for calibration. Then, with the motion capture recording at the same time, participants were scanned in 7 dynamic postures using the Human Solution body scanner.

Phase 3: Two kinds of human models were simulated in this phase: 1. the first kind human model is standard standing model which were generated based on participants' photos of three view, height, weight and standard standing scan. 2. The other kind of human model is dynamic body model which was created on the basis of weight, height and skeleton data derived from motion capture.

3.4 Key Measurements

As this study only focused on key body parts' measurement variations during dynamic motions, the key body measurements were selected and listed in Table 1.

Table 2. Descriptive data of all subjects collected from body scanning (units: cm, kg)

Subject No.	s1	s2	s3	s4	s5	s6	s7	s8	s9	s10	s11	s12	s13	s14	Mean	Max	Min	SD
Bust girth	90	97.9	89.1	90	93.4	88	94	90	82	89.5	88.9	100.5	98	91.9	91.6	101	81.7	4.85
Waist girth	80.6	88.8	79.8	88	82.3	78	88	79	71	78.3	73.4	89.9	81.5	84.4	81.6	89.9	70.6	5.77
Hip girth	95.5	90.5	90.7	96	91.7	91	99	92	88	91.2	86.1	97.2	94.5	93.6	92.6	98.6	86.1	3.49
Shoulder length	12.8	14.5	15.8	15	17.3	14	15	13	14	15.2	12.8	13.9	18.3	14	14.6	18.3	12.8	1.62
Upper arm girth	28.1	31.1	25.8	27	26.7	26	27	26	25	26.7	26.8	31	35.6	25.5	27.7	35.6	24.8	2.93
Elbow girth	26.3	26.8	24.1	25	23.9	25	25	24	23	24.3	26.3	25.6	28.1	24.5	25.1	28.1	22.6	1.43
Max thigh girth	53.1	54	48.7	52	51.3	51	56	51	45	51	47.6	55.3	56.2	47.4	51.4	56.2	44.5	3.43
Knee girth	36.1	34.4	35.7	37	36.6	35	39	37	34	35.1	35	36.8	37.7	37.9	36.1	39.1	33.6	1.52
Calf girth	38.1	38	33.8	38	35.2	37	37	36	33	36.1	35	36.8	38.4	35.8	36.3	38.4	33	1.64
Arm length	64	57.4	59.9	58	59.5	61	54	57	58	57.2	55.6	58	58.9	55	58.2	64	54.3	2.53
Crotch length	77.7	61.2	64.9	69	60.4	73	68	69	65	67.1	69.6	62	66.2	68.3	67.3	77.7	60.4	4.67
Armscye girth	44.9	52.8	40.9	48	46.4	44	52	43	43	44	44.8	52.3	50.6	42	46.3	52.8	40.9	4.67
Height	181	169	179	173	167	168	165	177	172	171	165	168	176	175	172	181	165	5.16
Weight	68	66.4	57.6	65.6	59.1	58.6	65.5	60	53	58.8	54.3	69.4	73.8	63.6	62.4	73.8	53	6.
BMI	20.7	23.2	17.9	21.9	21.2	20.8	24.1	19.1	17.9	20.1	19.9	24.6	23.8	20.8	21.1	24.6	17.92	2.15

3.5 Data Analysis

Body Measurement Change in Dynamic Postures. To examine the measurement variation during dynamic motions, data collected from dynamic postures were compared with standard pose scan measurement using descriptive statistics and graph.

Validity of Using New Method for Body Measurement. Measurement obtained from the new method (motion capture and photos) was compared with scan measurement using Mann Whitney test and mapping to examine its' reliability. The analysis was conducted from two aspects: (1) standard pose and (2) dynamic poses. By using Mann Whitney test, the body measurement differences of scan and motion capture simulation can be known. Mapping can give us a clear thought the positions and degree of these difference on human body.

4 Results

Table 2 descriptive statistically described the participants involved in the experiment, with an average 172 cm height and 62.4 kg weight. Their BMI range is from 17.92 to 24.6 and all subjects' the waist girth is under 90 cm, which indicates they are all in normal weight. Their average girth of bust, waist and hip is 91.6, 81.6 and 92.6 cm.

4.1 Body Measurement Variation

To study the body measurement variations, the measurements of 7 dynamic poses are extracted and compared with the standard standing measurement collected using body

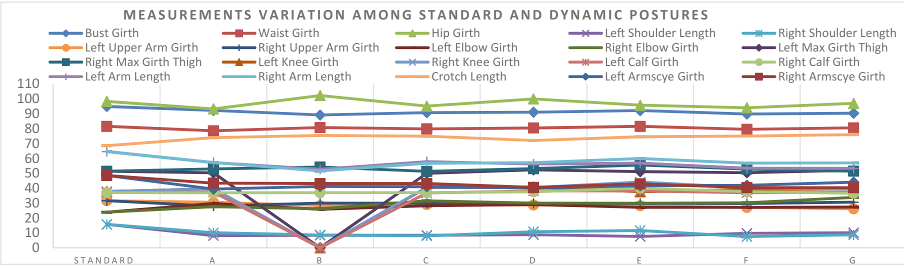

Fig. 3. Measurements variations of standard and dynamic poses

scanning. From the Fig. 3, it can be found that measurements vary differently among dynamic poses. One thing to note is that as pose b is subject sitting on left feet, the thigh, knee and calf girth cannot be extracted from body scanner.

Some measurements such as waist girth, max thigh girth, calf girth and upper arm girth show a quite flat curve which means these measurements vary little among poses. While the curve of measurements like bus girth, hip girth, arm length and shoulder length show a greater variation. Table 3 shows the features of key measurement including means, max and min value. Taken the postures into consideration, we can infer that the movement of arm impact the bust girth and shoulder length as when subjects raise arms the bust girth and shoulder length decrease especially when subjects' two arms were all raised above their head. The hip girth might have related with the leg movement, as when subject squatting down or lift their legs, hip measurement increase compared with standard measurement.

Table 3. Measurements descriptive statistics of standard and dynamic poses (unit: cm)

	Bust Girth	Waist Girth	Hip Girth	Left Shoulder Length	Right Shoulder Length	Left Upper Arm Girth	Right Upper Arm Girth	Left Elbow Girth	Right Elbow Girth	Left Max Thigh Girth
Means	91.3	80.3	96.9	9.6	10.1	28.7	29.9	27.2	29.1	51.1
Max	94.9	81.5	102.2	15.7	15.7	31.6	31.6	29.7	33.8	52.3
Min	89.1	78.5	93.2	7.6	7.5	26.2	28	23.8	23.8	50

	Right Max Thigh Girth	Left Knee Girth	Right Knee Girth	Left Calf Girth	Right Calf Girth	Left Arm Length	Right Arm Length	Crotch Length	Left Armscye Girth	Right Armscye Girth
Means	52.8	39.2	40.3	37.4	37.5	56.5	57.6	73.8	42.2	42.8
Max	55.6	40.8	44.1	38.2	40	64.6	64.6	76	48.5	48.5
Min	51.3	37.6	37.8	36.8	36.6	52.7	51.6	68.5	39.4	40.3

4.2 Validity Test of Simulated Model Measurements

Standard Pose. To examine the validity of data collected with new method, scan measurement and simulated model measurement (derived from motion capture data, photos and subjects' weight and height) were compared to find the differences extent. From the descriptive statistics of both scan and simulated model measurement shown in Table 4, we can see the average simulated model measurements are slight larger than scan measurement in bust, hip, shoulder length, thigh, knee and armscye girth and slight smaller in waist, elbow, calf and crotch length. For upper arm girth and arm length, the average simulated model measurement is much larger than scan data.

Table 4. Descriptive statistics of scan and simulated model measurement (unit: cm)

	N	Scan				Simulated Model			
		Min	Max	Mean	SD	Min	Max	Mean	SD
bust_girth	14	81.7	100.5	91.6	4.9	85.3	97.6	92.3	3.9
waist_girth	14	70.6	89.9	81.6	5.8	74.7	86.5	80.5	3.3
hip_girth	14	86.1	98.6	92.6	3.5	86.7	98.3	93.1	3.5
shoulder_length	14	12.8	18.3	14.6	1.6	13.9	15.7	14.7	0.6
upper_arm_girth	14	24.8	35.6	27.7	2.9	29.2	32.9	31.1	1
elbow_girth	14	22.6	28.1	25.1	1.4	21.8	27.8	24.5	1.7
max_thigh_girth	14	44.5	56.2	51.4	3.4	48.5	57.6	53.1	2.8
knee_girth	14	33.6	39.1	36.1	1.5	33.2	38.9	36.3	1.8
calf_girth	14	33	38.4	36.3	1.6	32.1	37.8	35.3	1.8
arm_length	14	54.3	64	58.2	2.5	59.3	64.6	61.8	1.7
crotch_length	14	60.4	77.7	67.3	4.7	60.4	69	65.5	3.2
armscye_girth	14	40.9	52.8	46.3	4.1	44.3	48.5	46.6	1.2

To further examine if these 2 measurements are significantly different from each other, the Mann Whitney test is conducted. It can be found that the among the 12 key measurements, as results shown in Table 5, p-values of upper arm girth and arm length are smaller than 0.005, which means simulated model measurement is significantly different from the scan measurement in upper arm girth and arm length. While other 10 key measurements show no significantly differences between simulated model measurement and scan measurement.

Further, to explain the measurement differences in a more visible way, the simulated model and scan model were mapped. Color was used in mapping to indicated the positions and extent of measurement differences (Fig. 4) in which color of red and deep blue indicate the largest differences between 2 models in positive and negative while green color areas mean the measurement differences are small. The whole range of color bar is from −20 to 20 mm. From the mapping results of all subjects shown in Fig. 5, most areas in torso are in green especially areas near the abdomen and back while upper arm and scapula shows the most measurement differences between

Table 5. Mann Whitney test result of scan data and simulated model data (unit: cm)

	Bust Girth	Waist Girth	Hip Girth	Shoulder Length	Upper Arm Girth	Elbow Girth	Max Girth Thigh	Knee Girth	Calf Girth	Arm Length	Crotch Length	Armscye Girth
Model	90	80.6	95.5	12.8	28.1	26.3	53.1	36.1	38.1	64	77.7	44.9
	97.9	88.8	90.5	14.5	31.1	26.8	54	34.4	38	57.4	61.2	52.8
	89.1	79.8	90.7	15.8	25.8	24.1	48.7	35.7	33.8	59.9	64.9	40.9
	89.6	87.5	95.5	14.8	27.2	25.2	52.3	36.5	38	58.2	69	47.7
	93.4	82.3	91.7	17.3	26.7	23.9	51.3	36.6	35.2	59.5	60.4	46.4
	88.2	77.5	91.3	13.7	26	24.6	51.2	34.5	36.6	61.1	73.3	43.6
	93.7	88.1	98.6	14.9	27	25	55.7	39.1	37.1	54.3	67.7	51.9
	89.5	79.1	92.1	13	25.8	23.8	51.4	36.6	35.9	56.8	69.4	43.4
	81.7	70.6	87.6	13.9	24.8	22.6	44.5	33.6	33	58.2	65	43.1
	89.5	78.3	91.2	15.2	26.7	24.3	51	35.1	36.1	57.2	67.1	44
	88.9	73.4	86.1	12.8	26.8	26.3	47.6	35	35	55.6	69.6	44.8
	100.5	89.9	97.2	13.9	31	25.6	55.3	36.8	36.8	58	62	52.3
	98	81.5	94.5	18.3	35.6	28.1	56.2	37.7	38.4	58.9	66.2	50.6
	91.9	84.4	93.6	14	25.5	24.5	47.4	37.9	35.8	55	68.3	42
Scan	94.88	81.51	98.27	15.71	31.6	23.84	51.36	37.76	36.99	64.56	68.54	48.52
	94.47	80.67	89.74	13.92	32.34	25.97	55.97	38.15	37.14	60.91	68.81	47.32
	92.55	78.51	95.1	15.71	30.89	23.79	52.26	34.24	33.83	63.75	68.71	46.92
	95.45	83.22	95.22	14.35	31.83	24.12	55.77	37.18	35.04	62.63	63.42	47.6
	92.99	77.19	91.24	14.52	30.75	23.01	51.77	35.31	35.01	60.44	61.35	45.9
	89.97	81	91.95	15.08	30.94	24.24	51.76	35.43	34.17	60.16	62.23	45.44
	97.64	86.52	96.64	14.61	31	26.27	54.79	37.09	36.39	60.04	68.97	46.67
	88.76	79.59	92.63	14.72	31.52	26.08	51.55	37.4	36.77	63.49	67.4	46.63
	85.29	74.7	87.02	14.51	29.37	22.86	49.53	33.2	32.1	61.75	63.5	45.28
	88.31	77.99	91.81	14.94	30.25	21.84	52.1	35.09	34	61.71	61.5	45.9
	87.38	76.22	86.71	14.01	29.24	22.43	48.54	33.68	32.54	59.26	60.42	44.34
	97.23	84.69	94.96	13.85	30.96	24.76	57.14	38.39	37.04	60.65	67.96	46.63
	95.88	82.81	96.71	14.7	32.87	27.84	57.63	38.9	37.8	63.67	67.65	48.07
	92.07	81.97	94.94	15.03	32.13	25.78	53.05	36.91	35.85	62.7	66.6	47.43
Sig.	0.713	0.581	0.646	0.408	0.002	0.251	0.168	0.550	0.198	0.000	0.358	0.291

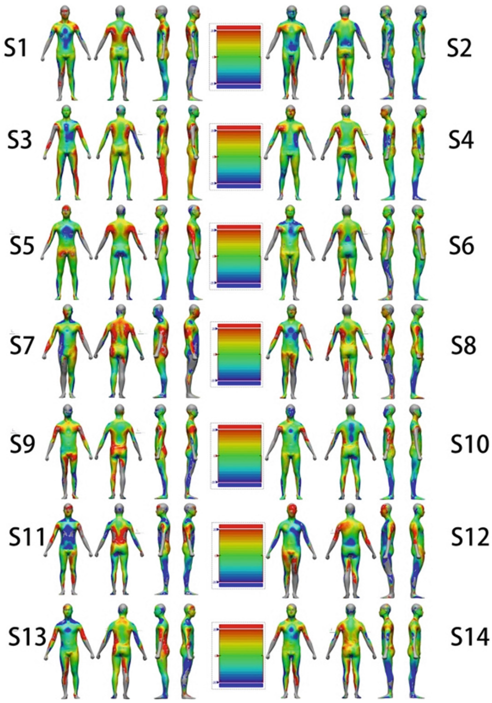

Fig. 4. Standing pose mapping

simulated model and scan model. For the legs, differences mainly show in the outer sides of thigh and calf.

Dynamic Poses. Simulated model was also generated on the basis of skeleton information collected from motion capture (Fig. 5). For each pair, simulated model is on the left side. While we found that as the simulated skeleton data is not aligning with the scan data though the poses seem similar. Also, the measurement difference can be observed that measurement of simulated model is generally a bit larger than the real scan. Thus, dynamic simulated model needs further improvement for later studies.

5 Summary

This study has two goals: 1. Investigate the measurement variations between dynamic poses and standard standing pose. 2. Developing a new method to collect body measurement and examine its' reliability by comparing with 3D body scan data. To reach the goal, we attached marker on subjects' skin surface and designed 7 dynamic poses for experiment. Subjects were scanned in dynamics postures and recorded by motion capture simultaneously. Data collected from dynamic postures and standard standing postures was compared and analyzed.

Fig. 5. Dynamic poses comparison

Results of investigating the measurement change indicates that though variation extents are different, measurements do change when subjects performing dynamic postures. Combining the specific postures and the measurement data including max, min and mean value, we can infer some inherent regulation between measurement variation and dynamic poses: Bust girth and shoulder length is related with arm and shoulder movement, measurements tend to decrease when arm is lifted overhead. Leg movement impact the hip girth the most, hip measurement may increase during leg motions including squatting and lifting.

Based on the motion capture, photos, subjects' height and weight, we simulated customized model for each subject as a new method to obtain body measurement in an easier way. The reliability test of simulated model measurement in standard standing posture suggested that it has little difference compared with scan measurement in same pose in most measurements except the upper arm girth and arm length. With more improving in simulating the arm part, this method enables a faster and easier way to extract human body measurement which can be further used in later research area for instance online shopping and virtual fitting. We also examined the simulated model with dynamic scans while the results need further improving as the skeleton movement cannot be aligned at present.

These findings lay a foundation for later studying body measurement in dynamic motions and provide reference to industries such as apparel industry to help with improving the pattern making and size. Limitations of this study are: 1. There are limited subjects included in the experiment. 2. More dynamic postures should be added to explore the measurement variation regulations. 3. Skeleton data of motion capture need to be improve for dynamic model simulation.

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Ergonomic Performance of Work Systems

On Ergonomic Perception

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Abstract. Ergonomics has developed as an application of knowledge accumulation in very different qualities that can improve the efficiency of human performance in different directions. Ergonomics which is also related to different branches of science covers a wide range of applications. Ergonomics has great importance in determining both sensual, perceptual and mental evaluations and anthropometric requirements of the user. The factors in perception must also be taken into account in the evaluation of the environment perceived by human being, making an ergonomic assessment in particular requires having an ergonomic perception in this sense. The perception of ergonomics can be achieved by acquiring knowledge or training in this field. This study was conducted to measure the perception of ergonomics. 220 active students in the Vocational High School of Technical Sciences and 342 employees working in garment enterprises participated in the study. As a result of the analyzes, it was revealed what the perceptions of the ergonomics of the students and employees participated in the study are, and some suggestions were made.

Keywords: Ergonomic perception · Garment enterprises · Physiological characteristics · Perception

1 Introduction

Ergonomics aims to make people's lives humanitarian, make them fit for humanity and improve people's quality of life. At the same time, to make the surrounding area suitable for health conditions, the elimination of a number of danger possibilities, arrangement of working hours, ensuring working order suitable for physiological characteristics, ensuring that the tools and equipment used are compatible with the work and the user are the main purposes. At this point, on the one hand, human efficiency and comfort are enhanced, and on the other hand, it is ensured that the designed environment is safe for human beings.

Execution of work and working environment by taking into account the physiological and mental limitations of the human being is important both for occupational health and occupational diseases and for efficiency [1, 2]. It is necessary to consider specific engineering approaches in order to be created an ergonomic work environment and to be taken into account the physical and mental workload of employees.

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Ergonomics is defined as balancing the workload and labour force in the best way possible to protect the individual's health and to increase the producing. Besides it is implementing biological information within the fields of anatomy, physiology and experimental psychology, to succeed the human-machine-environment system [3] that ergonomics is the long duration between (also related with) individual's education process and working process.

As a personal working field; ergonomics provide the necessary conditions for adopting "people" and "working" to each other, by searching features and abilities of human organism. It enables people to be aware of their own abilities and to realize them effectively. Ergonomics maintains the individual not to be distressed due to extreme enforcements while working so that it can acquire success in business [4–6].

Ergonomics deals with the substantial criteria such as physical and mental health for employees, efficiency and quality for employers; it aims to improve the whole elements of system also human performance by providing human & system harmony [7].

Ergonomic studies are not limited to solely business environment; it is necessary to benefit ergonomics not only within the manufacturing process but also usage and repairment processes of the products created by the modern technology. The necessity mentioned is emerged by the reality that the product herein is just for the human [8]. Regarding the processes of producing, consuming, using and repairing are not existed without humans; designing each of the products and enabling life easier are suggested to be necessary due to physical features of the human.

According to the information referred; education relating ergonomics is being a pre-condition for individuals anymore in order to have a healthy and secured further life.

The concept of ergonomics is suggested to be a working pattern relating school, student and instructor, by providing ergonomics according to educational institutions. The target of the ergonomics education is creating a perception about the theme and encouraging the individual for working life via reliable behaviours [9].

By applying the ergonomic principles within the schools; suitable classrooms, studying environments and workshops can be provided due to the student's age, body structure, professional studies and perceiving features: Therefore, it is possible for them to learn and implement the first experiences relating ergonomics by better methods. Readymade garment manufacturers include many departments such as designing, manufacturing, ironing, quality controlling and warehouse. Operating the mentioned departments and evaluating their risk factors to meet can be provided by workshop educations. So that; the individuals acquire awareness about ergonomics and its principles via correctly designed education.

Operating the functions of respiratory system, circulatory system, muscle metabolism, digestive system, secretion system and nervous system for human body in a sufficient level is related with well operating process of perception organs. The information perceived by perception organs from outside are to reply via an action within central nervous system by hands, arms and various organs of the human body. The success of the system is related with the reply's relevance. The volume of information signals perceived from present environment or machine besides qualification of the employee have effect on the reply's relevance and success of the system [10, 11]. The mentioned effects are shown below in Fig. 1:

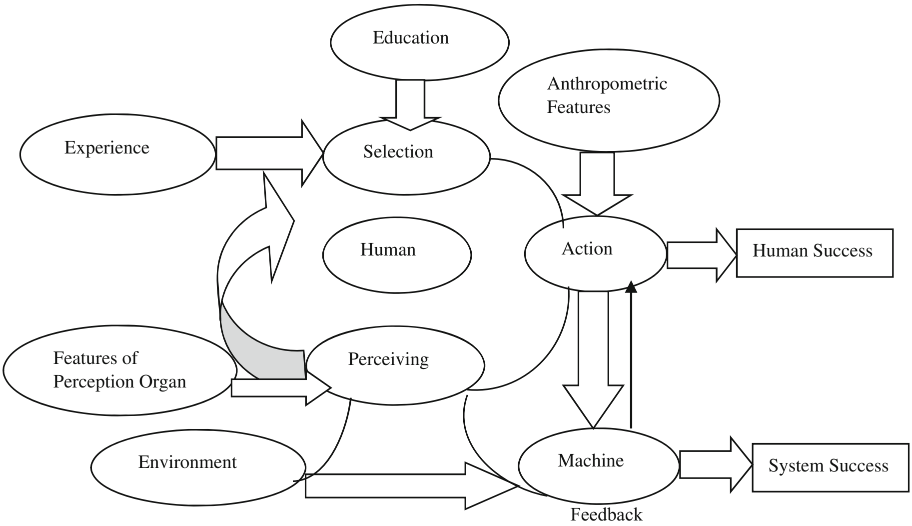


Fig. 1. Duty request of human and features

There are 3 elements like human-machine-environment occurring the production system. The features of environment also affect machines as it has effect on human [12], the information acquired from environment and machine are subsequently transmitted to central nervous system. The central nervous system prepares the most proper reply due to the received information which is called as "selection work". Perceiving and selection create mental burden for humans which is having effect on experiences gained, education, burden and the selection's relevance [13]. The implementation of the selection transforms into action by nervous system, skeleton and muscles, hand, arm and various activities of the body. The action taken creates a burden for the human. Perceiving, the success of the selection and action reveal business success of the human. Eventually, business success of the human reveals the success of the system and mechanical production.

2 Methodology

The aim of the research is evaluating the ergonomic perception of the students attending university also employees and managers from readymade garment enterprises. The sample herein is occured of 220 students living in Bursa and İstanbul also 342 employees from the enterprises listed in the first 500 companies in 2015 which are located in İzmir and İstanbul.

Inquiry forms created for the research is applied for the students attending universities also employees and managers within the selected readymade garment enterprises which are being active in the year of 2016. Consequently valid 562 forms are evaluated.

It is asked to the participants whether they have education relating ergonomics or not by the research. Furthermore; the perceptions of the students, managers and employees are revealed additionally several suggestions are offered related with the ergonomics which is suggested to be necessary for each step of the human life.

3 Results and Discussion

Demographic information belonged to the students, acquired by the research is as follows: 58% of the students are between 20–25 ages, 51% of them are attending the 1st grade also 58% of the students are male.

According to Table 1; it is revealed that 98% of the participants do not have ergonomic education. So, the result illustrates here the students have no education about ergonomics; neither theoretical nor practical one. Being uneducated about a very necessary theme for the whole life means they may face various matters within many fields such as health. There are several fields based on ergonomic information with also their methods and technics; of which implementation necessitates ergonomic education.

Table 1. The distribution of the students due to age, grade, gender and their ergonomics education

Age	f	%	Grade	f	%
Less than 20	77	35.0	1. Grade	112	**50.9**
20–25	128	**58.2**	2. Grade	74	33.6
26–30	11	5.0	3. Grade	34	15.5
41–45	4	1.8	Total	220	100.0
Total	220	100.0			
Gender	f	%	Ergonomics Education	f	%
Female	92	41.8	Yes	5	2.3
Male	128	**58.2**	No	215	**97.7**
Total	220	100.0	Total	220	100.0

Table 2 illustrates that 31% of the managers and employees from readymade garment enterprises are between 26–30 ages, 41% of them are graduated from university, 78% are occurred of female employees or managers. Also; 68% of the participants are revealed to be uneducated about the ergonomics theme, which is suggested to be causative for further several matters.

According to Sanders and McCormick [14]; ergonomics defined as designing tools, machines, systems, duties, businesses and environment to have efficient, safe, comfortable and effective usage also exploring and implementing the human behaviours, abilities, limitations and characteristics exists everywhere humans live. Ergonomic information is suggested to be known compulsorily especially in the working environment.

Because majority of the day is spent within the mentioned environment and many situations can affect people there. So that; ergonomics can contribute the human's welfare related with health, security and comfort.

Many situations we can meet during our lives and the environments we work within, may include harmful elements for human health. In many countries; the diseases related with muscle and skeleton system also psychological disorders are suggested to be the reason for absence, losses, accidents, injuries and deaths. Some of them are occured by technical systems, equipment and designing matters. But one of the major reasons is the existence of the employees having no education, information and perception about the ergonomics.

Table 2. The distribution of the employees due to age, graduation, gender and their ergonomics education

Age	f	%	Education	f	%
20–25	57	16.7	Primary School	91	26.6
26–30	105	**30.7**	High School	105	**30.7**
31–35	84	24.6	University	139	**40.6**
36–40	75	21.9	Graduate-Doctorate	7	2.0
41–45	14	4.1	Total	342	100.0
Greater than 46	7	2.0			
Total	342	100.0			
Gender	f	%	Ergonomics Education	f	%
Female	268	**78.4**	Yes	108	31.6
Male	74	21.6	No	234	**68.4**
Total	342	100.0	Total	342	100.0

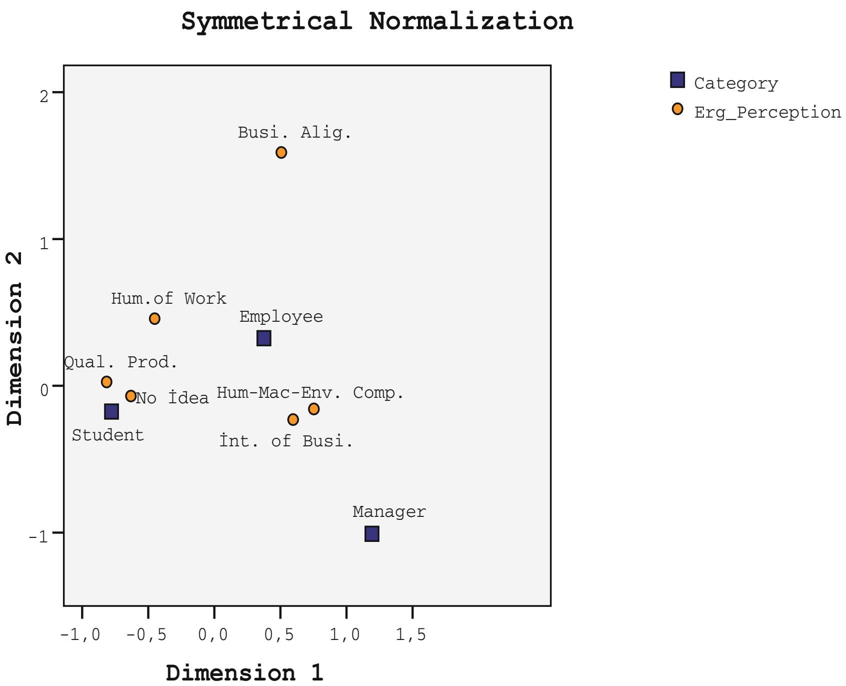
Compliance analysis is benefited in Fig. 2 to determine the relations between variables and their categories. The mentioned analysis is a defining type multivariate statistical technique in order to analyze the relations between variables, by two or more dimensional cross flow plates. Due to the analysis held; each of the relations determined between categories of the variables are examined graphically and eventually concluded [15, 16].

The results of the analysis are illustrated below in the perception map:

Chi-square distance measure is used relating the dimensions' calculating within the axis in the map and Symmetrical Normalization method is benefited in the study.

According to the analysis held; Chi-square value is calculated as 127,113 besides significance level is evaluated as .000. So that; relation between the variables is suggested to be existed. 88.2% of the relation between variables is explained by 1st dimension and the rest 11.8% is explained by 2nd dimension.

As a group participating in the study; students are observed to define ergonomics by the expression of "I don't have any idea" in the context of Ergonomics Perception Map and the other concept defined by them is "Qualified production" expression partially. The expression of "I don't have any idea" herein is related with the data as 98% of the students had mentioned that they didn't have ergonomics education.



Variables Benefited: Participant type The expression used to define the ergonomics*
■ *Participant Type: Student, Employee, Manager*
○ *Ergonomics Perception: Qualified production, Business compliance, Humanization of work, Human-Machine-Environment harmony, Workplace adjustment, Adjustment of business machines, I don't have any idea*

Fig. 2. Ergonomics Perception Map

Employees within the map are observed to define ergonomics via the expressions as "Human-Machine-Environment harmony" and "Humanization of work". The employees, as working people, perceive the ergonomics concept more differently and they evaluate it towards a wider framework. At this point; experiences they had within their working life are suggested to be contributive for the perception.

As a group participating in the study; managers are observed to define ergonomics by "Workplace adjustment" expression. By comparing with the other groups; managers used a more general definition and they define ergonomics via the words meaning the harmony in the environment. Hence; the managers related with ergonomics are suggested to have a more general perception in physical, psychological etc. manners.

4 Conclusions and Recommendations

Developing technologies cause significant changes today within the working life like the other various fields. As a result; very fast and intensive mechanization is experienced during the production process. The mentioned fast change diversifies the abilities of people actually working in the production process in physical and mental manners besides it creates a substantial pressure on the employees.

Ergonomics education herein is suggested to be very important related with preventing the negative effect or decreasing the mentioned effect into minimum level.

The attitudes and behaviours of employees observed related with occupational health and safety within readymade garment enterprises are the results of the education they had so far. Experiencing the various situations like lighting, noise, vibration, dust, chemical exposure, lifting, correct posture and etc. is probable during working there. Acting and having proper attitudes due to mentioned situations acquire ergonomics education.

According to the results;

- 58% of the students participating in the study are between 20–25 ages, 51% of them are attending the 1st grade, 58% of the students are male also 98% of the mentioned group did not have education about ergonomics so far.
- 31% of the employees are between 26–30 ages, 41% of them are graduated from university, 78% of the group is occured of female employees (readymade garment sector is generally run by women) and 68% of the employees did not have ergonomics education.
- According to Ergonomics Perception Map analyzed; students as a group participated in the study are observed to define ergonomics by the expressions of "*I don't have any idea*" and *"Qualified production"*. Besides employees define the mentioned theme as "*Human-Machine-Environment harmony*" and "*Humanization of work*" also managers define ergonomics via "*Workplace adjustment*" expression.

Evaluating the results acquired generally;

- Education relating ergonomics must be taught as from primary school by stages.
- Ergonomics education must be formed due to the manner as "an education in all fields during life".
- Education relating ergonomics must be given due to the sectors in the further stages owing to their own varied features.
- Systematic programs must be prepared based on the idea of "a definite process is needed to form a perception".
- Education programs within the schools must be based on systematic programs.
- The theme must be admitted as a preferential one within the state policies concerning its contribution to both sectors and the country about occupational health and safety.
- Ergonomics education must be supported by health sector authorities due to its key role in human health and to decrease occupational diseases.
- In-service training programs must be applied periodically after the ending of fundamental ergonomics education process within the labour intensive sectors such as readymade garment manufacturing etc.
- Web sites must be formed to acquire correct and updated data relating ergonomics and they must be kept updated.
- General policies must be developed in order to create perception and conscious about ergonomics.

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Formulation of Field Data Base Model of Productivity for Standalone Sewing Machine Operation Based on Ergonomic Considerations

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Abstract. The sewing machine operator is a most busy operator in culturally different background country like India. The sewing machine operation involves various activities for execution of different tasks. During sewing machine operation the workers performs each type of activity which forms a man–machine system where workers anthropometric data, postures, their skills, motivation, workstation, the working seasons and their workplace influence the performance. This is where their productivity, human energy input, quality and quantity is highlighted. In order to establish relationship amongst input and responses of activity, the mathematical models of sewing machine operation needs to be developed. This article highlights the detailed methodology of mathematical model formulation for the productivity of the standalone sewing machine operation. Present study is done on thirty male sewing machine operators working on manually driven sewing machine from more than last 10 to 12 years in central India. This operation is characterized by a static sitting posture, with forward inclination of head and trunk. Since the operators are sitting on stools without back support, ankle and knee angles are in uncomfortable position. The eyes are constrained towards visual control of work, while the hands are continuously directing the sewing material with the absorption of vibrations on working surface of sewing table. This paper details the formulation of field data based model to analyze the impact of various machining field parameters on the productivity of the sewing machine operation. In all, 39 independent variables are studied to analyze their effect on the dependent variable productivity. The 39 independent variables are then grouped to form 5 dimensionless pi terms using the Buckinham's Pi Theorem. Further, a model is developed using matrix analysis and the effect of the independent pi terms on the dependent pi term is established. Model derived by combining positive and negative pi terms, further analyzes the effect of the independent variables on the productivity. The models are validated to gauge the accuracy. Formulation of mathematical model and sensitivity analysis reveals that the environmental condition and badly designed stools used for sitting while in working position in the workshop, majorly affects the productivity. Further, to improve productivity, it is necessary that the seating stool used should be properly designed by using

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ergonomic considerations. Other factors that affect productivity are BMI of the operator and years in operation as well as anthropometric data of the operators.

Keywords: Productivity · Mathematical model · Ergonomically designed stool · Environmental factors

1 Introduction

The sewing machine operation involves various activities for execution of different tasks in sewing. During sewing machine operation the operators perform each type of activity which forms a man–machine system (Fig. 1). In this man–machine system operator's anthropometric data, posture, their skills, motivation, workstation environment and design, the working season influences their performance. Field database modeling is applied to any type of man–machine system. It is the relationship between input/cause and output/response variable. The operators productivity is studied in this paper. These operators are involved in manual sewing machine operation which causes stress and fatigue and hence the need was felt to study their productivity.

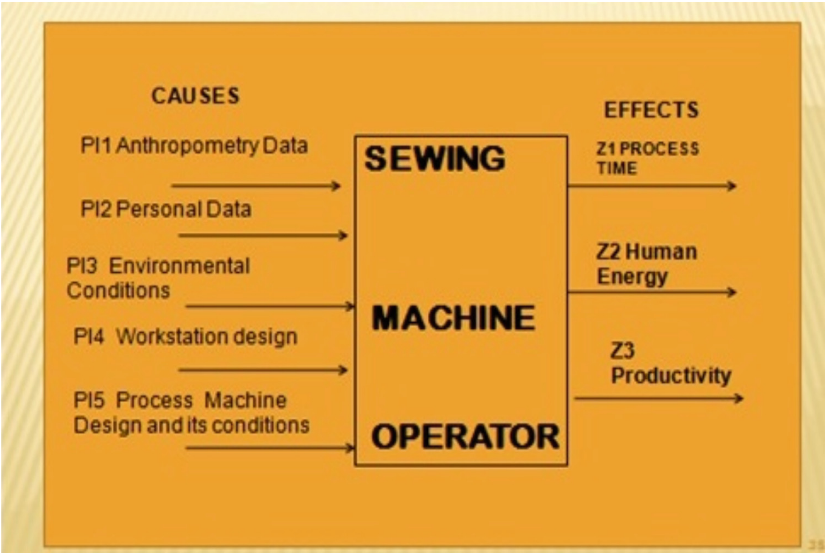

Fig. 1. Man–machine system

2 Selection of Operators

The operators under study were all male operators. They have an experience of working on standalone machines of more than 10 years. The survey method was used, where a questionnaire with the help of Dutch musculoskeletal questionnaire (DMQ) in Indian context was generated.

3 Methodology

This paper details the formulation of Field Database modeling to analyze the impact of various field parameters in and around sewing machine operation on the productivity. There are few totally physical phenomena that cannot be represented by application of basic balances of mechanics. But such complex man–machine operated system can be arrived at mathematical model by adopting the theory of experimentation suggested by Hilbert Schank Junior. The model formulation is done by using the following methodology (Fig. 2):

Fig. 2. Man–machine system under study: line diagram and actual operator at work

- Identification of causes/input independent and responses/output dependent variables.
- Identification of extraneous variables.
- Reduction of independent variables into dimensionless terms by adopting dimensional analysis method.
- Data collection of sewing machine operators on existing process.
- Formulation of Exponential Form of model in field database management.
- Formulation of Response curve model in field database management.
- Model optimization.
- Sensitivity analysis.

3.1 Identification of Independent Variables

Any physical quantity that undergoes change can be said to be variable in general. If particular variable can be changed without affecting other variable then it is independent variable. Similarly if a particular variable changes its response of one or more variables then it is called dependent variables. The variables which changes its response over which we don't have control as regards what way those variables would vary w.r.t. time such variable are called as extraneous variables.

Causes or Independent Variables. 39 Independent variable are identified in the present phenomena. These are grouped in 5 PI terms by using Buckingham Pi Π theorem. They are:

- Π_1 = Anthropometric dimensions of operator.
- Π_2 = Environmental condition factors
- Π_3 = Personal factors of operator.
- Π_4 = Workstation Design.
- Π_5 = Process machine design conditions.

3.2 Responses or Dependent Variables

Dependent variable identified is productivity of sewing machine operators and analysis of effect of independent variables on productivity of operators is studied by mathematical model formulation tool (Table 1).

Table 1. Process variables (dependant and independent)

Sr. no.	Variable name	Symbol	Dimensional parameters
1	Height of operator	A_1	L^1 (cm)
2	Weight of operator	A_2	M^1 (kg)
3	Sitting height	A_3	L^1 (cm)
4	Sitting eye height	A_4	L^1 (cm)
5	Elbow sitting Ht.	A_5	L^1 (cm)
6	Knee ht.	A_6	L^1 (cm)
7	Buttock knee height	A_7	L^1 (cm)
8	Popliteal height	A_8	L^1 (cm)
9	Elbow to elbow span	A_9	L^1 (cm)
10	Hip breadth sitting	A_{10}	L^1 (cm)
11	Inclination of head (α)	A_{11}	0° (degree)
12	Inclination of eyeball (β)	A_{12}	0° (degree)
13	Inclination of back w.r.t. table (θ)	A_{13}	0° (degree)
14	Age of operator	P_1	T^1

(*continued*)

Table 1. (*continued*)

Sr. no.	Variable name	Symbol	Dimensional parameters
15	Experience of operator	P_2	T^1
16	Skill of operator	P_3	T^1
17	Health of operator	P_4	Rating scale (1–10)
18	Enthusiasm of operator	P_5	Rating scale (1–10)
19	Habits of operator	P_6	Rating scale (1–10)
20	Temperature of workstation	Tw_1	0° (centigrade)
21	Noise of workplace	Nw_1	decibels
22	Noise of workplace while working	Nw_2	decibles
23	Illumination of workplace	Iw_1	Lumens
24	Height of stool	H_1	L^1 (cm)
25	Ht. of working table	H_2	L^1 (cm)
26	Surface length of working table	H_3	L^1 (cm)
27	Area of stool	H_4	L^2 (cm)
28	Back support length	H_5	L^1 (cm)
29	Position of paddle	H_6	L^1 (cm)
30	Arm reach (elbow to working table)	H_7	L^1 (cm)
31	Speed of operator	S0	$T - 1$
32	Length of leg	LL	L^1 (cm)
33	Angle of seat (if any)	D_{11}	0° (degree)
34	Size of treadle (area)	Td	L^2 (cm)
35	Length of push rod	Psrd	L^1 (cm)
36	Axle size	Ax	L^1 (cm)
37	Diameter .of leather belt	Lb	L^1 (cm)
38	Pulley diameter. On m/c head	Pmc	L^1 (cm)
39	Flywheel diameter	Fwh	L^1 (cm)
40	Stitching time/day	St	length./h
41	Stitching length/day	Stl	length./h

3.3 Reduction of Variables

As the number of independent variables are too large they are to be reduced to few by using dimensional analysis by applying Buckingham's Pi theorem. When this theorem is applied to a system having n independent variables and m primary dimensions, number of pi terms are formed. Using three primary dimension terms L, M, T . if the product of these pi terms is taken then it will yield dimensionless pi terms. By using this approach the independent pi terms are formed. Table 2 will show independent pi terms.

Table 2. List of independent variables

Sr. no.	Pi terms	Group for forming independent terms	Dimensional analysis
1	Π_1	Anthropometric data of operator	Π_1 = (A_1,A_3,A_4,A_5,A_9)/(A_6,A_7,A_8, A_{10},LL)
2	Π_2	Personal data of operator	Π_2 = (P_1,P_3,P_4)/(P_2,P_5,P_6)
3	Π_3	Environmental conditions of workplace	Π_3 = (TW_1,NW_1)/(IW_1,NW_2)
4	Π_4	WorkStation data	Π_4 = [(h_1,h_5/h_4), (h_2,h_3/h_6)]/[(so/h_7, LL), (A_{11},A_{12},A_{13})]
5	Π_5	Components of machine process and its conditions	Π_5 = [(Lbelt), (Pmc),(H_3)]/[(Td), (Psrd), (Ax), (Fwh)]

4 Formulation of Models Based on Observed Data

Dependent Variable Productivity is Z_3 = Total length of Stitching work per day/ Stitching time per day during Experimentation 5 Independent Pi terms (Π_1, Π_2, Π_3,Π_4, Π_5) and one dependent pi term (Π_6) are available for model formulation. Each dependent Π term is the function of the available independent terms.

$$\Pi_6 = \mathrm{f}(\Pi_1, \Pi_2, \Pi_3, \Pi_4, \Pi_5) \quad (1)$$

A Probable exact mathematical form for the dimensional equation of the phenomenon could be the relationships assumed to be of exponential form. So, the model representing the behavior of dependent pi terms Π_6 with respect to various independent pi terms can be obtained. The model representing the behaviour of dependent Pi term with respect to various independent pi terms can be obtained as follows:

$$\Pi_6 = \mathrm{K}(\Pi_1^{\alpha 1} * \Pi_2^{\alpha 2} * \Pi_3^{\alpha 3} * \Pi_4^{\alpha 4} * \Pi_5^{\alpha 5}) \quad (2)$$

Therefore 5 unknown terms in the Eq. 2 can said as Constant of Proportionality K & indices a_1, a_2, a_3, a_4, a_5.

By using classical experimentation of mathematical form of Curve fitting Constant.

$$\mathrm{Z} = \mathrm{A} + \mathrm{Bx} + \mathrm{Cy} + \mathrm{Dz}$$

By taking log on both sides equation can be formulated.

Taking log on both sides of Eq. 2

$$\log \Pi_6 = \log \mathrm{K} + a_1 \log \Pi_1 + a_2 \log \Pi_2 + a_3 \log \Pi_3 + a_4 \log \Pi_4 + a_5 \log \Pi_5 \quad (3)$$

We assume:

$Z_1 = \log \Pi_6, K = \log a0, A = \log \Pi_1, B = \log \Pi_2, C = \log \Pi_3, D = \log \Pi_4, E = \log \Pi_5$

Putting the values in Eq. (4)

$$Z = K + a_1 * A + a_2 * B + a_3 * C + a_4 * D + a_5 * E \quad (4)$$

Equation (4) is a regression equation of Z on A, B, C, D, E in a dimensional co-ordinate system

$$\begin{aligned}
\Sigma Z &= n * K + a_1 \Sigma A + a_2 \Sigma B + a_3 \Sigma C + a_4 \Sigma D + a_5 \Sigma E \\
\Sigma ZA &= K\Sigma\ A + a_1 \Sigma A * A + a_2 \Sigma B * A + a_3 \Sigma C * A + a_4 \Sigma D * A + a_5 \Sigma E * A \\
\Sigma ZB &= K\Sigma B + a_1 \Sigma A * B + a_2 \Sigma B * B + a_3 \Sigma C * B + a_4 \Sigma D * B + a_5 \Sigma E * B \\
\Sigma ZC &= K\Sigma C + a_1 \Sigma A * C + a_2 \Sigma B * C + a_3 \Sigma C * C + a_4 \Sigma D * C + a_5 \Sigma E * C \\
\Sigma ZD &= K\Sigma D + a_1 \Sigma A * D + a_2 \Sigma B * D + a_3 \Sigma C * D + a_4 \Sigma D * D + a_5 \Sigma E * D \\
\Sigma ZE &= K\Sigma E + a_1 \Sigma A * E + a_2 \Sigma B * E + a_3 \Sigma C * E + a_4 \Sigma D * E + a_5 \Sigma E * E
\end{aligned}$$

After substituting values in the above Eq. 5 one will get set of 5 equations. These are solved by using MATLAB and values obtained are as shown in the Table 3.

Table 3. Deduction of values of indices for output variables

Index values (after process in matlab)	Productivity
a0	1
a1	0.5557
a2	0.0732
a3	−2.0403
a4	0.3630
a5	0.0022

Putting values for indices and curve fitting constants for the equation of dependent Pi terms, exact model of productivity in Exponential form is obtained as shown in Eq. 5

$$\mathbf{Z_3 = 1\,\Pi_1^{\ 0.5557} * \Pi_2^{0.0732} * \Pi_3^{-2.0403} * \Pi_4^{0.3630} * \Pi_5^{0.0022}} \quad (5)$$

4.1 Formulation of Model Based on Clubbing of All Independent PI Terms

In this field data is represented by clubbing of independent data and representing them on X axis and corresponding values of dependent pi terms on Y axis. All 5 independent pi terms have been identified as Π_1, Π_2, Π_3, Π_4, Π_5 are clubbed together to form, $Z_3 = f(\Pi_1, \Pi_2, \Pi_3, \Pi_4, \Pi_5)$ using various combinations with multiplication and division (Fig. 3).

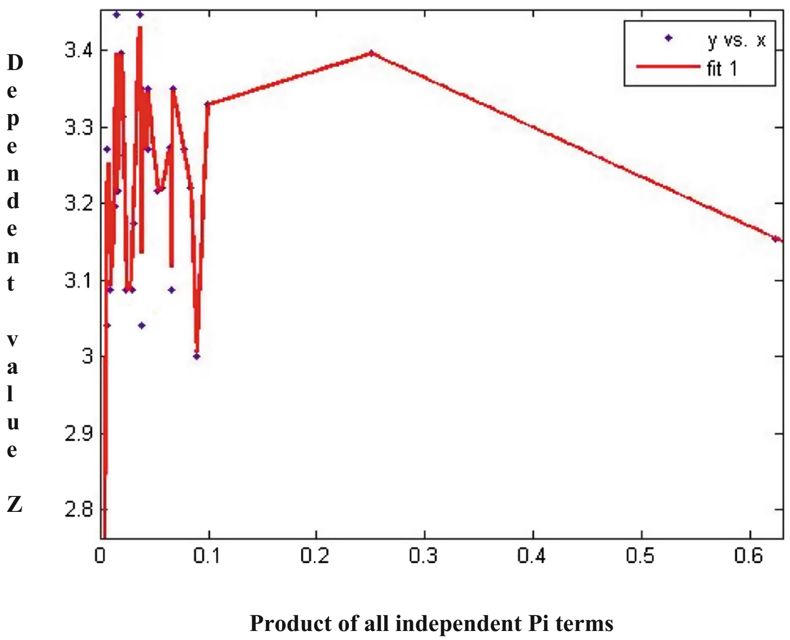

Fig. 3. Linear interpolant graphical analysis

Linear interpolant: f(x) = piecewise polynomial computed from p

Coefficients: p = coefficient structure

Goodness of fit: SSE: 0; R-square: 1; Adjusted R-square: NaN; RMSE: NaN

Linear model Poly6:

$$f(x) = p1 * x^{\wedge}6 + p2 * x^{\wedge}5 + p3 * x^{\wedge}4 + p4 * x^{\wedge}3 + p5 * x^{\wedge}2 + p6 * x + p7 \quad (6)$$

Coefficients (with 95% confidence bounds):

- p1 = 3.067e + 004 (−1.067e + 006, 1.129e + 006)
- p2 = −2.169e + 004 (−1.198e + 006, 1.155e + 006)
- p3 = −1287 (−3.767e + 005, 3.741e + 005)
- p4 = 2274 (−4.451e + 004, 4.905e + 004)
- p5 = −319.7 (−2860, 2220)
- p6 = 14.02 (−43.29, 71.33)
- p7 = 3.076 (2.668, 3.484)

Goodness of fit: SSE: 0.3794; R-square: 0.1434; Adjusted R-square: −0.08006; RMSE: 0.1284.

The above both graphical analysis also shows that the value of Z goes on decreasing after, when x = 0.3 and y = 0.5 (Fig. 4).

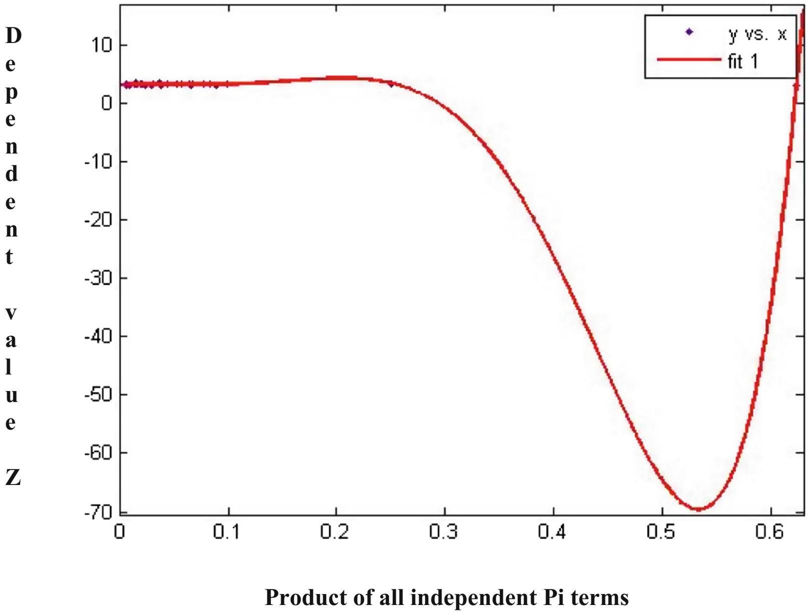

Fig. 4. Linear model Poly6 graphical analysis

5 Conclusion

Referring to Eq. 5, it is observed that the absolute index of a1 of Π_1 term is highest i.e. Π_1 = 0.5557. This indicates that, the highest influence of the pi term Π_1 is on productivity. This is because the a_1 index is positive, the relationship between the productivity Π_1 is direct. Meaning that if the value of Π_1 increases the productivity will increase. This pi term is related to anthropometric data of operator with respect to the stool on which he is seating. The reasoning behind this can be that, if the height and other specifications of the stool were designed ergonomically then the operator is at ease in sitting position while working. The other parameter i.e. Π_4 which is related to workstation design has a next high positive index. This also indicates that if the workstation data Π_4 value increases then it will help in increase of productivity. The third Π_3 term related to environmental factors shows negative index. This helps in decline of productivity because the operator is continuously working in hot and dry weather conditions as in Nagpur region. All the three pi terms shows us that the productivity of the operator could be increased if he is working in ergonomically designed workstation in better environmental conditions [1]. The other pi terms are very less influencing factors on productivity.

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Formulation of Field Data Based Model of Human Energy Expenditure During Wheat Grinding Operation Based on Anthropometric and Ergonomic Considerations

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Abstract. This paper highlights the detailed methodology of mathematical model formulation for the human energy expenditure in the wheat grinding operation. This paper details the formulation of field data based model to analyze the impact of various machining field parameters on the human energy expenditure in the wheat grinding operation. In all, 34 independent variables are studied to analyze their effect on the dependent variable human energy expenditure. The independent variables are then grouped to form 7 dimensionless pi terms using the Buckingham's Pi Theorem. Further, a model is developed using matrix analysis and the effect of the independent pi terms on the dependent pi term is established. Model derived by combining positive and negative pi terms, further analyzes the effect of the independent variables on the human energy expenditure. The models are validated to gauge the accuracy. Formulation of mathematical model and sensitivity analysis reveals that the anthropometric data of the operators has the highest influence on the human energy expenditure during the wheat grinding operation. Other factor that significantly affect the human energy expenditure is the environmental conditions in the workshop, majorly ambient temperature in the workshop. Research suggests that as the temperature inside the workshop increases, the human energy expenditure also increases.

Keywords: Wheat grinding · Field data based model · Human energy · Sensitivity · Optimization

1 Introduction

Wheat is a major food staple in India, and is crucial to India's food economy. With wheat production of 70 to 75 million tons annually and a large demand, India's wheat economy is now the second largest in the world.

In the olden days, household had a 'chakki' to mill the wheat. It consisted of two stone disks, each about 20″ in diameter, and 3″ thick. The top disk sat on a spindle located on the bottom disk. The different length spindles were used to determine the coarseness of the output. Modern flour mills use rotating millstones and are often driven by electric motors. The millstones do not touch each other when in operation.

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There is a gap between the static bedstone and rotating runnerstone which is determined by the size of the grain. Grain is fed from a chute into a hole, known as the eye, in the centre of the runnerstone. An intricate system of groves, known as furrows, distributes the grains across the millstone surface and also serves to ventilate and cool the millstones. The grinding surfaces of the millstones are known as lands and are divided into areas called harps. Once ground, the flour passes along narrow groves called cracking, and is expelled from the edge of the millstones.

2 Experimental Setup

Wheat grinding operation is carried on a wheat grinding machines. A motor provides the power to turn the runnerstone at a given rotational speed. The power and the rotation per minute of the motor are determined during the research. The wheat grinding operation is carried out by an operator. The anthropometric as well as personal data such as age, skill, years in operation etc., of the operators are determined and taken as input variables for the system. Similarly, environmental parameters are also taken as input variables. The machine parameters play a significant role in deciding the human energy expenditure and form part of the input variables.

A series of experiments were performed to study the effects of these variables on the human energy expenditure in the wheat grinding operation. These experiments were carried out to investigate the effects of various field input parameters mentioned above on the human energy expenditure in the operation i.e. total output during grinding wheat into flour. The output was measured and recorded using appropriate storage devices (personal computer) for further analysis.

3 Need to Formulate the Field Data Based Model

Data sets contain information, often much more than can be learned from just looking at plots of those data. Models based on observed input and output data (from real life situation) help us abstract and gain new information and understanding from these data sets. They can also serve as substitutes for more process-based models in applications where speed is critical or where the underlying relationships between different activities are poorly understood.

Thus, it is not possible to plan such activities on the lines of design of experimentation [1], especially for the dynamic system (which exists in wheat grinding process). When one is studying any completely physical phenomenon but the phenomenon is very complex, to the extent that it is not possible to formulate a logic based model correlating causes and effects of such a phenomenon, then one is required to go in for the field data based models [2]. In view of the dynamic nature of the context under investigation (which reveals complex phenomenon), it was decided to formulate a field data based model in the present investigation rather than using a theoretical approach.

4 Formulation of Field Data Based Model

4.1 Wheat Grinding Process as a System

The process during wheat grinding operation can be effectively explained with the Block Representation of wheat grinding phenomenon under study (Fig. 1).

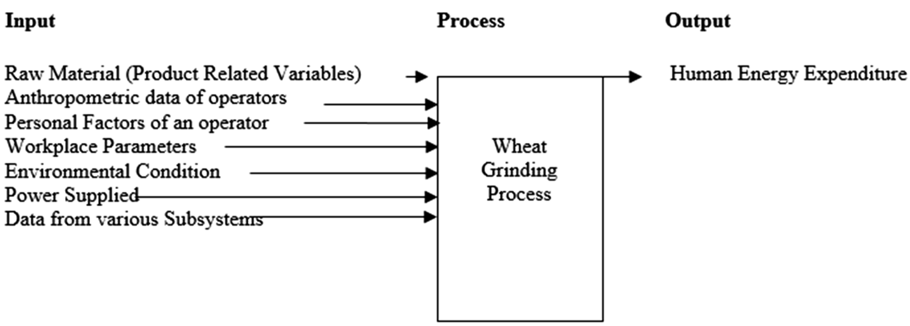

Fig. 1. Block Representation of wheat grinding phenomenon

4.2 Identification of Independent, Dependent Variables

The term variables are used in a very general sense to apply to any physical quantity that undergoes change. If a physical quantity can be changed independent of the other quantities, then it is an independent variable. If a physical quantity changes in response to the variation of one or more number of independent variables, then it is termed as dependent or response variable. Initially the independent and dependent variables under study were identified. Tables 1 and 2 depict the independent and dependent variables along with the MLT indices and test envelops respectively [3].

Table 1. List of identified independent (input) variables for wheat grinding process

S. no	Type	Variable Name	Symbol	MLT indices	Test envelop
1	C1	Wight of Wheat	Ww	$M^1L^0T^0$	2 constant
2	A1	Total Height	Th	$M^0L^1T^0$	149.86 to 182.88
3	A2	Shoulder Height	Sh	$M^0L^1T^0$	127 to 157.48
4	A3	Waits Height	Wh	$M^0L^1T^0$	73.66 to 101.6
5	A4	Wrist Height	Wrh	$M^0L^1T^0$	60.96 to 91.44

(*continued*)

Table 1. (*continued*)

S. no	Type	Variable Name	Symbol	MLT indices	Test envelop
6	A5	Arm Span	As	$M^0L^1T^0$	161.84 to 201.16
7	A6	Arm Reach	Ar	$M^0L^1T^0$	61.9 to 87.12
8	A7	Elbow Height	Eh	$M^0L^1T^0$	95.91 to 115.21
9	A8	Elbow Span	Es	$M^0L^1T^0$	37.46 to 47.29
10	P1	Experience of the Operator	Eo	$M^0L^0T^1$	5 to 30
11	P2	Age of the Operator	Ao	$M^0L^0T^1$	22 to 56
12	P3	Body Mass Index – Prime (BMI)	BMI	$M^0L^0T^0$	14.4 to 32
13	E1	Ambient Temperature	At	$M^0L^0T^0$	35 to 41
14	E2	Illumination at Workplace	Iwi	$M^0L^0T^0$	247 to 410
15	E3	Illumination outside Workplace	Iwo	$M^0L^0T^0$	2400 to 3400
16	E4	Noise Level at Work Place	No1	$M^0L^0T^0$	53 to 68
17	E5	Noise Level at Work Place (While machine is working)	No2	$M^0L^0T^0$	86 to 98
18	W1	Hp of the Machine Motor	HP	$M^1L^2T^{-3}$	7.5 to 20
19	W2	Motor Speed	Ms	$M^0L^0T^{-1}$	960 to 1440
20	W3	No. of Phases	P	$M^0L^0T^0$	3 constant
21	W4	Pulley Diameter Ratio	PDr	$M^0L^0T^0$	0.66 to 1
22	W5	Pulley RPM Ratio	PRr	$M^0L^0T^0$	0.66 to 1
23	W6	Distance Between pulleys	Dpp	$M^0L^1T^0$	70 to 72.5
24	W7	Hooper Height	Hh	$M^0L^1T^0$	150 to 155.5
25	W8	Break Height	Bh	$M^0L^1T^0$	48 to 54.4
26	D1	Drum Diameter	Dd	$M^0L^1T^0$	40.64 to 50.8
27	D2	Drum Width	Dw	$M^0L^1T^0$	7 to 8
28	GS1	Stone Hardness	Sh	$M^0L^0T^0$	8 constant
29	GS2	Stone Surface Roughness	Ra	$M^0L^1T^0$	0.00002 to 0.00004
30	GS3	Stone Density	Sd	$M^1L^{-3}T^0$	2.21 to 2.90
31	GS4	Stone Weight1	Sw1	$M^1L^0T^0$	23 to 41.5
32	GS5	Stone Weight2	Sw2	$M^1L^0T^0$	20.7 to 35.2
33	S1	Shaft Diameter	Dsh	$M^0L^1T^0$	3.95 to 4.15
34	S2	Shaft Length	Sl	$M^0L^1T^0$	80 to 81.5

Table 2. List of identified independent (response) variables for wheat grinding process

S.no	Type	Variable name	Symbol	MLT indices	Unit of measurement
1	Hr	Human Energy Expenditure	Hr	M0L0T0	Dimensionless

4.3 Formation of Different Pi Terms Formulated by Buckingham's Pi Theorem

There are several quite simple ways in which a given test can be made compact in operating plan without loss in generality or control. The best known and the most powerful of these is dimensional analysis. In the past dimensional analysis was primarily used as an experimental tool whereby several experimental Variables could be combined to form one.

Using this principle modern experiments can substantially improve their working techniques and be made shorter requiring less time without loss of control. Deducing the dimensional equation for a phenomenon reduces the number of independent variables in the experiments. The exact mathematical form of this dimensional equation is the targeted model. This is achieved by applying Buckingham's π theorem [4].

Initially it was necessary to formulate relationships such as

$$\begin{aligned} Z1 = f[&(C1)(A1, A2, A3, A4, A5, A6, A7, A8), (E1, E2, E3, E4, E5), (W1, W2, \\ &W3, W4, W5, W6, W7, W8), (D1, D2), (GS1, GS2, GS, GS4, GS5)(S1, S2)] \end{aligned} \quad (1)$$

Where

- Product related variable (C1)
- Anthropometric Data of an operator (A1,A2,A3,A4,A5,A6,A7,A8)
- Environmental conditions (E1,E2,E3,E4, E5)
- Workplace Parameters (W1,W2,W3,W4,W5,W6,W7,W8)
- Grinding Drum Parameters (D1,D2)
- Grinding Stone Parameters (GS1,GS2,GS,GS4,GS5)
- Power transmission shaft parameters (S1,S2)

The pi terms are formulated by applying Buckingham's Pi theorem in order to combine the variables and facilitate further analysis.

Thirty four independent variables are grouped into seven independent pi terms and a separate pi term is formulated for dependent variable human energy expenditure as depicted in Table 3 below.

4.4 Approach for Formulation of Models Based on Observed Data

It is necessary to correlate quantitatively various independent and dependent terms involved in this phenomenon. This correlation is a mathematical model as a design tool for such situation. The Mathematical model for wheat grinding operation is as given below.

Table 3. List of different dimensional Pi terms formulated by Buckingham's Pi theorem

S. no	Independent dimensionless ratio	Independent dimensionless ratio	Nature of basic physical quantities
1	π_1	π_1 = (Th)(Sh)(Wh)(Wrh)/(As)(Ar)(Eh)(Es)	Anthropometry related Pie Term
2	π_2	π_2 = (Eo)(BMI)/Ao	Personal Factors of operator
3	π_3	π_3 = (At) (No1)/(Iwi) (No2)	Environmental Conditions
4	π_4	π_4 = $(Dpp^2)(Hh^2)(Bh^2).(Ww^3)(Ms^9)(p)^s(PDr)(PRr)/HP^3$	Power Generation Parameters
5	π_5	π_5 = Dd/Dw	Drum Related Parameters
6	π_6	π_6 = (sh) $(Ra^6)(Sd^2)$/(Sw1)(Sw2)	Stone Related
7	π_7	π_7 = Dsh/Sl	Shaft Related
S. no	**Dependent Dimensionless Ratio**	**Dependent Dimensionless Ratio**	**Nature of Basic Physical Quantities**
1	π_8	π_8 = Hr	Human Energy Expenditure

Formulation of Models Based on Observed Data. Seven independent pi terms (π1, π2, π3, π4, π5, π6 and π7) and one dependent pi term (π8) were decided during experimentation and hence are available for the model formulation. Each dependent π term is the function of the available independent terms

$$\pi 8 = f(\pi 1, \pi 2, \pi 3, \pi 4, \pi 5, \pi 6, \pi 7) \tag{2}$$

A probable exact mathematical form for the dimensional equations of the phenomenon could be relationships assumed to be of exponential form [5]. For example, the model representing the behavior of dependent pi term π8 with respect to various independent pi terms can be obtained as under.

$$\pi 8 = a0\, \pi 1a1 * \pi 2a2 * \pi 3a3 * \pi 4a4 * \pi 5a5 * \pi 6a6 * \pi 7a7 \tag{3}$$

There are eight unknown terms in the Eq. (3) i.e. constant of proportionality a0 & indices a1, a2, a3, a4, a5, a6, a7.

The values of exponent a1, a2, a3, a4, a5, a6, a7 are established independently at a time, on the basis of data collected through classical experimentation. There are eight unknown terms in the Eq. (3), curve fitting constant a0 and indices a1, a2, a3, a4, a5, a6, a7. To get the values of these unknowns we need minimum a set of seven set of all unknown dimensionless pi terms.

$$Z = A + bX + CY. \tag{4}$$

The Eq. 3 can be brought in the form of Eq. (4) by taking log on both sides.

$$\mathrm{LOG}\,\pi 8 = \mathrm{LOG}\,a0 + a1\,\mathrm{LOG}\,\pi 1 + a2\mathrm{LOG}\,\pi 2 + a3\,\mathrm{LOG}\,\pi 3 + a4\,\mathrm{LOG}\,\pi 4 + a5\,\mathrm{LOG}\,\pi 5 + a6\,\mathrm{LOG}\,\pi 6 + a7\,\mathrm{LOG}\,\pi 7 \quad (5)$$

After solving using MATLAB, the mathematical model formulated is

$$\pi 8 = 0.1282\,\pi 10.7394 * \pi 20.0245 * \pi 3 - 0.1778 * \pi 40.0765 * \pi 50.0422 * \pi 6 - 0.0696 * \pi 71.4237 \quad (6)$$

Formulation of Models Based on Combination of Observed Data. Two more independent pi terms (πa, πb) were formed and already formed one dependent pi term (π8) were decided during experimentation and hence are available for the model formulation.

πa is formed by the product of the positive independent π as specified in Eq. (6).

$$\pi a = (\pi 1 * \pi 2 * \pi 4 * \pi 5 * \pi 7) \quad (7)$$

πb is formed by the product of the negative independent π as specified in Eq. (6)

$$\pi b = (\pi 3 * \pi 6) \quad (8)$$

Each dependent π term is the function of the available independent terms

$$\pi 8 = f(\pi a, \pi b) \quad (9)$$

A probable exact mathematical form for the dimensional equations of the phenomenon could be relationships assumed to be of exponential form. For example, the model representing the behavior of dependent pi term π8 with respect to various independent pi terms can be obtained as under.

$$\pi 8 = a0\pi aa1 * \pi ba2 \quad (10)$$

Therefore two unknown terms in the Eq. 10 i.e. constant of proportionality a0 & indices a1, a2.

The values of exponent are a1 and a2 are established independently at a time, on the basis of data collected through classical experimentation. There are three unknown terms in the Eq. (10) curve fitting constant a0 and indices a1 and a2. To get the values of these unknowns we need minimum a set of three set of all unknown dimensionless pi terms.

After solving using MATLAB, the mathematical model formulated is as indicated herein

$$\pi 8 = 0.3395\,\pi a\,0.0087 * \pi b - 0.0187 \quad (11)$$

5 Graphical Analysis of Combination of Observed Data for Individual Mathematical Model for Dependent Pi Term Hr

To obtain 2-D graph, dependent pi term π8 is plotted on Y axis, where as the product of all independent pi terms is plotted on the X axis (Fig. 2).

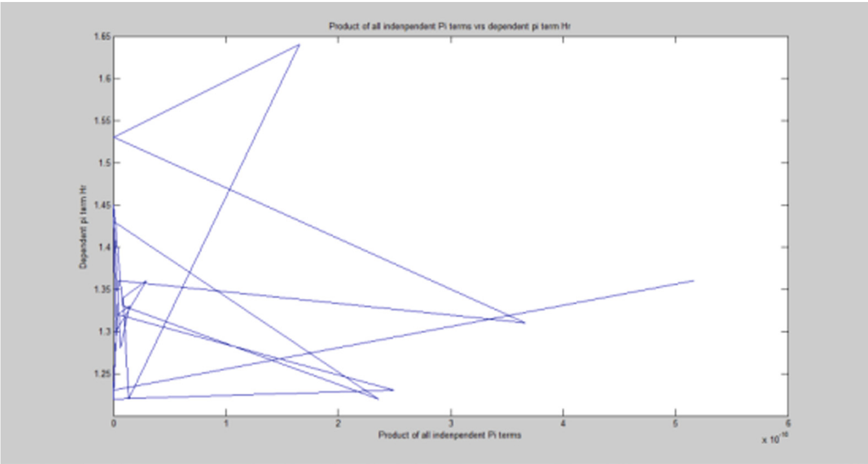

Fig. 2. 2-D plot of product of all independent pi terms Vs dependent Pi term π8

It can be observed from the plot that as the product of the independent pi terms increases, the Human Energy Expenditure Hr, as tends to gradually increase. 5 peaks observed, needs involvement of 10 mechanisms.

To obtain 2-D graph, dependent pi term π8 is plotted on Y axis, where as the product of all positive independent pi terms is plotted on the X axis (Fig. 3).

It can be observed from the plot that as the product of the independent positive pi terms increases, the Human Energy Expenditure Hr, as tends to gradually increase. 5 peaks observed, needs involvement of 10 mechanisms.

To obtain 2-D graph, dependent pi term π8 is plotted on Y axis, where as the product of all negative independent pi terms is plotted on the X axis (Fig. 4).

It can be observed from the plot that as the product of the independent negative pi terms increases, the Human Energy Expenditure Hr, as tends to gradually decrease. 8 peaks observed, needs involvement of 16 mechanisms.

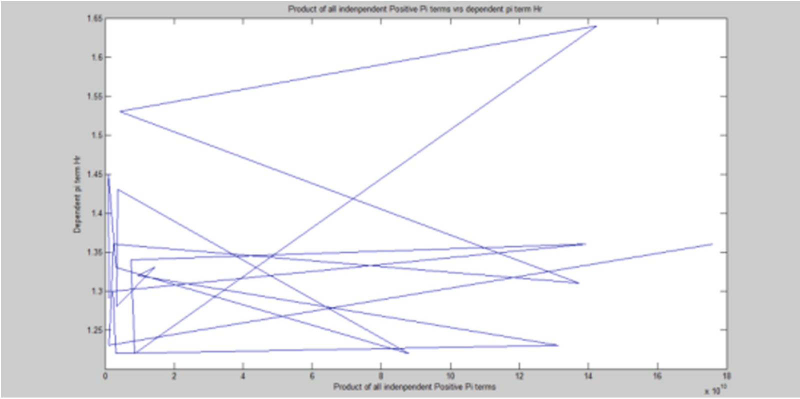

Fig. 3. 2-D plot of product of all independent positive pi terms Vs dependent Pi term π8

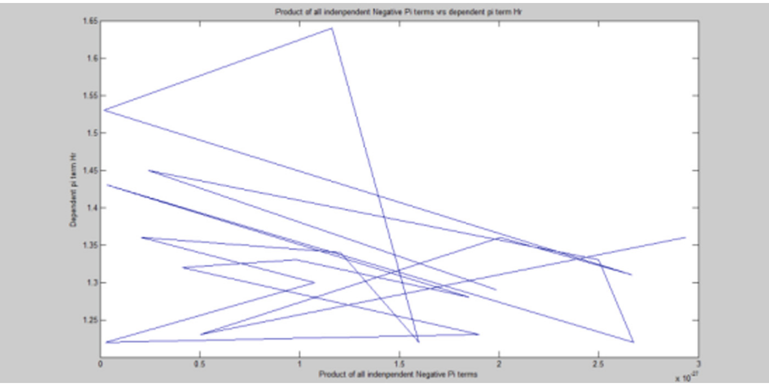

Fig. 4. 2-D plot of product of all independent negative pi terms Vs dependent Pi term π8

6 Model Sensitivity Analysis

The influence of the various independent π terms has been studied by analyzing the indices of the various π terms in the models. Through the technique of sensitivity analysis, the change in the value of a dependent π term caused due to an introduced change in the value of individual π term is evaluated. In this case, change of ±10% is introduced in the individual independent π term independently (one at a time). Thus, total range of the introduced change is ±20%. The effect of this introduced change on the change in the value of the dependent π term is evaluated. The average values of the change in the dependent π term due to the introduced change of ±10% in each independent π term. This defines sensitivity [5]. The total % change in output for ±10% change in input is shown in Table 4.

The graphical distribution of the sensitivity analysis of the formulated model with respect to different pi terms is shown in Fig. 5.

Table 4. Sensitivity analysis of the formulated model

Pi terms	% change	Pi terms	% change	Pi terms	% change	Pi terms	% change
π1	0.148	π3	−0.036	π5	0.008	π7	0.285
π2	0.005	π4	0.015	π6	−0.014		

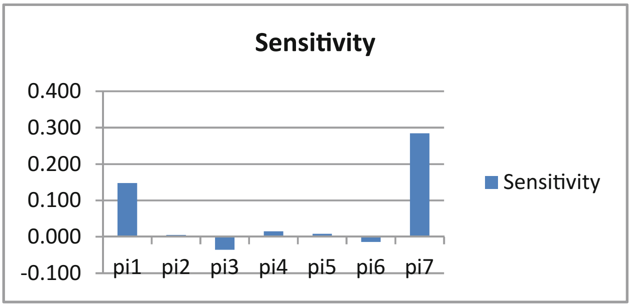

Fig. 5. Graph of sensitivity analysis of the formulated model for human energy expenditure

7 Model Optimization for the Human Energy Expenditure

The ultimate objective of this work is not merely developing the models but to find out best set of independent variables which will result in minimization of the objective functions. In this case, there is one objective functions corresponding to human energy expenditure in grinding process. The objective function for the human energy expenditure in wheat grinding process needs to be maximized. The models have non-linear form; hence, it is to be converted into a linear form for optimization purpose. This can be achieved by taking the log of both the sides of the model. The linear programming technique as detailed below is applicable for wheat grinding operation.

Taking log of both the sides of the Eq. 4, we get the objective function

$$\begin{aligned} Zmin = {} & LOG(0.1282) + 0.7394LOG(\pi 1) + 0.0245\,LOG(\pi 2) - 0.1778\,LOG\,(\pi 3) \\ & + 0.0765LOG(\pi 4) + 0.0422LOG\,(\pi 5) - 0.0696LOG(\pi 6) + 1.4237\,LOG\,(\pi 7) \end{aligned} \tag{12}$$

Subject to the following constraints

- 1X1 + 0X2 + 0X3 + 0X4 + OX5 + OX6 + OX7 <= LOG (Max π1)
- 1X1 + 0X2 + 0X3 + 0X4 + OX5 + OX6 + OX7 >= LOG (Min π1) ….and so on up to

$$\begin{aligned} & 0X1 + 0X2 + 0X3 + 0X4 + OX5 + OX6 + 1X7 < \; = LOG\,(Max\,\pi 7) \\ & 0X1 + 0X2 + 0X3 + 0X4 + OX5 + OX6 + 1X7 > \; = LOG\,(Min\,\pi 7) \end{aligned} \tag{13}$$

On solving the above problem by using MS solver we get values of X1, X2, X3, X4, X5, X6, X7 and Z.

Thus π8 min = Antilog of Z and corresponding to this value of the π8 min the values of the independent π terms are obtained by taking the antilog of X1, X2, X3, X4, X5, X6, X7 and Z.

The optimized values are tabulated in Table 5.

Table 5. Optimized values of response variables for human energy expenditure

Pi terms	Log values	Anti Log values	Pi terms	Log values	Anti Log values
Z	0.738	5.47	π_4	7.823	6652731
π_1	0.302	2.0045	π_5	0.705	5.07
π_2	0.455	2.851	π_6	−27.403	3.95E−28
π_3	0.926	8.43	π_7	−1.311	0.0489

On substituting the values of π1 to π7 in equation 8.17, Zmin = 0.59.

Thus, conclusion can be drawn that on reaching the optimized values of π1 to π7, one can minimize the value of response variable Human Energy Expenditure to 0.59 (Fig. 6).

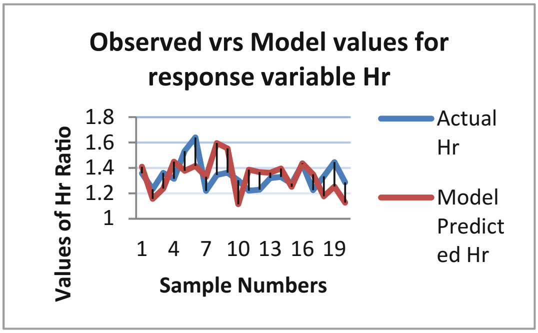

Fig. 6. Actual observed and mathematical model predicted values for dependent variable productivity reliability = 100 − percentage mean error

8 Validation of the Formulated Generalized Field Data Based Model

The validity of the formulated model can be checked by comparing the actual experimental value of the pi term related with human energy expenditure and its values obtain from the formulated mathematical model (Table 6).

$$\text{Mean Error (Hr)} = \sum(\text{xi} * \text{fi}) / \sum(\text{fi}) = 0.32\% \qquad (14)$$

Table 6. Actual observed and mathematical model predicted values for dependent variable productivity

S. no	Actual Hr	Model Predicted Hr	% error	S. no	Actual Hr	Model Predicted Hr	% error	S. no	Actual Hr	Model predicted Hr	% error
1	1.36	1.41	−3.83%	7	1.22	1.33	−9.12%	13	1.32	1.36	−3.23%
2	1.23	1.16	6.15%	8	1.34	1.60	−18.8%	14	1.33	1.40	−5.07%
3	1.36	1.24	9.18%	9	1.36	1.55	−14.0%	15	1.28	1.25	2.08%
4	1.31	1.45	−10.3%	10	1.30	1.11	14.51%	16	1.43	1.44	−0.39%
5	1.53	1.38	10.20%	11	1.22	1.39	−13.5%	17	1.22	1.35	−10.2%
6	1.64	1.42	13.73%	12	1.23	1.37	−11.3%	18	1.33	1.18	11.85%
								19	1.45	1.25	13.37%

$$\text{Reliability} = 100 - \sum(\text{xi} * \text{f}i) / \sum(\text{fi}) = 99.67\% \tag{15}$$

9 Interpretation and Discussion

9.1 Mathematical Model for Human Energy Expenditure

Referring to Eq. 6, it is observed that the absolute index of a1 of π1 term is the highest viz. 0.7394. The pi term π1 is related to the anthropometric data of the operators.

This indicates the highest influence of the pi term π1 on the human energy expenditure. Since index a1, is positive, the relationship between human energy expenditure and π1 is direct, meaning that if value of π1 increases, the human energy expenditure shall increase. The π1 term has total height, shoulder height, waist height and wrist height (all height related parameters) and arm span, arm reach, elbow span and height in the denominator, a very high positive index of π1 indicates that as the ratio between the height related parameters and the horizontal reach, related parameters increases, the human energy expenditure increase.

Referring to Eq. 6 it is observed that the absolute index of a3 of π3 term is the high viz. 0.0245. This indicates the highest influence of the pi term π3 on the human energy expenditure. Since index a3, is positive, the relationship between Human energy expenditure π3 is direct, meaning that if value of π3 increases, the human energy expenditure shall increase which is undesirable. This pi term is related to the environmental conditions in the workshop. π3 majorly has ambient temperature in the workshop in the numerator, this indicates that as the temperature inside the workshop increases, the human energy expenditure also increases. In order to reduce the human energy expenditure, the temperature in the work shop may be reduced.

9.2 Interpretation for Curve Fitting Constant

The magnitude of the curve fitting constant for the mathematical model as depicted in Eq. 6 for Human energy expenditure is 0.1282. This value represents collectively the influence of various extraneous variables that affect the human energy expenditure but are not part of the study. Such extraneous factors in this case are related to factors such as vibration in the machine, condition of the machine components, hours of continuous operation by the operator, his psychological condition and power fluctuations etc.

9.3 Formulation of Models Based on Combination of Observed Data for Dependent Pi Term Human Energy Expenditure

With reference to Eq. 11 one understands that the indexes a1 and a2 of πa formed by the product of all positive pi terms and πb formed by the product of all the negative pi terms are 0.0087 and −0.0187 respectively. It may be safely concluded that the positive pi terms put together have a significant and positive impact on the response variable human energy expenditure. In order to reduce the human energy expenditure, the parameters in π1, π2, π4, π5, π7 should be decreased whereas parameters in π3, π6 should be increased.

9.4 Reliability of the Model

From the values of percentage error, one can infer that the mathematical models can be successfully used for the computation of the values of dependent pi terms and subsequently that of the response variables.

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Posture Analysis of Face Drilling Operation in Underground Mines in India: A Case Study

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Abstract. The face drilling operation is manual in nature in the majority of the underground mines in India. Because of the existence of extreme working environment, use of heavy power drills by a group of operators, and uneven and slippery surface in a confined workspace, the operators have to assume awkward work postures at different heights of the mining face. A number of ergonomic problems, such as different kinds of musculoskeletal disorders (MSDs), low back pain (LBP) and vibration-induced diseases are reported among these operators, and hence, a biomechanical evaluation of such jobs has become a necessity. In this paper, the details of biomechanical modelling and analysis of different kinds of work postures related to this job are presented. A number of preventive and remedial measures for determining the appropriate values of the parameters for better design for such a job are proposed.

Keywords: Biomechanical evaluation · Face drilling · MSDs · Ergonomic design · Preventive measures

1 Introduction

It was not too long that people loaded ore and coal by hand and basket, although many jobs still require high levels of physical labour, mechanization has greatly reduced the physical demands placed on mine worker. Today mines are safer than at any period in the past and safety is now an important part of mine management coupled with the concern for productivity and the resultant economic viability of the mining operation. Over the last quarter century technology has done much to increase productivity and safety in mining industry. Now more attention to be paid to how people and technology would work together. How could equipment and task be designed to match the capabilities and limitation of the people who had to operate and maintain them. This is one of the question addressed by human factors. The purpose of this study is to investigate the utility of human factor for the design of equipment, tasks, procedure and environments with in the mining industry.

Human factors is the systematic application of relevant information about human characteristics, abilities, expectations, and behaviours to the design of machine tools, facilities, procedures, and environments that people use. The goal of human factors is to enhance the operational efficiency, and the health and safety of the people using the system. Human factors has wide applications in mining. The literature review revealed that it has been extensively used in other countries to increase safety and productivity.

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However, its application in Indian mining industry is very limited. in this thesis, an in-depth investigation of human factors on drilling operation in a drive and raise face has been carried out, as drilling operation is one of the elementary and most human factors concern mining operation. It is very important to go through literatures before conducting any study.

Ayoub et al. (1980) have been conducted a study on manual material handling activities. They develop different load handling capacities of individual and group [1]. Their basic approach based on three factor psychophysical, physiological and biomechanical. Kroemer (1983) has conducted a study over an isoinertial technique to assess individual lifting capacity [2]. Chaffin et al. carried out study on volitional postures during maximum pull/push exertion in sagittal plane [3].

The basic model of human factors of drilling operation is as follows. Here 5 drilling crew (in case of drive face) and 3 drilling crew (in case of raise) are involved in operating 2 jack hammers and I jack hammers respectively. Drilling the hole alters the environment. It puts a hole where noise and dust are generated. These various aspects of the environment affect the worker by reducing visibility creating new hazards or perhaps causing a temporary or partial loss of hearing. It is very apparent that these various job stressors that is various environmental stressors like heat, humidity, dust, noise and other stressors like physical demands, postural demands make the job uncomfortable. But one should be very precise on how can the job can be designed with in physical limits of workers by reducing of fatigue Impact in productivity.

2 Objective

The objective of the study is to conduct a symmetric investigation of drilling operation in a metal mine to improve physical comfort in jobs of the workers. The basic aim to analyse design drilling job by studying following

1. Anthropometry of the drillers
2. Postural analysis of drilling crew while working.

3 Development of Methodology

The study has been conducted in one of the copper mines, mine located in the district of Bihar. The study has focused at drive and raise faces on some of the human factors aspects, namely anthropometry, postures study and energy expenditure to improve worker's efficiency. For that some experimental and analytical procedures on each of the aspects have been developed.

3.1 Anthropometry

Anthropometry deals with the measurement of the dimensions and certain other physical characteristics of the body, such measurements are relevant to the design of the things people use. Body measurements vary as a function of age, sex and different ethnic populations. In connection with age, stature and related dimension generally increase until the late teens or early twenties, remain relatively constant throughout early adulthood, and decline from early to middle adulthood into old age. These anthropometric data have application in the design of facilities and things people use. However, the design of many work situations should take into account the interaction of body members and thus should be based in part on functional data. In the use of anthropometric data for designing the data should be reasonably representative of the population that would use the item. The design should be such that it can accommodate abroad spectrum of people.

In this study, design aspects of drilling machine or the dimension of the workspace are not considered. Here more stress are given on the selection of workers who can be accommodate for particular situations. The workers should be chosen so that they can conveniently reach the work surface height. Other application of this anthropometry is in postural analysis. As the body dimension of person determines the posture of that person for a particular working situation. This anthropometry data, which is shown in Table 1, is a very useful tools for posture analysis. For measuring the anthropometry the 5 drilling crews have been chosen. Their anthropometry data have been taken by using the anthropometer. The anthropometer consists of different instrument like stature gauge, beam calipers (straight legs and bowed legs), slide calipers, outside calipers, scale, tape measure, disinfectant cotton case.

Table 1. Anthropometry data table of Miners

Body dimension	Minimum	Maximum	Average
Height	155	166	160.8
Sitting height normal	78	87	82.7
Sitting height erect	83	90	86
Elbow to elbow breadth	39	51	44.2
Seat breadth	35	42	38.4
Knee height	52	57	53.7
Popliteal height	50	44	46.1
Thigh clearance height	5.1	7.3	5.7
Buttock knee length	42	57	50.6
Buttock popliteal height	49	41	45.4
Elbow rest height	22	30	26.3
Fore arm length	43	46	44.5
Arm length	28	31	31
Shoulder head length	25	27	25.5

3.2 Postural Analysis

Posture-related musculoskeletal disorders are common occupational problems. These are particularly prevalent in heavy demanding work situation like mining operations. Proper ergonomic design allows workers to maintain correct postures and hence, increases perceived comfort while reducing postural complaints. Worker's performance is improved after postural problems have been corrected. It is very difficult to assess the appropriateness of certain body postures as there is no clear idea exists by which the appropriateness, acceptability, healthfulness, comfort of various postures can be judged. The two main criteria on which the appropriate posture can be determined are as follows.

4 Biomechanics of Musculoskeletal System

4.1 Mechanics of Musculoskeletal System

Biomechanics is the science that, among other things, considers the actions of the human body in bringing about controlled movements and applying forces, torques, energy, and power to external objects. The basic principle of lifting involves the physics of levers. When a load is held in the hands, the load as well as the person's mass creates rotational movements or torques at the various joints of the body. The skeletal muscles are positioned to exert forces at tie these joints to counteract the movements due to the load and body weight. The problem is that the muscles are positioned so that they act through relatively small moment arms. For the arm to maintain its position, the biceps muscle must exert a force sufficient to overcome the weight of the load and the weight of the forearm and hand. The spine is made up of a series of bony vertebras stacked up with flexible fibrous pads, called disks, between divided into five sections, and the vertebras in each section are numbered. Most back injuries occur in the lower lumbar spine, land the L5/S1 disk (sacrovertebral joint). Biomechanical models have shown that during the lifting of a weight, the bending moment at the L5/S1 joint can become quite large due, in part to the weight of the upper body. To counteract this moment, the muscles of the lower back region must exert large forces because they operate on very small moment arms (approximately 2 in.). The large forces generated by the lower hack muscles are the primary sources of compression forces on the L5/S1 disk. The only force that acts to diminish the compression forces of the spine is intra-abdominal pressure the amount of compressive force that the vertebras can tolerate before experiencing micro fractures is a function of, among other things, age, sex, and prior compressive stresses experienced. There is, however, considerable individual differences in compression tolerance within any age group. According to NIOSH (27), the following is the current view on the genesis of a ruptured disk. Repeated compressive stresses, especially from lifting, are sufficient to cause micro fractures in the cartilage end plates and subchondral bone of the vertebras, which it is believed alters the metabolism and fluid transfer to the disk. If this occurs, the begins to degenerate, and its capacity to withstand further compression loads decreases. The result is that the disk squeezes out from between the vertebras and presses on the spinal nerve root. This is commonly called a slipped or ruptured disk. In fact, most low-back injuries do not suddenly start with a jabbing pain, although such cases are easily remembered. Most often, the symptoms are slow to develop, with stiffness, dull aching pain, and finally incapacitating discomfort that can occur hours or days later. The most important rule is to bring the Corse (really the L5/S1) as close as possible to the centre of gravity of the load. The closer the L5/S1 joint is to the load the shorter the moment arm and the lesser the force applied to the back. A second and subordinate principle, is that the back should be kept straight and vertical during a lift. In that posture, the compressive forces on the spine are more or less evenly distributed over the load-bearing surface of the vertebras. When the trunk is allowed to bend forward, the forces are concentrated on the front edges of the vertebras and tend to squeeze the disk toward the rear of the vertebral column. It is obvious from the above discussion that the posture study at worksite should be conducted and the analysis of those postures would be done by measuring the energy expenditure and by studying the biomechanics of the person.

For observing those postures, posture study form has been developed which has been shown in Table 2.

Table 2. Postural study form

NAME	1	2	3	4	5	6
NAME 1	XYZ					
NAME 2						
NAME 3						
NAME 4						
NAME 5						

In posture study form, the followings are portrayed

1. Observation at - Here the name of the mine where the study has been conducted is noted.
2. Section - the name of the particular section of the mine where the observations have been taken is given.
3. Date - The particular date at which the postures have been taken.
4. Name - Name of the drillers whose postural observations have been taken.
5. Time - The particular time when a postures is noted.
6. Position of the hole -The position of the hole from the floor which is marked as 01–07 for the drive and 01–05 for the raise and the respective height from the floor of the code have been shown accordingly.
7. Location-This indicates the location of the drillers at the face. If, left side of the face then A, else if right side of the face then B.
8. Type of posture - The variety of postures is numbered as 1, 2, 3 and so on. For example, the postural observation is coded as xyz. Here x indicates position of the hole from the floor. y indicates the location of the drillers. z indicates the number of the postures. The appropriateness of the posture can be judge studying the biomechanics of the person. For analysis, a standard procedure has been developed which has been discussed below.

A posture of having maximum occurrence has been chosen from various posture taken by a person drilling at a particular height. If there is on repeated postures then a posture is arbitrarily chosen for comparative analysis. The postures are compared with each other and given a relative ranking based on the following factors.

Difference of Erect Height with Respect to Hole Position Height. As it is apparent that if the difference between the erect height and the hole position height increases then the stress on person doing the work will also increase. Here, the maximum height of the drilling from the floor is 2.2 m and the minimum erect height among the drilling crew is 1.3 m, and thus resulting a maximum difference of 0.9 m. Based on this difference a suitable scale (shown in Fig. 1(a)) is constructed and divided into 10 equal parts and ranks are assigned to them

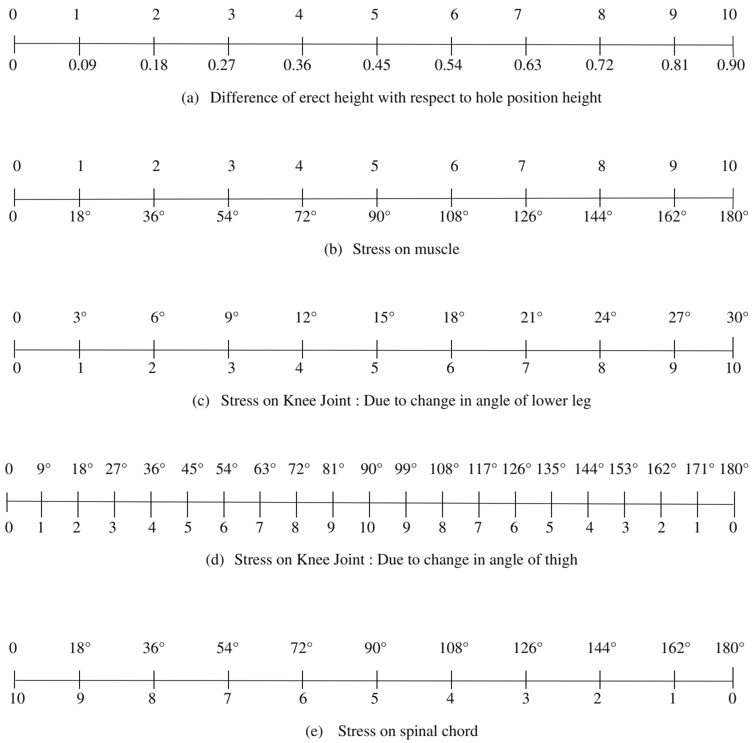


Fig. 1. Division of scale of different parameters like erect height, stress on muscle, stress on knee joint, stress on spinal chord

Stress on Muscle. Stress on hand muscles increases when the hand moves apart horn the body. Maximum possible angle between the hand and the body is 180. According to that a suitable scale is constructed and the relative ranking rate is given in the Fig. 1(b).

Stress on Knee Joint. The stress on knee joint due to change of thigh angle, change of lower leg angle.

Change of Thigh Angle. It is obvious that if the thigh is deviated from its vertical position then the stress on knee joint increases. Tile stress on knee joint maximum when the thigh making an angle 90 to it's vertical position. The stress again decreases if angle exceeds 90 and stress becomes minimum when the angle is 180. For that we have made a scale starting from zero to 180 and divided it into 20 equal parts. The rank increases as the angle increases, reaches a maximum at 90 thereby reduces and becomes minimum at an angle 180. For that a suitable scale also developed which is shown in Fig. 1(c).

Change of Lower Leg Angle. The stress on knee joint increases as the lower leg deviates from it's original vertical position. According to our field observations, the maximum deviation of the lower leg angle from it's vertical position is approximately 30. According to that a scale is developed which is shown in Fig. 1(c).

Stress on Spinal Chord. The stress on spinal chord is more if the - bending of vertebral column is more. The angle between the thigh and the vertebrae is assumed as a reference for measuring the stress on spinal chord. When the reference angle is more, the stress is minimum and the stress is maximum when the angle becomes zero. According to that a scale is constructed which is shown in Fig. 1(d).

The total sum of the scores gives an estimated figure of a relative stress on a person doing work with a particular posture.

5 Analysis

For this study, postural observation has been noted for the miners drilling at various heights. For analysis posture have been chosen by following rules which have been discussed in previous methodology part. A posture analysis of drive is given in appendix. From the general observations of the postures based on human factors principles, the following points can be derived, (1) It is seen that the persons having good erect height face less difficulties at the upper holes than the persons having shorter erect height. (2) The persons of shorter height are taking better postures than the taller persons at the lower holes (3) sometimes the persons are taking awkward postures wrongly although they can do the same work with better postures. (4) Sometimes they are forced to take the awkward postures as (a) the work space is not sufficient. (b) The working face is watery. (c) There is mismatching of proper combination of drillers.

From the observational study, it is very difficult to assess the superiority of one posture over the other for drilling a whole particular height. Hence, as discussed previously a ranking procedure has been developed for postural analysis. The overall rankings of those postures of different drillers, drilling at different heights have been shown in Table 3. It is clear that higher the rank means the greater discomfort of posture. For example, at the drilling height of 2.2 m from the floor, the total ranking of Miner 1, Miner 2, Miner 3, Miner 4 and Miner 5 are 18, 17, 17, 15, 15. It can be said that for 2.2 m height Miner 5 and Miner 4s posture is best and Miner 1's posture is the worst at that height. Similarly, at the heights the best and worst postures can be found out from the rankings.

Table 3. Overall ranking based on posture

Drilling Height	Over all ranking				
	Miner 1	Miner 2	Miner 3	Miner 4	Miner 5
2.2	18	17	17	15	15
1.8	12	11	11	9	12
1.5	7	15	14	9	2
1.1	9	9	3	0	0
0.7	2	2	6	5	6
0.4	25	20	26	27	16
At floor	19	15	15	15	15

6 Biomechanical Analysis

Here a free body diagram of a posture is drawn shown in Fig. 2. From this diagram we can write the equilibrium equations. F = compressive force on spine

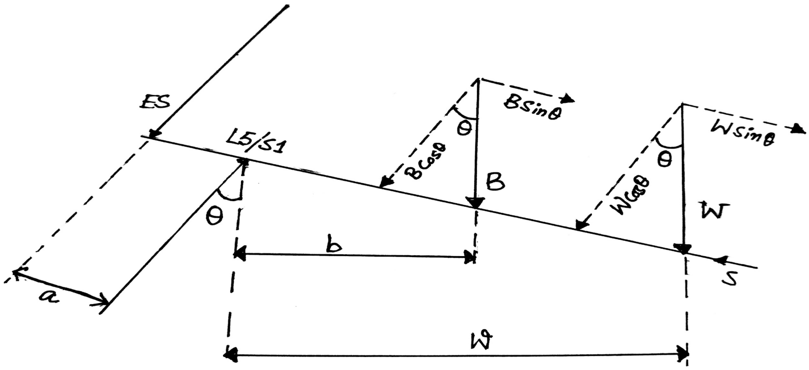


Fig. 2. Free body diagram of a posture B = body weight, W = drill machine weight b = distance between body CG and L5/S1, w = distance between drill and L5/S1, θ = bending angle, a = distance of electro spine force to compressive force

$$\begin{aligned} &\text{Moment around L5/S1}: \ ES * a = B * b + W * w \\ &\text{Forces in spine direction: } F - ES - B\cos\theta - W\cos\theta = 0 \\ &\text{Force perpendicular to spine: } S - B\sin\theta - W\sin\theta = 0 \end{aligned} \quad (1)$$

From this equation, we can say when the distance between L5/S1 and body weight point or drill distance increase compressive force will be increased exponentially. Because of this force many MSDs and LBPs can be occurred.

From the analysis following points can be derived:

(1) The maximum difficulties are faced when drilling at 0.4 m from the floor. (2) The postures are much better when drilling at 1.5 to 1.1 m holes than the others. (3) At upper holes the maximum stress occurs on the biceps muscles. (4) At the lower holes the maximum stress occurs on the thigh, knee joint and spinal chord causing back pain.

7 Conclusion

Conclusions are derived from this case study are given below:

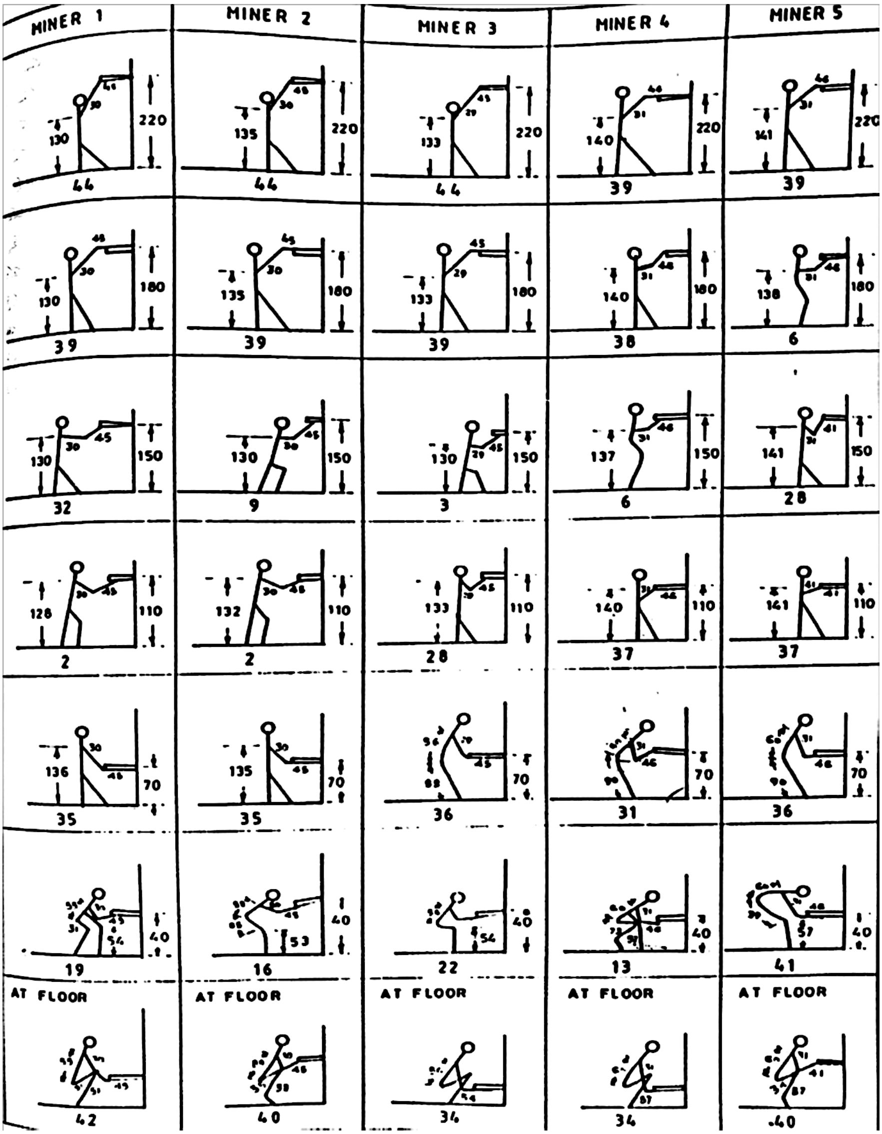
From Anthropometry study (i) it is seen that that the average erect height of driller is 160.80 m. It may be possibly average height of the worker is somewhat short to drill upper holes. (ii) The arm length and fore arm length of drillers is quite short.

(2) postural and biomechanical analysis - (i) It is seen horn the observation of postures that the persons having good erect height drill the hole with comfortable postures than the shorter persons for the upper holes (ii) The maximum difficulties are faced when drilling at 0.4 m from the floor (iii) The postures are much better when drilling at 1.5 to 1 1 m holes than the others. (iv) To drill the lower holes the maximum stress occurs on the thigh, knee joint and spinal chord causing back pain. (v) Sometimes the persons are taking awkward postures wrongly although they can do the same work with postures. (vi) Sometimes they are forced to take the awkward postures as (a) the work space is not sufficient. (b) The working face is watery. (c) There is mismatching of proper combination of drillers.

From the above study, the followings can be suggested. (i) Select the proper drilling crew having both shorter and taller persons so that for the upper holes the taller persons and for the lower holes shorter persons can be employed. (ii) In general, the anthropometry study reveals that the workers were not taking comfortable postures for drilling the extremely upper holes. Increased floor height can possibly alleviate this problem. (ii) Maintain proper sequence of drilling operation so that both the machine do not come close together at a time. (iv) For a particular drilling height some awkward postures taken by the workers should be possibly eliminated. (v) Postures should be taken in such a way so that there is less bending of vertebrae and keep the body as straight as possible keeping the body as near as possible to the drill machine.

Scope of Future Work. Extensive study would be done on anthropometry postural biomechanical analysis of some posture. In this study the other human factor aspects especially environmental effects was not conducted. Also details analysis of force biomechanically can be done. That can be done in future.

Appendix: Posture Analysis of Drive



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Heart Rate Based Evaluation of Operator Fatigue and Its Effect on Performance During Pipeline Work

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Abstract. Human fatigue caused by either physical exertion or mental strain is one of the most significant factors that constrain operator's functional capability to fulfill specific tasks. To ensure working performance and to improve occupational health, this paper aims to develop a quantitative method to evaluate operator fatigue during conducting pipeline works. A Japanese version of Borg's Rating of Perceived Exertion (RPE) scale and heart inter-beat intervals (RR interval) are measured in an experiment study. Hurst exponent (HE) is extracted from detrended fluctuation analysis (DFA) to define the fractal structures of RR interval time series. Results show that HE during working condition is significantly higher than during rest condition.

Keywords: Human fatigue · Heart rate variability · Detrended fluctuation analysis · Pipeline work

1 Introduction

Fatigue has been identified as one of the most significant factors that lead to accidents in a wide range of industries. Just like many other conceptual constructs of human factor, fatigue is rarely well defined since its complexity in practical situation: it is caused by many factors and linked to a series of degradation of human capability. It generally falls into two categories: mental and physical fatigue according to the definition given by the International Maritime Organization as quoted "A reduction in physical and/or mental capability as the result of physical, mental or emotional exertion which may impair nearly all physical abilities including: strength; speed; reaction time; coordination; decision making; or balance" [1]. Furthermore, operators always have to utilize both physical exertion and mental attention in conducting many real-world tasks, such as connecting and tightening flanges of pipes, whose perfect sealability is crucial for the safety of entire power-plant. Generally, operator's competence to fulfill specific tasks degrades along with the accumulation of physical and mental fatigue. Early detection and avoidance of operator's fatigue and the followed performance degradation thus would be helpful for the improvement of safety as well as the operator's comfort.

The Borg's Rating of Perceived Exertion (RPE) is one subjective method to measure individual's perception of exertion during physical work or exercise [2]. RPE provides a way to measure the intensity of physical exertion and has been found positively correlated with the increase of heart rate (HR) [3]. However, the accumulation of fatigue and

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exhaustion would also happen even when workload decreases or HR keeps constant. HR dynamics is a complex interacted process that reflects instantaneous changes of body position, physical movement, and mental state. It is therefore inaccurate to simply use the value of HR as an objective measure of physical fatigue. In addition to absolute HR value, features that extract from time/frequency/nonlinear based methods of heart rate variability (HRV) have been developed for clinical diagnosis and athletic exercise [4, 5]. Based on detrended fluctuation analysis (DFA), Chen et al. [6, 7] studied the fractal properties and developed a cardiac stress index (CSI) to measure subject's cardiac stress status during cycling exercise in a relatively short term. Nevertheless, seldom research attention has been paid to the operator's short-term fatigue in actual or quasi-actual working situation.

This paper aims to study the accumulation of fatigue and its effect on working accuracy during pipeline work. Section 2 elaborates the methods and materials, including the preprocessing of original RR interval series, methods of DFA, and experiment settings. Section 3 presents and discusses results of the experimental study. Finally, conclusions are drawn in Sect. 4.

2 Methods and Materials

2.1 Experiment Settings

Eleven male university students (age 26 ± 2.8) voluntarily participated in the experiment study, which was approved and conducted complying the Kobe University Guidance of Research on Human Subject. All experiments were conducted between 1–4 o'clock p.m. Caffeine intake and strenuous exercise were prohibited in the day of experiment. Before the participants signed the consent form, experiment purpose, its outline and their rights were explained. The experiments were arranged in the following temporal order: Instruction and preparation (wear heart rate sensor), practice, two-minute rest, formal experiment, and two-minute recovery baseline. The recovery baseline condition was measured three minutes after formal experiment. Heart rate monitoring started before the two-minute rest.

Figure 1 shows the experiment apparatus, each flange that connected pipes consisted of four bolts. The bolts must be tightened evenly and moderately to ensure sealability. In the practice session, the participants used a torque-measuring wrench to get used to torque of 20 Nm. During formal experiment, the participants were instructed to continuously tighten each of the bolt diagonally and as evenly as possible by using traditional wrench. The torque variance of four bolts of each flange is used as a measure of work performance. Participants reported subjective degree of fatigue in a number that corresponded to Borg's RPE scale for every two flanges. The experiment ended as long as the participant reported RPE scale as 20 (exhausted) or finished tightening all 26 flanges.

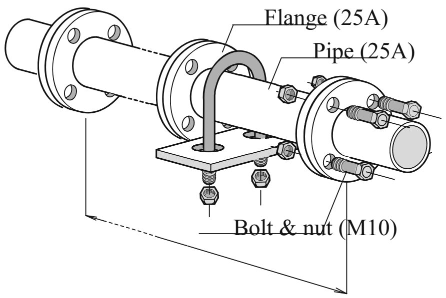

Fig. 1. Sketch of experiment apparatus, flanges and bolts.

2.2 Heart Rate Monitoring and Signal Preprocessing

A chest strap heart rate sensor RS800CX (Polar Electronics) was used to continuously measure the heart rate of each participant. RR interval series in unit of milliseconds were extracted and analyzed post-experiment. In practical environment, RR interval series are always contaminated by artifacts that caused by poor skin-electrodes contact, body motions, and/or sweating. The necessity of preprocessing RR interval series has been widely agreed since even one single ectopic RR interval data can have a serious impact on the interpretation of the results, especially for short-term analysis [8]. In addition, deletion of ectopic beats can cause information loss and error of spectrum features. Therefore, automatic recognition and replacement of outliers must be conducted before extracting features from RR interval data. In this study, we utilized a preprocessing method that combined recursive percentage filter and median filter, which was similar to that proposed by Mishra and Swati [9]. As shown in Eq. (1), consider an RR interval series (n), the first step is to recognize any data point that is more than t_1 larger or smaller than last sample, then replace it using a moving average window.$abs\{\cdot\}$ is absolute value operator and w_m is length of the moving window.

$$if\ \frac{abs\{x(n) - x(n-1)\}}{x(n-1)} > t_1,\ \hat{x}(n) = mean\left\{ x(n+m):abs\{m\} \leq \frac{w_m - 1}{2} \right\}. \quad (1)$$

The second step is to segment the original data into 5 min samples and a median based pulse rejection filter is applied [10]. The recognition of outlier is based on Eq. (2), where med [·] is median operator and x_m is the median value of the segmented signal (n). The recognized outlier is then replaced by the median value of moving window as shown in Eqs. (3) and (4).

$$D(n) = \frac{abs\{x(n) - x_m\}}{1.483med\left[abs\{x(n) - x_m\}\right]} \quad (2)$$

$$\hat{x}(n) = \begin{cases} x(n) & if\ D(n) \leq t_2 \\ x_i(n) & if\ D(n) > t_2 \end{cases} \quad (3)$$

$$x_i(n) = med\left\{ x(n+m):abs\{m\} \le \frac{w_m - 1}{2} \right\} \tag{4}$$

The threshold value t_1 was set as 30%, t_2 was set as four and window length w_m was five. According to above method, one typical example of RR interval series preprocessing is shown in Fig. 2. The total length of measured signal is 3445 and 9 points are edited by percentage filter and 23 points edited by median filter.

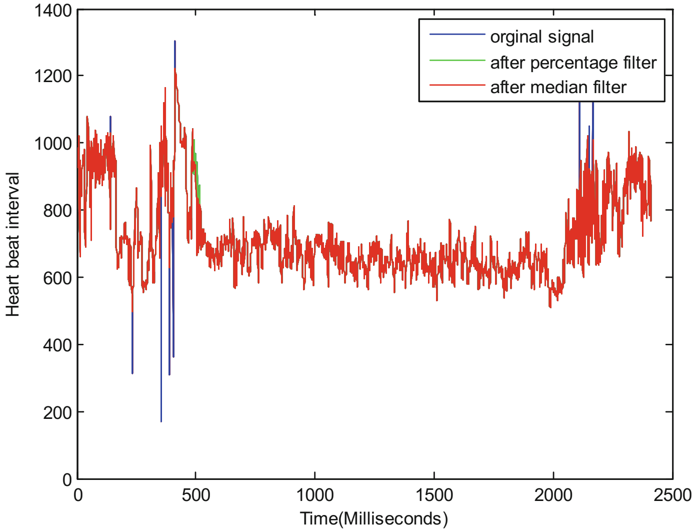

Fig. 2. Participant 9: RR interval time series preprocessing

2.3 Detrended Fluctuation Analysis (DFA)

DFA was firstly proposed by Peng et al. [11] and was widely used to study the fractal properties and long-term autocorrelations of nonstationary time series. Fractal geometry originally depicts the roughness of a surface and is applicable to time series data in the following essence: a process with stronger fractal characteristics does not adhere to equilibrium around any specific scale such as a constant heart rate [12]. According to [11, 13], monofractal DFA consists of four steps as shown in Eqs. (5)–(8). First, calculate the cumulative deviation of signal x, where $\bar{x}$ is the mean of x:

$$Y(i) = \sum_{k=1}^{i} \left[x_k - \bar{x} \right],\ i = 1, \ldots, N \tag{5}$$

Then divide $Y(i)$ into $N_s = int(N/s)$ nonoverlapping segments of length s. Calculate the local trend for each of N_s segments by a least-square fit of the series and determine the variance for each segment $v = 1, \ldots, N_s$:

$$F^2(v,s) = \frac{1}{s}\sum_{i=1}^{s}\left\{Y[(v-1)s+i] - y_v(i)\right\}^2 \tag{6}$$

For monofractal analysis, average $F^2(v,s)$ over all segments to obtain the second order fluctuation $F(s)$:

$$F(s) = \sqrt{\frac{1}{N_s}\sum_{v=1}^{N_s} F^2(v,s)} \tag{7}$$

Hurst exponent (HE) h that characterizes fractal properties is then extracted from the slope by fitting the log-log linear relationship between $F(s)$ and s. s ranged from 4 to 60 with a step size of 2 in this paper.

$$h = \frac{log_2^{F(s)}}{log_2^s} + c \tag{8}$$

According to [14], HE of biomedical signals generally ranges from 0.5 to 1.5. HE is 0.5 when the signal is white noise (Gauss distributed), while 1.0 indicates a pink noise and 1.5 indicates a brown noise.

3 Results and Discussion

A Japanese translation of Borg's RPE proposed and tested by [3] (Scheme C) was used as a subjective fatigue measure. Experiment data of one participant was not correctly recorded and was excluded from further analysis. Ten sets of experiment data are available for analysis and all data are presented in the form of means ± standard deviation (SD) over ten participants. Paired t test was used to check the statistical significance and $p = 0.05$. Experiment ended after 24.6 ± 2.5 flanges were tightened with seven participants finished all 26 flanges.

3.1 Borg's RPE and Heart Rate

HR of rest, pipeline work, and recovery baseline were 72.5 ± 8.0, 98.0 ± 11, and 83.7 ± 12, respectively. The maximal rate of increase in heart rate during work condition was 62% ± 15%, indicating that heart rate significantly increased to adapt to workload. After cropping RR interval series into epochs of tightening every two flanges, Borg's RPE highly correlated with the decrease of RR interval, the *Person's* correlation coefficient was −0.81 ± 0.2. It corresponds with the former study [2, 3] that RPE scale is able to track the changes in HR. However, working performance (variance of torque) correlated neither with RPE scale nor with mean RR interval as shown in Fig. 3.

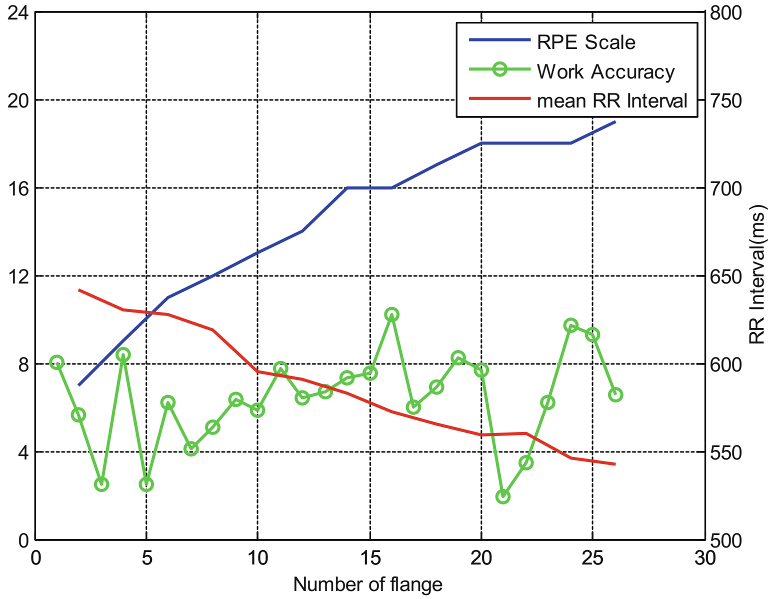

Fig. 3. Participant 6: Negative correlation between mean RR interval and RPE scale. Green line shows SD of tightened torque of each flange and is considered as a measure of work accuracy.

3.2 Working Accuracy and Hurst Exponent

SD of tightened torque of each flange was considered as one performance measure since evenly tightened bolts were crucial for the sealability of connecting flanges. The first and latter half of torque variance were 5.6 ± 2.1 Nm and 6.2 ± 2.0 Nm, indicating that the bolts were more evenly tightened in the first half when participants' degree of fatigue was lower, although the difference is not statistically significant ($p = 0.16$) (Fig. 4b).

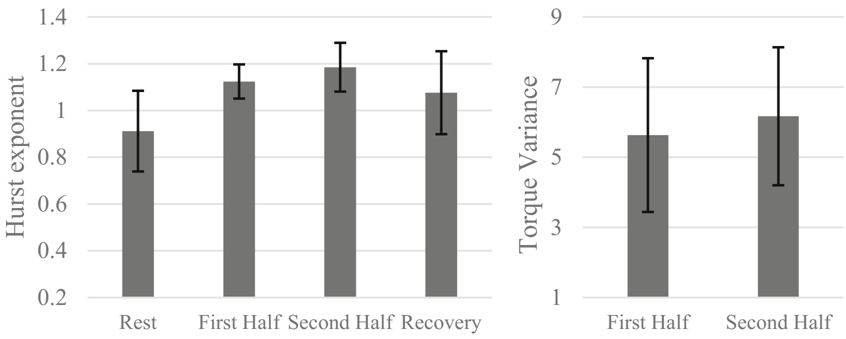

Fig. 4. **a.** HE of rest, first half of pipeline work, second half of pipeline work, and recovery condition. **b.** Torque variance during first half and second half of pipeline work. Error bar is SD over all participants.

To check the robustness of applying DFA to RR interval series, we randomly shuffled the RR interval series of one experiment for 100 times. Randomly shuffled signals were almost white noises as $h = 0.52 \pm 0.01$. HE of rest, first half of pipeline work, second half of pipeline work, and recovery baseline were 0.91 ± 0.17, 1.12 ± 0.07, 1.19 ± 0.10, and 1.08 ± 0.18, respectively. HE of working condition is significantly bigger than that of rest condition ($p = 0.003$). This result corresponds with the findings of [15], in which HE was found bigger under shooting exercise than under rest condition. Besides, HE during the second half of pipeline work was significantly higher than first half ($p = 0.04$), which might be caused by the accumulation of fatigue.

Furthermore, RR interval series were cropped into segments that corresponded with the onset of tightening each flange and ended 40 s later after accomplishment of tightening each flange. HEs were then calculated as shown in Fig. 5. A weak positive correlation between HE and torque variance was found for five participants. The average *Person's* correlation coefficient was 0.26 ± 0.1. It indicates that the participant's working accuracy was lower when HE was higher, although this cause-and-effect relationship is unclear.

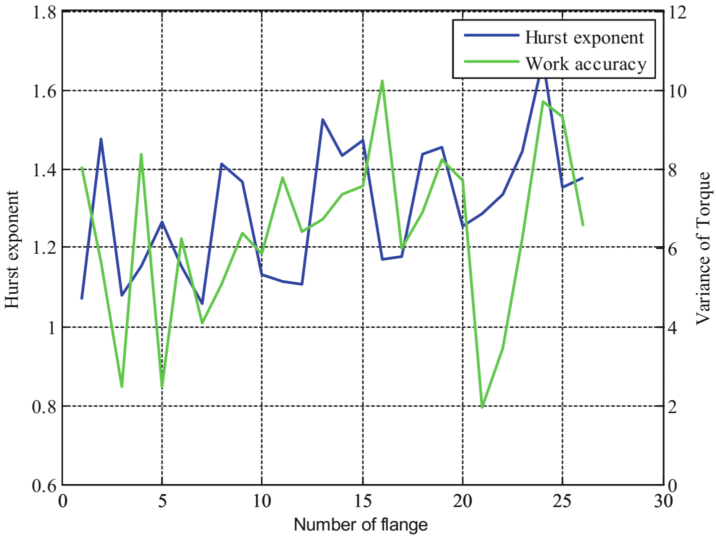

Fig. 5. **Participant 6:** Correlation between Hurst exponent and work accuracy

3.3 Cardiac Stress Index (CSI)

Chen et al. developed a cardiac stress index to online monitor human cardiac stress during cycling exercise [6] and CSI was further proved in [7]. According to [7], CSI was defined as

$$CSI = \frac{Number\ of\ events\ with\ h\ lower\ than\ 1}{Total\ number\ of\ events}$$

In [7], HE *h* was calculated in a one-minute sliding window with a step of 20 s. In this study, tightening of every single flange was considered as an event and RR interval series were cropped into corresponding segments with a delay of 40 s. CSI of each participant was then calculated. However, from the beginning to the end of pipeline work, CSI shown a decreasing trend rather than an increasing trend although the RPE scale indicated the increase of subjective fatigue. This inconsistency with the former study [6, 7] might be caused by the following reasons: First, Hurst exponent that extracted from DFA is affected by the settings of scale *s* in Eqs. (6) and (7), especially when the signal length is different. Second, in [6, 7], the experiment task was cycling exercise that required relatively monotonous physical exertion of lower extremities while this paper studied one real-world task that required both complex physical exertion and mental attention.

4 Conclusions

In an effort to develop a quantitative evaluation of operator fatigue degree throughout conducting pipeline works, an experiment study was designed and conducted in this paper. Borg's RPE scale, performance measure, and RR interval series were measured and analyzed. The results show that:

- Along with the continuous pipeline work, RPE scale generally increases while RR interval decreases, and they are highly correlated (Pearson's correlation coefficient $r = -0.81 \pm 0.2$);
- HE of working condition ($h1 = 1.16 \pm 0.08$) is significantly (paired T test, $p = 0.003$) higher than baseline condition ($h2 = 0.91 \pm 0.17$), which indicates that RR interval series show more auto-correlation structures in working condition compared to rest condition;
- Working performance of first half (5.6 ± 2.1 Nm) is better than the latter half (6.2 ± 2.0 Nm) although the difference is not statistically significant, indicating that the bolts are more evenly tightened in the first half when participants' degree of fatigue is lower;
- CSI derived from cycling exercise is not applicable to pipeline work in this study.

The main limitation of this on-going study is the small size of samples and this paper fails to develop a cross-individual regression model to predict working accuracy. Besides, error of performance measure existed since the measured torque of tightened bolts were affected by the order of measuring. We expect to solve these limitations in future study.

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Assessment of Heat Stress Impacts on Construction Workers: A South African Exploratory Study

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Abstract. The impact that heat stress has to the construction field is an ever-evolving topic as its also impacted by the change in climate. The South African climate temperatures escalated dramatically in the previous years leading to heat stress warning from the weather services towards the construction working conditions. The working conditions associated with heat stress may work against the foremen or anyone that spends most of their times not protecting themselves against the fast-changing temperatures in the construction sites resulting in heat stroke, heat exhaustion, heat syncope, heat cramps and heat rush. However, due to a low number of deaths on the construction site compared to the mining field, it has been taken not so much as a risk unless there is a heat wave warning. The aim of the research is to theoretically assess the impact that heat stress has to the construction field and the change in weather temperatures over the years. The study will contribute to the growing body of knowledge on heat stress and it impact in the construction industry.

Keywords: Heatwave · Heat stroke · Heat stress · Construction work conditions · IEC 61508 · OHSA codes

1 Introduction

Gauteng is the smallest province in South Africa with its name meaning “Place of Gold”. It is the largest province with people from not only its neighboring provinces but also neighboring countries and around the world relocating to find employment. The capital city of South Africa is situated in Gauteng-Pretoria. The province and all its cities may be the smallest in the country, however, according to the 2009 National Climate Change Response Policy of Johannesburg, it states that “South Africa is by far the largest emitter of greenhouse gases (GHGs) in Africa and is one of the most carbon emission-intensive countries in the world due to its energy intensive economy and high dependence on coal for primary energy. In world terms, South Africa is the 11th highest emitter of greenhouse gases”.

The GHGs contribute to the changes in weather and for some industries such as construction, that may cause its workers to have outdoor thermal discomfort by both direct and distributed solar irradiation between the human and its habitat. After all, the body heat is gained from the environment and the metabolism [1]. Firstly, an access change in temperature either being cold or hot may have an impact to the work

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environment. The increase in temperatures may cause heat stress, and heat strain resulting from heat stroke. A mild or moderate heat stress may cause discomfort and may affect performance and safety but not being harmful to health. The contribution that the working environment deposits to the body may cause the body to react to a heat strain. Heat strain is the overall physiological response resulting from heat stress [2]. Moreover, heat is removed from the body quicker when there is movement and less clothing as that does also play a role in the increase in body heat.

Secondly, according to the Occupational Health and Safety Act, 1993 (Act no 85 of 1993) its states that “to provide for the health and safety of persons at work and for the health and safety of persons in connection with the use of plant and machinery; the protection of persons other than persons at work against hazards to health and safety arising out of or in connection with the activity of persons at work; to establish an advisory council for occupational health and safety; and to provide for matters connected therewith.” [3].

In addition, the country’s designers must ensure that their designs are safe and free of health and risk. The South African Construction Regulation states that;” designers shall modify and design or make use of substitute materials where the design necessitates the use of dangerous structural or other procedures or materials hazardous to health and safety, and that designers shall inform principal contractors of any known or anticipated dangers or hazardous or special measures required for the safe execution of the work” with research showing that - the designing for construction safety entails addressing the safety of construction workers in the design of the permanent feature of a project [1].

Every building that is being designed does come with its own attributes such as a building that use structural steel truss as compared to the wooden trusses. The structural steel building will have more hazardous material and would entail the design and engineer having to have a design plan for when the steel is being placed onsite.

The following is not limiting to the many health and safety risk that may occur on a construction site as a cause of nature (weather-related) and the machinery (man-made) used on site. Machines used such as cranes need to also be in compliance with the Driven Machinery Regulations Government Notice R295_February 26,1988 with the responsible driver of the machine been given proper training.

2 Heat Stress and Construction Workers

Construction work is one of the hardest manual work in the world and depending on the area that the project is based on, the weather may also pay a huge impact. However, due to the weather in Gauteng only recently increasing to a high unmanageable temperature, may construction companies did not see the need to have the health and safety risk assessment using the WBGT.

Heat stress is the perceived discomfort and physical strain associated with exposure to a hot environment, especially during physical work [1]. On a construction site, heat stress maybe caused by exposure to high temperature either form the direct sun light or the different factors such as:

- radiant heat sources such as arc welders;
- high humidity either natural or site specific as in a concrete pour;
- proximity to, or direct physical contact with hot plant;
- lack of air flow and/or adequate ventilation on site;
- heavy or restrictive personal protection equipment;
- working on the roof;
- crane and machine operators standing in the sun

The necessity for strenuous physical activity under these conditions has a high potential for causing heat related health complaints, illness, disability, and death, particularly in early, outdoor or external phases of construction [4].

The construction workers have more chances of being exposed to skin cancer due to the long working periods in the sun if not taking the necessary measures to protect themselves. After all, construction is hazardous profession. The short-term exposure may cause reddening of the skin or sunburn can blister the skin with the long-term increasing the chances of developing skin cancer [5] not limiting to financial, or emotional.

Heat stress does not only happen outdoors but also indoors according to the 2017 USA Infrastructure Health and Safety Association manual labor that may be taking place as according to Table 1 [6].

Table 1. Areas that heat stress may occur

Indoors	Outdoors
Steel mills and foundries	Roadbuilding
Boiler looms	Homebuilding
Pulp and paper mills	Work on bridges
Generation plants	Trenching
Petrochemical plants	Pouring and spreading tar or asphalt
Smellers	Working on flat or shingle roofs
Furnace operations	Excavation and grading
Oil and chemical refineries	Electrical utilities
Electrical vaults	
Interior construction and renovation	

2.1 Factors Contributing to Heat Stress

The heat transfer can be different from person to person. With the normal body temperature being 37 °C, a slight change and impact caused by the surrounding area may play a huge role. The body will start sweating and that causes the body to lose liquids and the person will have to replace the lost fluids with water stay hydrated. If the replacement of fluids is not done, it will mean less sweat is produces resulting in an inability to reduce body temperature as sweating does help the body to cool off. Heat stress is dependent on many factors such as [7, 8];

2.2 Personal Factors

- General health;
- Body weight;
- Age;
- Poor health (heat disease or high blood pressure)
- Low level of fitness
- previous heat experiences
- Especially medication
- Alcohol

2.3 Environmental Factors

- Radiant heat
- Humidity
- Air movement

2.4 Job Factors

- Clothing and Personal Protective Equipment (PPE)
- Workload (Table 2)

The acceleration of the symptoms may also accelerate depending on how above contribution are with each person. The symptoms are but not limited to [4];

- Muscle cramps
- Migraine
- Motion sickness
- Light headed
- Weakness
- Fatigue
- Irascible
- Dehydration
- Heavy sweating skin

It has been advised that if a worker is found showing the following symptoms, the site supervisor will have to make sure that precautions are taken for the worker to be cooled off, given water, left to rest and monitored [2]. Research has also shown that heat stress may lead to heat stroke.

Table 2. Type of building works

Light work	• Using a table saw • Some walking about • Operating a Crane, truck, or other vehicle • Welding
Moderate work	• Laying brick • Walking with moderate lifting or pushing • Hammering nails • Tying rebar • Raking asphalt • Sanding drywall
Heavy work	• Carpenter sawing by hand • Shoveling dry sand • Laying block • Ripping cut asbestos • Scraping asbestos fireproofing material
Very heavy work	• Shoveling wet sand • Lifting heavy objects

2.5 Heat Stoke

A heat stroke is a severe illness characterized by a core temperature >40 °C and central nervous system abnormalities such as delirium, convulsions and coma result from exposure to environmental heat or strenuous physical exercise.

The symptoms of heat exhaustion and heat stroke may vary from confusion, dark-coloured urine (a sign of dehydration) dizziness, fainting, fatigue, headache, muscle or abdominal cramps, nausea, vomiting, or diarrhoea with the symptoms becoming extreme with the increase in temperature and may cause a mental state behaviour, flushed skin and racing heartbeat to name a few [9]

3 Methodology

The research is based on literature review. The main aim of the research was to theoretically assess the impact that heat stress has to the construction field and the change in weather temperatures over the years. The study contributed to the growing body of knowledge on heat stress, its impact in the construction industry and ways that it can be prevented.

4 Findings and Preventions

4.1 Designing for Construction Worker Safety

Safety is an attitude starting from top management and is reflected on the job site in many ways; through training, housekeeping according to the Environmental Regulations for workplaces Government Notice R2281_ October 19, 1987, toolbox meetings, adherence to safety measures, maintenance of equipment and tools by the storeman with compliance to Electrical Installation Regulations Government Notice R2920_October 23, 1992 and Electrical Machinery Regulations Government Notice R1593_August 12, 1988, and intolerance of violation. Everyone that is onsite is responsible not only for themselves but fellow workers as any accident that may happen has an impact on the project. Either a decrease in productivity as the body will not be functioning on its normal state and that resulting in loss of productivity, increase in insurance cost and even result in the company losing points to be able to bid for the next project [10]. An extreme heat exposure may also result in cardiovascular diseases, mental health problems, and chronic kidney diseases [11].

- *Management*: Health and safety onsite belongs to everyone that will be part of the project and the engineer together with management have to create a system that can work for the project and the workers on the project to reduce the risk of heat stress onsite. Establishing a heat illness prevention program through safety lifecycle management plan
- *Training*: First Aid training can be done for all the employees and how they can handle themselves and fellow colleagues if need be for measures to be taken if an incident was to happen on site related to heat stress. Teaching the workers about the type of food to eat during hot days and what to stay away from may also help with the risk of being a victim.
- *Housekeeping*: the company has to create a cool working place for it employees and make sure that water stations are created in order for the workers to be able to have regular drinking station for all the hot days on site.
- *Toolbox talks*: Toolbox talks are created to always keep the workers up to date on what is happening around them and using the platform to remind them to always be safe and keep in mind that there is a heatwave around therefor, precautions of drinking lots of water, wearing clothes easy to cool them off and resting under a cool place is needed.

4.2 Project Life Cycle

The *Project Life Cycle* refers to a series of activities which are important to execute the objectives and goals of a project. The size and structure of the project doesn't have much impact as each project does undergo the following stages: starting the project, organizing and preparing, carrying out project work, and closing the project.

In the second stage of the life cycle-planning, a risk plan has to be created as it helps the management to identify risks and implement a plan to reduce them. It helps with categorizing and prioritizing each risk, likelihood of it happening, and recognize the effect on the project is the risk does happen [12]. The following will lead to a company creating a Safety Life Cycle Plan.

4.3 Safety Life Cycle

The concept of a safety life cycle plan involves the IEC 61508 which is a model of the stages of safety management in the life of a project (Fig. 2).

IEC 61508 is a system compromised of electrical and/or electronic elements used for many years to perform safety functions in most application sectors. The aim of the safety life cycle is to address independently of functional issues, thus overcoming the assumption that functional reliability will automatically produce safety [13]. It addresses building-related occupational safety and health risks for all affected workers and groups across all life cycle stages. With the idea of Leadership in Energy and Environmental Design (LEED) taking place in mostly in the new construction project, its rating already provides a partial foundation for Safety Life cycle with a prompt that the a building can serve as a place of employment as "improving health and well-being for building occupants is an explicit LEED objective" [14].

4.4 Increase in Temperatures

In Fig. 1, research shows that; with the rise in temperatures in Gauteng between 2011 and 2016 precautions need to be taken more when it comes to the risk assessment safety and health measurement to treating heat stress. The management may use the WBGT Concept when preparing for the safety lifecycle of a project in order to help them calculate the rate that heat stress may occur. Heat stress need to be taken more seriously as the change in greenhouse gases are also playing an impact (Fig. 3).

Fig. 1. Project life cycle stages

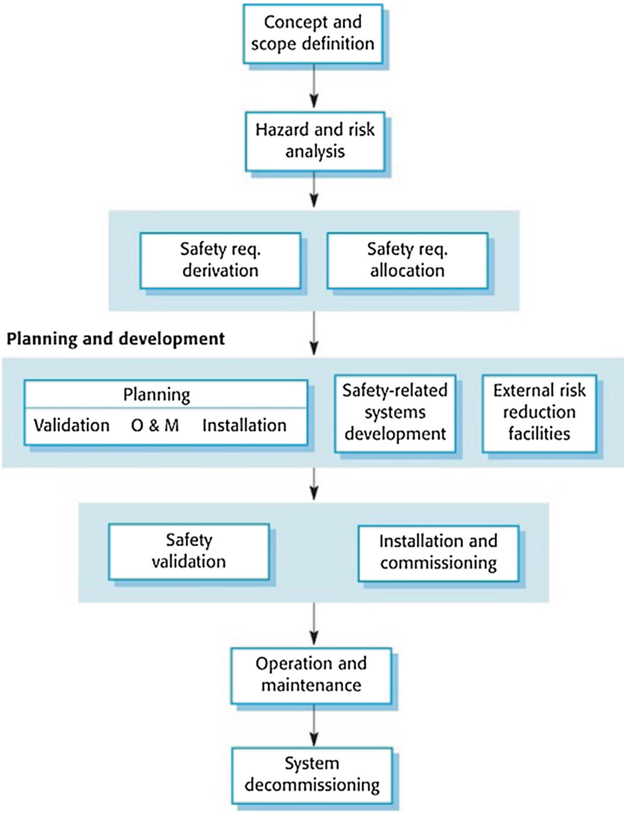

Fig. 2. IEC 61508 safety lifecycle plan [14]

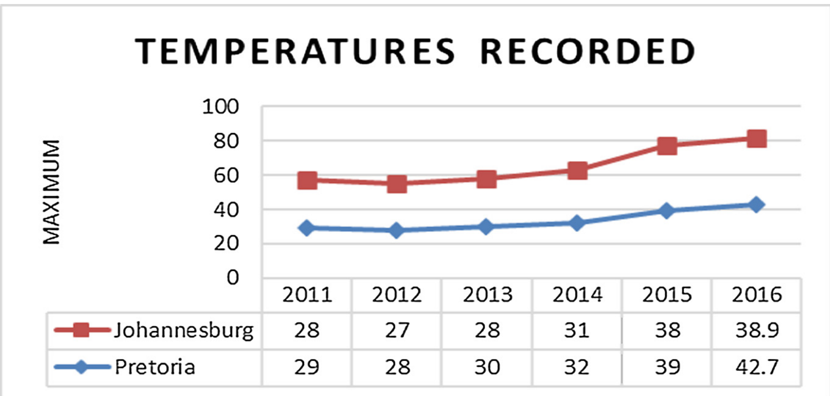

Fig. 3. Max. Temp. in Pretoria vs Johannesburg [9, 15, 16]

The Annual 2015/2016 Weather Services has predicted future trends in temperatures with them expected to rise drastically over the next four to five decades, with the trend continuing into the following decades and that will also mean changes an average seasonal temperature (Table 3) [16].

Table 3. Increase in average maximum day-time temperature

Season	Near future 2046–2065[2] (low/Hi[3])	Far future 2081–2100[2] (low/Hi[3])
Summer	+2.1 °C (1.6/2.7 °C)	+3.8 °C (2.9/5.1 °C)
Autumn	+2.3 °C (1.7/2.8 °C)	+4.5 °C (3.4/5.6 °C)
Winter	+2.3 °C (1.8/2.8 °C)	+4.5 °C (3.7/5.0 °C)
Spring	+2.6 °C (2.2/3.0 °C)	+5.0 °C (3.7/5.9 °C)
Annual	+2.3 °C (1.8/2.8 °C)	+4.4 °C (3.4/5.4 °C)

However, with the already existing shortage of water in South Africa, the increase in temperature will mean an increase in demand for water for air-conditioning heat rejection, irrigation, swimming pool top-up leading to a major strain on the water supply. Increase in temperature will also have an effect on the vegetation. In the South African county, a heatwave is considered to be when the temperatures are fire degrees higher than the highest recorded temperature [16]. The temperatures have an impact on the whole ecosystem and training for everyone is needed.

4.5 Wet Bulb Globe Temperature (WBGT)

Through the factors that were associated with the increase in heat stress, calculation and research done in the past, heat indicators and protective guidelines were created by the US Army many decades ago to help protect the workers from heat exposure using different entities. The WBGT takes the temperature, radiant temperature, humidity and air movement, and the basis for time limitations of work in different heat exposure standard heat exposure (heat stress and thermal stress index and predicted 4 h sweat rate) [9]. The concept is used to measure and estimate the effect of temperature, humidity, and solar radiation on human.

WBGT is a combination of three local climate meausrements; natural wet bulb temperature. The WBGT Formular provides a beginning point for making judgement and help with risk assessment management plan. The formular must be adjusted for clothing, work demands, and the workers's acclimatization state [2].

5 Lesson Learned from the Findings

Heat stress is a major impact to not only for outdoor workers but also indoors. Whether some construction companies may ignore the importance of having a heat preventive plan focused on each project based on where the site is situated, heat stress results may have an impact on any future programs that the company will have to be part of. Health and Safety motions should always be taken seriously as it involves all personnel that are involved in the company.

6 Conclusion

The aim of the research was to theoretically assess the impact that heat stress has on the construction industry and the changes in weather temperatures over the years. The reviewed literature informed that the greatest change and impact that has been experienced over time, is the change in temperatures that has an impact on construction projects, such as the – production, commercial, quality, and the health and safety departments. Heat stress has been taken lightly in the past and due to the increase in temperatures in the past years and its predictions in the South African. It is therefore recommended that management and all stakeholders of construction projects have to start taking precautions and creating a plan that will assist onsite workers and other personnels with the meance caused by heat stroke and heat stress in order to adeqautely protect construction works from the harmful effect of the sun. Construction is a profession that is continuously evolving with engineers always trying to find new ways to create new designs and that may also play a role in the Greenhouse gases that will later impact the increase the temperatures.

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Characteristics of Cutting Performance for Japanese Sewing Scissors Made by the "So-hizukuri" Forging Process

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Abstract. Scissors are commonly known as a tool that has been used since long ago. The X-shaped scissors currently commonly used in Japan date back to 160 years ago when Admiral Perry arrived in Uraga. Since that time Yakichi Yoshida, known as the originator of Japanese scissors, has made many reforms leading scissors to their present shape. His method is called "So-hizukuri", and today there is a very small number of artisans left who have inherited the So-hizukuri method. In previous research our research group investigated why sewing scissors made with the So-hizukuri method have a sharp cutting edge. The results showed that the surface of So-hizukuri method scissors blades have a curved surface with a difference of about 0–150 μm applied. It was suggested that the curved surface being applied causes the cutting power of the scissors to be focused onto the point where the two blades overlap when cutting cloth, leading to a sharp cutting edge. We also confirmed that when the two blades overlap the parts of the other blades are separated. In this research, we intend to extract characteristics of the So-hizukuri scissors with sharp cutting edges which were not clarified in the previous research. We had a tailor who is a specialist in handling scissors use new So-hizukuri sewing scissors and So-hizukuri sewing scissors which have been used for more than 20 years and which were both made by the same scissors artisan, and examined what effect this had on the operations of the person handling the scissors when cutting cloth. We had the person cut the same cloth under the same conditions using the same method, and recorded the process with a high-speed camera for analysis. The results showed a clear difference in the movements of the tailor when handling the So-hizukuri scissors and the cheap scissors, but no significant difference between the new So-hizukuri scissors and the So-hizukuri scissors which had been used for more than 20 years. We considered the reasons for this difference including an interview with the tailor, which we will report here.

Keywords: Scissors · Cutting · Motion analysis · Acceleration

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1 Introduction

The X-shaped scissors currently commonly used in Japan are said to have been brought to Japan 160 years ago at the end of the Edo period when Admiral Perry's black ships arrived in Uraga. Among these, the scissors called "sewing scissors" can be said to have undergone changes to make them uniquely Japanese. The scissors brought to Japan at that time were intended to cut thick felt, etc., and they were large with a total length of about 330–360 mm and a weight of about 1 kg, which made them ill-suited for small Japanese hands. It was Yayoshi Yoshida who improved those scissors through repeated trial and error to create the shape of modern scissors. The original forging process he created, called "So-hizukuri", is a method whose techniques were passed down from parents to children and included some implicit aspects [1]. However, in today's era of mass consumption there are currently only a few artisans who possess the skills for "So-hizukuri".

In previous research this research group investigated the secrets of the sharp blade possessed by So-hizukuri sewing scissors. The reason X-shaped scissors are able to cut cloth in the first place is that the two blades of the scissors are created to with a miniscule width between them so they are almost touching. It was shown that So-hizukuri scissors are created to make this contact point as small as possible to cause stress concentration at the cutting point between the two scissor blades. When measuring the two blades of scissors created with the So-hizukuri method using a three-dimensional measuring device, we made the origin point on the overall blade on the inner size 0 and found that a 15 μm curved surface was applied at the deepest point. Due to the application of this curved surface on the inner side of the two scissor blades, when cutting cloth the breaking point where the two blades overlap becomes a pinpoint, and the structure of the scissors focuses the power of the scissors onto this pinpoint. This structure seemed to be the reason that So-hizukuri scissors have a sharp cutting edge [2].

Next our research group investigated the effects of the sharp cutting edge of So-hizukuri sewing scissors on the people handling the scissors when cutting cloth. We had a tailor who is a specialist in handling scissors cut cloth with commonly available cheap scissors from a retail store and So-hizukuri sewing scissors created by an artisan possessing the skills of the So-hizukuri method, and recorded this process with a high-speed camera. We also used an optical microscope to view the cut surfaces. We analyzed the video from the high-speed camera and compared the scissor blade positions, opening and closing speeds, and time to cut the cloth, which revealed significant differences in the movements of the tailor handling the two scissors. It would not be an exaggeration to call the tailor a specialist at cutting cloth. Precisely because he is a specialist, even when cutting using scissors with a poor cutting edge, he instantly adjusts his movements to attempt to cut the cloth. We can say that because the cheap scissors had a poor cutting edge and due to the tailor's attempt to successfully cut the cloth, he was forced to naturally use his judgment to change his movements. This resulted in a significant difference between the motions of the tailor when using these two scissors. Furthermore, when observing cross-sections of the cloth cut with the respective scissors using an optical microscope, we found that the surface cut with the cheap scissors was flattened as if it had been crushed, and the length of the fibers was also uneven. On the other hand, with the So-hizukuri sewing scissors there were no flattened places on the fibers of the cut surface, and the length of the fibers were also uniform where cut. The reason for these results seem to be that the cheap scissors with the poor cutting edge are forcibly crushing and detaching the fibers rather than actually cutting them. We concluded that these differences in cutting edges would impact the efficiency of the tailor's work as well as the final product [3].

And so in this research we will analyze and compare the movements of a tailor cutting cloth using new So-hizukuri sewing scissors and So-hizukuri sewing scissors which have been used for over 20 years, both crafted by the same scissors artisan, in order to further clarify the characteristics of So-hizukuri scissors. Generally, tools and instruments deteriorate after many years of use. We will examine what kind of differences there are in the movements of a tailor cutting the same cloth in the same direction and under the same conditions but using new scissors and those used for over 20 years, and whether there are differences or not, what kind of sensation the tailor experienced when using them via an interview. And through this research we hope to extract new characteristics of So-hizukuri scissors which were not clarified in the previous research.

2 Methods

2.1 Test Subject

A tailor with more than 45 years of experience in high-end apparel.

2.2 Procedures

We had a tailor cut cloth made of synthetic fibers using So-hizukuri scissors created newly for this research (Fig. 1), So-hizukuri scissors which the tailor has possessed himself for more than 20 years which were made by the same artisan as the aforementioned new scissors (Fig. 2), and sewing scissors purchased at a 100 yen retail store (Fig. 3). Hereinafter these will be referred to as brand-new so-hizukuri scissors, over 20 years so-hizukuri scissors, and 100-yen scissors, respectively.

Fig. 1. Brand-new so-hizukuri scissors.

Fig. 2. Over 20 years so-hizukuri scissors.

Fig. 3. 100-yen scissors.

For the direction of cutting the cloth we used three categories: “vertical direction”, where the tailor cut mainly the crosswise threads which weave the cloth; “horizontal direction”, where the tailor cut mainly the warp threads which weave the cloth; and “bias”. In this research we analyzed the motions cutting in the “bias” direction. We had the tailor cut the cloth using the workbench which he uses in his everyday work.

A high-speed camera, Photron© FASTCAM SA4, was set up in front of the workstation. Markings were made on two points along the blade: Point 1, about a third of the way below the tip of the blade, and Point 2, at the base by the screw. The cutting process was filmed in its entirety and analyzed. Another marking was made on the fabric to indicate the end so that each cutting test would cover the same distance. The motions of the scissors through Points 1 and 2 recorded on the high-speed video camera were entered in as data on the x axis, y axis, xy synthesis, then calculated the marker points, speed and acceleration (Fig. 4).

After the examination, we interviewed the tailor to ask him how he felt when handling the respective scissors regarding their ease and difficulty of cutting, etc.

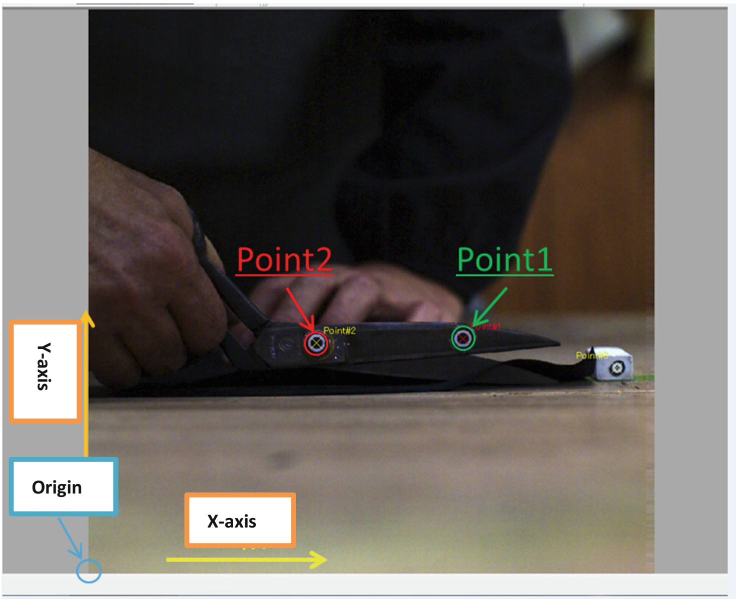

Fig. 4. The position of the marks.

3 Result and Discussion

Figure 5 shows the Point 1 location of brand-new so-hizukuri scissors on the X-axis, Fig. 6 shows the Point 1 location of over 20 years so-hizukuri scissors on the X-axis and Fig. 7 shows the Point 1 location of 100-yen scissors on the X-axis.

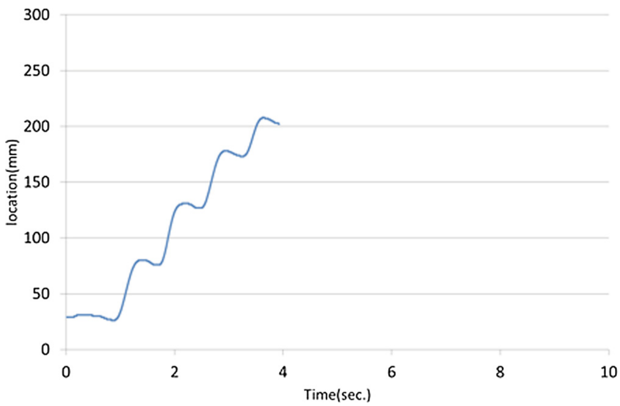

Fig. 5. The Point 1 location of brand-new so-hizukuri scissors on the X-axis.

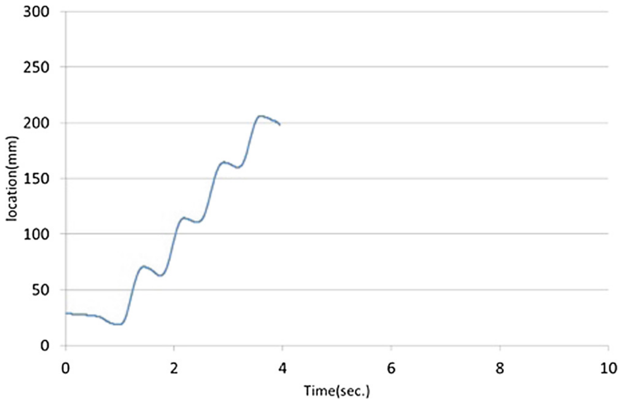

Fig. 6. The Point 1 location of over20years so-hizukuri scissors on the X-axis.

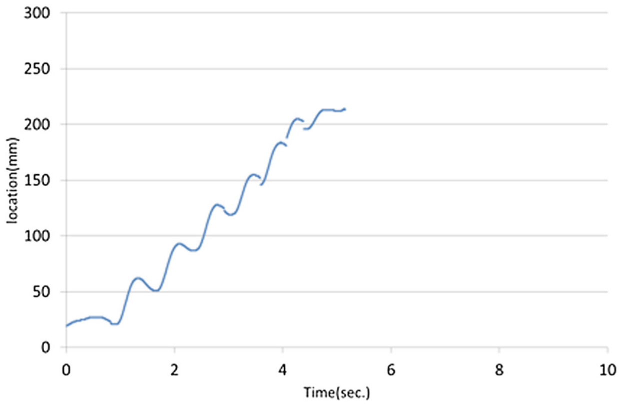

Fig. 7. The Point 1 location of 100-yen scissors on the X-axis.

Figure 8 shows the Point 1 location of brand-new so-hizukuri scissors on the Y-axis, Fig. 9 shows the Point 1 location of over 20 years so-hizukuri scissors on the Y-axis and Fig. 10 shows the Point 1 location of 100-yen scissors on the Y-axis.

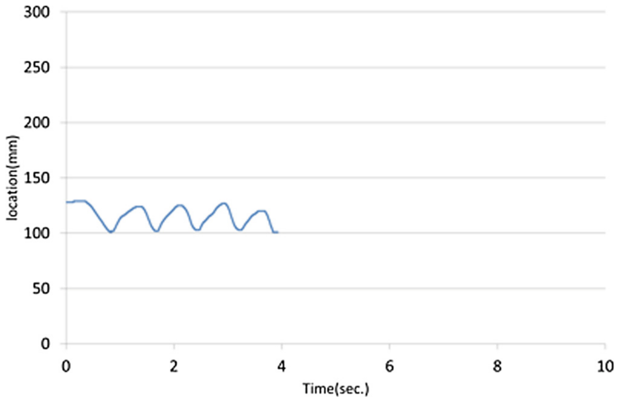

Fig. 8. The Point 1 location of brand-new so-hizukuri scissors on the Y-axis.

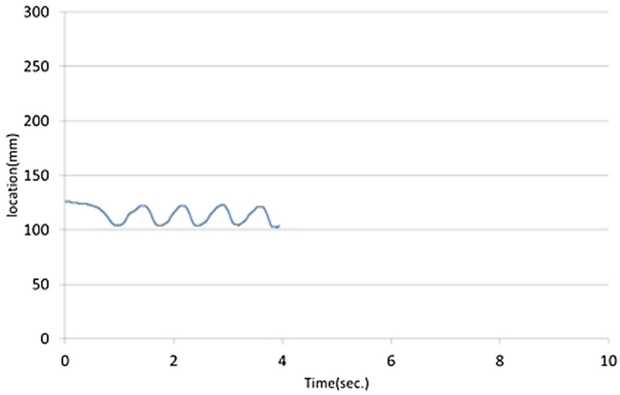

Fig. 9. The Point 1 location of over20years so-hizukuri scissors on the Y-axis.

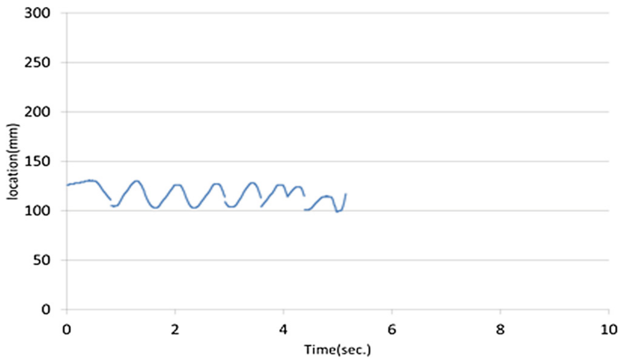

Fig. 10. The Point 1 location of 100-yen scissors on the Y-axis.

Figure 11 shows the Point 1 velocity of brand-new so-hizukuri scissors on the X-axis, Fig. 12 shows the Point 1 velocity of over 20 years so-hizukuri scissors on the X-axis and Fig. 13 shows the Point 1 velocity of 100-yen scissors on the X-axis.

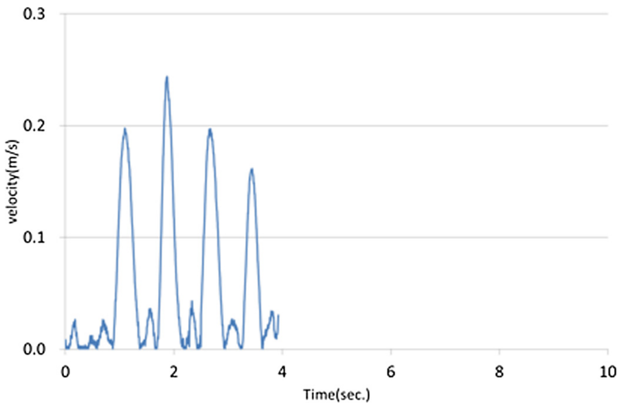

Fig. 11. The Point 1 velocity of brand-new so-hizukuri scissors on the X-axis.

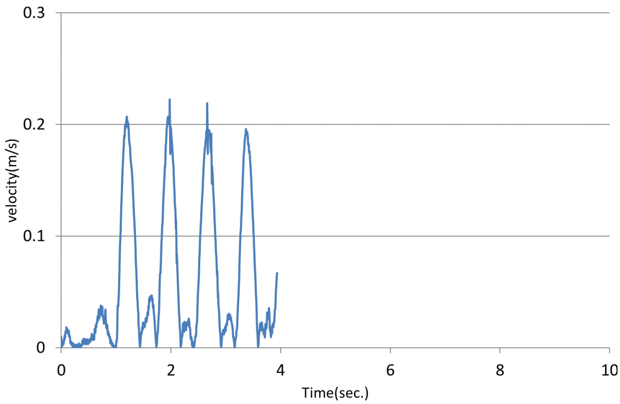

Fig. 12. The Point 1 velocity of over 20 years so-hizukuri scissors on the X-axis.

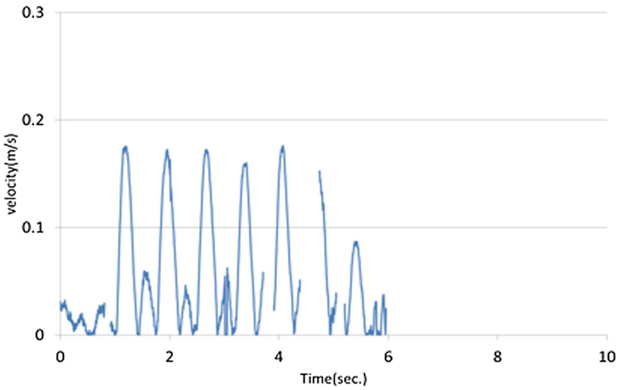

Fig. 13. The Point 1 velocity of 100-yen scissors on the X-axis.

Figure 14 shows the Point 1 velocity of brand-new so-hizukuri scissors on the Y-axis, Fig. 15 shows the Point 1 velocity of over 20 years so-hizukuri scissors on the Y-axis and Fig. 16 shows the Point 1 velocity of 100-yen scissors on the Y-axis.

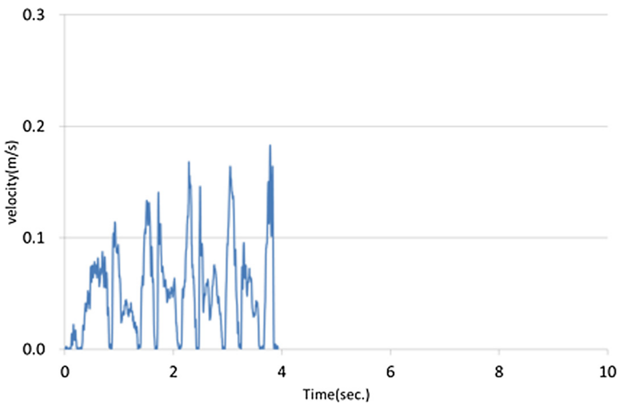

Fig. 14. The Point 1 velocity of brand-new so-hizukuri scissors on the Y-axis.

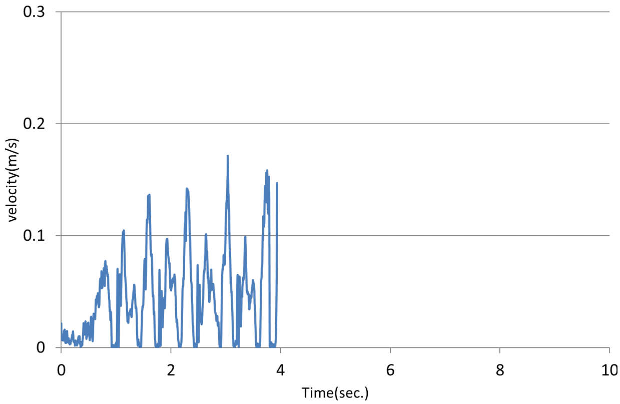

Fig. 15. The Point 1 velocity of over 20 years so-hizukuri scissors on the Y-axis.

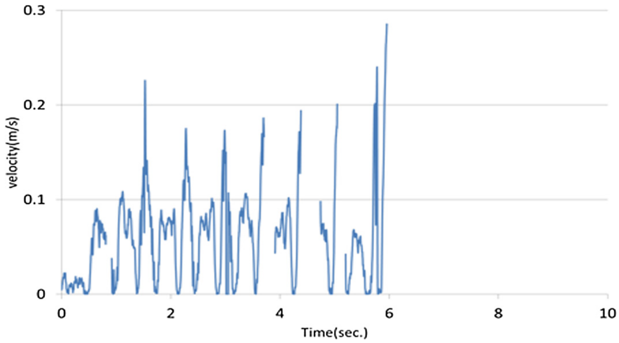

Fig. 16. The Point 1 velocity of 100-yen scissors on the Y-axis.

The above results are all when cutting the synthetic fabric in the bias direction. The results of this research showed that even when a tailor who specializes in using scissors is cutting the same cloth under the same conditions and in the same direction, there will be differences in the blade opening and closing speed and number of openings as well as the cutting time depending on the scissors he uses. Conversely the results also showed that despite using different scissors the movements of the tailor were almost unchanged between the different scissors. We additionally conducted an interview with the tailor when considering these results.

Looking at all the data from Figs. 5 to 16, we see that brand-new so-hizukuri scissors and over 20 years so-hizukuri scissors both take about 4 s for point1 to move. On the other hand, we see that the 100-yen scissors take 5.4 s for point1 to move. This means that both the brand-new so-hizukuri scissors and over 20 years so-hizukuri scissors take about 4 s from starting to cut the cloth until finishing the cut, while the 100-yen scissors take 5.4 s to cut the cloth.

Looking at Figs. 9, 10, and 11, in the case of brand-new so-hizukuri scissors, over 20 years so-hizukuri scissors and 100-yen scissors, the Point1 mark moves in the Y axis direction at an amplitude of almost the same interval in the range of about 40 mm from starting to cut until finishing cutting. This means that when cutting the cloth the scissor blades opening and closing is repeating at a width of about 40 mm each time. The opening and closing distance of the scissor blades is almost the same for all three pairs of scissors, but the brand-new so-hizukuri scissors and over 20 years so-hizukuri scissors open and close 5 times, as opposed to 8 times for the 100-yen scissors.

In this research, the same type of cloth is continuously cut under the same conditions and for the same distance. Looking at the movement of Point1's progression in the X axis direction in Figs. 5, 6, and 7, the brand-new so-hizukuri scissors and over 20 years so-hizukuri scissors display almost the same movement. For both scissors Point1 proceeds about 50 mm in about 0.8 s, recedes once about 7 mm, and then within the next second proceeds about 50 mm and then back again about 7 mm, routinely repeating the same movement. This means that the brand-new so-hizukuri scissors and over 20 years so-hizukuri scissors both open and close their blades about one time per second, cut about 50 mm of cloth, and then the scissors are withdrawn about 7 mm in the opposite direction from the direction the cloth is being cut in before once again cutting the next approximately 50 mm and repeating this motion. The 100-yen scissors cuts forward about 50 mm in about 0.68 s during the first cut, which is the same as the other two scissors. However, with each cut the distance cut decreases, namely to about 40 mm the second time and 30 mm the thied time (Fig. 7). Furthermore, it can be said that after making one cut in the cloth the brand-new so-hizukuri scissors and over 20 years so-hizukuri scissors are both moved in the opposite direction of the cloth cutting with the same motion, but we see that while this receding distance is about 7 mm with the brand-new so-hizukuri scissors and over 20 years so-hizukuri scissors, with the 100-yen scissors it is about 15 mm. Why is the movement different in this way? According to the interview with the tailor, no matter what type of cloth he is cutting, after proceeding with one cut he draws the scissors back once before entering into the next cut. This draw-back distance can be called an implicit motion of the tailor, but precisely when the cutting edge of the scissors is poor the tailor will draw the scissors back even further. When the cutting edge of the scissors is poor, the cloth cannot be cut in spite of pressing the scissors in the cutting direction, which means that the cloth is simply pressed in the direction by the scissors and not cut, therefore the tailor adjusts by drawing the scissors back to be able to cut.

Looking at the velocity in the Y direction in Figs. 14, 15, and 16, the brand-new so-hizukuri scissors repeat a speed from 0 m/s reaching its peak at about 0.1 m/s, and a speed from 0 m/s reaching its peak at about 0.17 m/s. The over 20 years so-hizukuri scissors repeat a speed from 0 m/s reaching its peak at about 0.1 m/s, and a speed from 0 m/s reaching its peak at about 0.15 m/s. The 100-yen scissors repeat a speed from 0 m/s reaching its peak at about 0.1 m/s, and a speed from 0 m/s reaching its peak at about 0.2 m/s.

From this it can be said that the time for all three of the scissors' blades to grasp the cloth and cut forward when cutting the cloth is about 0.1 m/s. On the other hand, the speed of opening the scissor blades before making the next cut can be said to be faster for the 100-yen scissors than with the brand-new so-hizukuri scissors and over 20 years so-hizukuri scissors. According to the interview with the tailor, when using scissors with a poor cutting edge he increases the number of times opening and closing the blade to cut the same distance but reduces the distance cut each time, cutting by degrees. Looking at the movement of Point1's progression in the X axis direction in Figs. 5, 6, and 7 and comparing the brand-new so-hizukuri scissors and over 20 years so-hizukuri scissors with the 100-yen scissors, we see that the 100-yen scissors are cutting the cloth in smaller increments. This can be said to indicate that different movements appear when using the 100-yen scissors than with the brand-new so-hizukuri scissors and over 20 years so-hizukuri scissors.

The above facts show that while there are slight differences, the movements of the tailor using brand-new so-hizukuri scissors and over 20 years so-hizukuri scissors are almost the same in terms of cloth cutting time, number of openings and closings of the scissor blades, opening and closing speed, and distance withdrawn before making the next cut. This can be said to indicate that with both pairs of So-hizukuri scissors being made by the same artisan, even though one pair is new and one pair has been used for 20 years, this has no effect on the cutting movements of a tailor. The reason for this can surely be said to be that despite 20 years of use having passed the cutting edge has been maintained without dulling. According to the interview with the tailor, he performed maintenance on the scissors about one time per year. He also stated that good scissors can be re-sharpened when they have stopped cutting well due to use to return their cutting edge to the same as when they were new. What are commonly referred to as bad scissors will cut when they are new but quickly lose their cutting edge and cannot be re-sharpened to return their cutting edge, with even worse scissors being impossible to re-sharpen at all.

An analysis of the movements of a tailor using new and old So-hizukuri scissors created by the same artisan showed that he could cut the cloth with almost the same movements using both scissors, but there were slight differences in the details. The tailor explains this saying that because his own hands are so used to the over 20 years so-hizukuri scissors, this made them feel easier to use. It can be said that while there is no difference in the cutting edge, after using the scissors for many long years they mature to fit his own movements, and slight differences in the tailor's movements appear.

4 Conclusion

Scissors are tools generally created to cut paper and cloth, but as they are called "scissors that can cut" and "scissors that cannot cut" we in this research group believed that in the aspects other than the simple purpose of scissors they were not equal and so we began this research. And so we focused on the sewing scissors which have evolved in Japan, first studying the secrets of the sharp cutting edge possessed by sewing scissors which are made with the ancient method called So-hizukuri. Next we had a tailor who is a specialist in handling scissors cut cloth multiple times using So-hizukuri scissors and cheap scissors and analyzed his movements to find differences in the movements and also learn that the way the So-hizukuri scissors and cheap scissors have cut a cross-section of the cloth is also different.

It is generally known that tools and instruments deteriorate after many years of use. In this research we had a tailor use cheap scissors, new So-hizukuri scissors and So-hizukuri scissors which had been used for more than 20 years to cut the same cloth in the same direction and under the same conditions, clarifying that whether using the new or old So-hizukuri scissors the movements of the tailor were essentially the same. Furthermore, we learned that there are distinct difference in the tailor's cutting movements when using these 2 scissors compared to cheap scissors. The above facts confirmed that through maintenance it is possible for So-hizukuri scissors to maintain the same cutting edge as new scissors even after many years of use. No matter how good the cutting edge of scissors are, the fact that the cutting edge will worsen with use is the same for all scissors. However, it cannot be said that all scissors can be re-sharpened to restore their cutting edge when it has become poor. There are also some scissors which cannot be re-sharpened at all but which must be discarded after use. As was also stated in the interview with the tailor, it goes without saying that not only does a specialist in using scissors increase his work efficiency by using scissors which his hands are used to, considering the impact on the quality of the finished product scissors which can be re-sharpened to restore their cutting edge even after 20 years of use such as the scissors used in this study are necessary.

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Eye Movement Analysis of Japanese Sewing Scissors Craftsman

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Abstract. The purpose of this study is to elucidate the skill of a blacksmith who has an ability to produce a pair of scissors whose two blades accurately comes across in the length, width and angle of each blade, even though they were produced separately. The processing method this scissor artisan employs is known as "So-hizukuri" (total forging process). The elucidation was conducted through observing the line of sight of the artisan using an eye movement analysis camera during his forging process. There are four main stages in the So-hizukuri process, and each stage involves several steps. In this study, we asked the scissor artisan to wear an eye movement analysis camera while engaging with the "*Namatogi*" (grinding before quenching) step in the "rough finishing before quenching" stage, which is the second in the four main stages, and observed his eye movements. We viewed the video recorded by the eye camera, and studied which parts of the blades he focused on, and the amount of time he focused on each part, when the artisan was comparing the two blades by laying one blade on top of the other. As a result, it was clarified that the artisan works on each of the left and the right blade alternately and gradually at every step toward the final stage, as the left and right blades of the scissors come across accurately when the scissors are completed. At any point in the process, he did not focus on forging one blade intensively, use a measuring instrument to measure the length of the blades, or use one of the blades as a standard to match the other blade.

Keywords: Scissors · Process · Eye movement

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1 Introduction

"Artisanal Skill" is considered to be the highest form of tacit knowledge. Philosopher, Michael Polanyi who proposed the concept of tacit knowledge said; "We can know more than we can tell" [1].

Even though many artisans possess astonishing skills, they cannot verbalize the abilities they possess. Our study group is conducting research on how to transform the tacit knowledge of artisans into explicit knowledge. As one of the research theme, we are researching the tacit knowledge hidden behind scissors production skill of scissors makers. A pair of scissors is a tool that is familiar to everyone from a child to adult. It is widely used in both domestic and work situations. It is so closely associated with our daily life, so we rarely think about their existence. However, its history and the production process are surprisingly not widely known. Most people probably think that scissors are produced in iron factory using a "scissors making machine". In fact, there is a uniquely Japanese scissors production process called So-hizukuri processing method. Until the 19th century, only U-shaped scissors existed in Japan. So-hizukuri is the process developed by Yakichi Yoshida, who is called as the father of Japanese sewing scissors making, after X-shaped scissors that is the mainstream of the current common scissors, were introduced to Japan. He developed this process through many trials and errors in order to produce scissors that fit the hand of Japanese people. Its production method is forging that heats soft iron and forms the desired shape through hammering; instead of casting that pours melted iron into a mold [2].

The technique of So-hizukuri was passed onto many people. When one studies the lineage of scissors maker originating from Yakichi Yoshida, it can be said that it expanding to 23 lines of descendants. The So-hizukuri technique was passed on through what is called as "from a Master to Disciples" process. It is said that there have been no textbooks or systematic explanations whatsoever in the way a master teaches his disciples. The disciples commonly describe the process of their learning as "the master taught me the skill through his fist" or "I stole the skill from the master by watching and learning". Therefore, it is almost impossible to ask the artisans to reminisce their exact leaning period and verbally describe how exactly they acquired their skills. Considering this situation, it can be said that the skills that scissor artisans have acquired are tacit knowledge. The lineages of artisans with So-hizukuri skill are gradually disappearing, and there are only a small number of artisans left today who possess this skill. In this study, we verified the skill of one of the remaining artisans who were trained in So-hizukuri process through the eye of science, and at-tempted to transform his tacit knowledge into explicit knowledge.

So-hizukuri process involves four main stages, and there are various steps in each stage. In this study, we focused on one step within in the second, "rough finish be-fore quenching", stage, namely the step to grind the scissors after forging using a grinder for rough finish. This step is commonly known as "*Namatogi*", or grinding before quenching. A pair of scissors immediately after forging does not have metallic sheen, the surfaces of the blades are uneven, and the individual parts of the blade, such as the joint area, the blade inset and the back, are not clearly defined. By the time the second stage of its production is completed, the left and the right blades come across almost perfectly in their shapes, the scissors start to have metallic sheen, the blades are sharp and they are extremely close to the final scissors form.

A common conception for the production of an object with left and right parts that are identical in size, combined and function together, it would be to decide the length first using a measuring instrument, such as a ruler, and produce both parts by matching them to this length. Alternatively, produce one part first and then make the other part following the measurement of the first, completed the other part as to be identical. Based on this general theory, we observed the process the artisan for producing both scissors blades separately. We clarified where the artisan looks and matches the measurements of both blades in order for the two blades to have an identical measurement by the eye camera observation. We requested the artisan to wear the eye camera while working for observing his line of sight. After the data collection, we showed the video recorded by the eye camera to the artisan and conducted an interview with him, and requested him to express why he focused on certain parts during the production, and their significance. We hope to record at least a part of the disappearing craftsmanship to the posterity through this study.

2 Methods

2.1 Participant

A scissor maker with more than 60 years experience in sewing scissors making with the skill of So-hizukuri processing method.

2.2 Procedures

The artisan with So-hizukuri skill was requested to produce a pair of sewing scissors according to the So-hizukuri processing method. The production process was filmed using an eye camera.

2.3 Recording Procedures

The eye movement was measured by the eye camera system (Tobii Technology K.K.). The sampling rate was set for 60 Hz.

3 Results

We verified how the artisan measures the size of the left and the right blades during the *Namatogi* step in order to make the size of the two blades identical. Moreover, we verified whether he compares the left and right blades in order to check their length and width. Firure1 shows the part names of the scissors. Table 1 shows chronologically the time spent when the artisan put the both left and right blades together during the *Namatogi* step. Table 2 shows chronologically the part of the blades he focused on when he checked the alignment of the left and right blades by putting one blade on the other during the *Namatogi* step.

Table 1. The time spent when the artisan put the both left and right blades together during the Namatogi step

Time indicated in the video	Frequency	Part being focused on while putting one blade over the other	Time spent on looking
0:36	1	Laid one blade on the other	1 s
0:41	2	He seems to focus around the *komi*	1 s
0:49	3	His focus moved to the edge of the blades	1 s
1:00	4	Focusing on the screw. Then on the edge	2 s for looking at two parts
1:04	5	Focused on the *mune* and then the edge	1 s for looking at two parts
6:59	6	From the right side of the screw to the thick part of the screw	2 s
7:31	7	Observe around the screw and at the same part from slightly to the side. Then finally compare the two blades by placing them next to each other	Looking until 7:39 (8 s). 1 s looking when the two blades are next to each other
7:54	8	The lowest part toward the blade from the screw, then the same part from the side	1 s for looking at two parts
8:26	9	From both sides. Flipped a few times and focused on the same part	Looking until 8:31 (5 s)
13:30	10	Around the *komi* on the thumb side near where the screw goes in, from the side. Then the left side toward the sloping part after the screw	3 s in total. (1 s for each part).
13:40	11	Same as the above	2 s
13:47	12 (End)	Completion of the *Namatogi* step	

From the moment the artisan sat in front of the grinder to start *Namatogi* work and the completion of the work, it took 13 min and 11 s for the artisan to complete the *Namatogi* step. During this time, he did not use a measuring instrument such as a ruler even once. The number of time he made the movement to match the two blades were twelve times during 13 min and 11 s. We counted from the moment he laid one blade on the other to subsequently separated them as one time. During the movements of putting together and separating the blades, the artisan sometimes focused exclusively on one spot of the scissors, but he sometimes focused on several spots of the scissors. The total time of these movements was 28 s. The time he spent on each movement was a few seconds (Fig. 1).

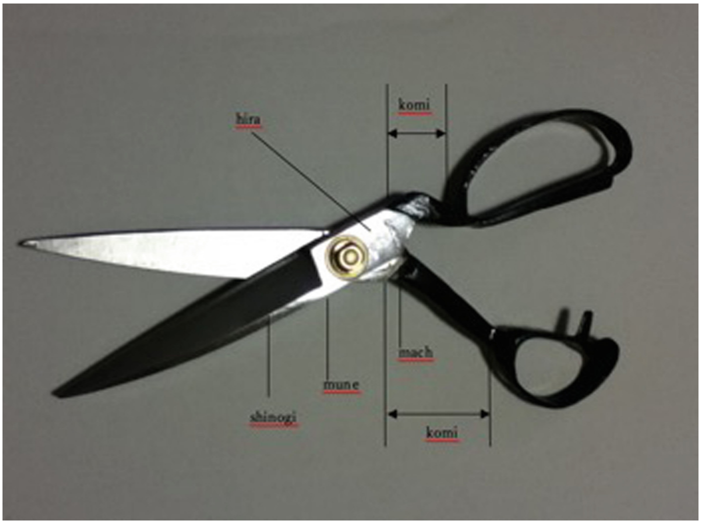


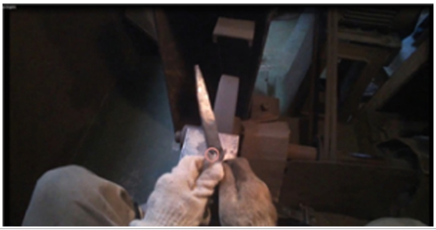
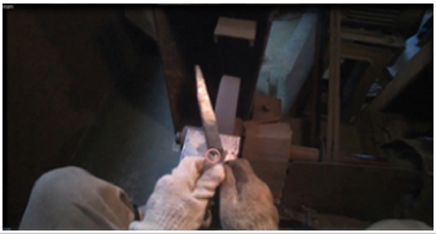
Fig. 1. The part names of the scissors

Table 3 shows the result of study to present how the artisan proceed the left and the right blades of scissors through the *Namatogi* step. The total time used for the *Namatogi* step is 13 min and 11 s. He grinded the blade to be gripped by other fingers (index and middle fingers) by 11 times and spent 355 s in total. And he grinded the blade to be gripped by a thumb by 9 times and spent 338 s in total.

4 Discussion

The interview with the artisan is combined with the discussion of the result of research on the *Namatogi* step. As mentioned above, *Namatogi* is one of the steps within the second main stage of So-hizukuri process, namely the “rough finish before quenching” stage that follows the “forging” stage. The two scissors blades after the forging stage has the iron color without sheen, and their surfaces are uneven. Also, the individual parts of the blade, such as the joint area, the blade inset and the back, are not clearly defined. However, when the *Namatogi* step is completed, the shape of the scissors is almost like the finished shape, with only the third, “quenching”, stage and the fourth, “polishing, adjustment and finishing”, stage remaining. The artisan completed this step in 13 min and 11 s. When the step was over, the total length of the scissors, the length and width of each blade and the length and width of each joint area matched accurately. Moreover, the *komi* and *machi* of each blade came across in the same angle. Generally, it is appropriate to use a measuring devices, in order for the separate individual blade to match and come across accurately in all parts. However, the artisan did not use any measuring devices in any point during the production process. In order to achieve two blades in the same size, the alternative method can be considered to produce one blade first, and then adjust the size and width of the other blade. However, this study clarified

Table 2. The part of the blades he focused on when he checked the alignment of the left and right blades by putting one blade on the other during the Namatogi step

Frequency of comparison	Time	The view of the artisan while the two blades are being overlapped
First time	0:36	
Second time	0:41	
Third time	0:50	
	0:50	
Fourth time	1:00	

(*continued*)

Table 2. (*continued*)

Frequency of comparison	Time	The view of the artisan while the two blades are being overlapped
	1:01	
Fifth time	1:04	
	1:05	
Sixth time	6:59	
	6:59	

(*continued*)

Table 2. (*continued*)

Frequency of comparison	Time	The view of the artisan while the two blades are being overlapped
Seventh time	7:31	
	7:34	
	7:36	
	7:39	
Eighth time	7:55	

(*continued*)

Table 2. (*continued*)

Frequency of comparison	Time	The view of the artisan while the two blades are being overlapped
Ninth time	8:26	
	8:31	
	8:31	
Tenth time	13:30	
	13:31	

(*continued*)

Table 2. (*continued*)

Frequency of comparison	Time	The view of the artisan while the two blades are being overlapped
	13:31	
	13:32	
Eleventh time	13:40	
	13:41	
End	13:47	

that during the 13 min and 11 s *Namatogi* step, the artisan compared the two blades only for 28 s. Additionally, the eye camera verified that the amount of time the artisan spent on focusing on checking the alignment of the left and right blades was 1 s or less

Table 3. The result of study to present how the artisan proceed the left and the right blades of scissors through the *Namatogi* step

Time indicated in the video	Retention time (s)/blade being polished	
	Lower fingers blade	Thumb blade
0:37–0:40	3 s	
0:41–0:49		8 s
0:51–0:55	4 s	
0:55–0:58		3 s
1:01–1:04	3 s	
1:09–1:18	9 s	
1:19–1:34		15 s
1:40–2:45	65 s	
2:49–3:50		61 s
3:51–4:12	21 s	
4:14–4:39		25 s
5:00–6:56	116 s	
7:01–7:30		29 s
7:40–7:54	14 s	
7:57–8:25		28 s
8:32–9:03		31 s
9:04–10:56	112 s	
11:09–13:27		138 s
13:34–13:40	6 s	
13:44–13:46	2 s	
Total	355 s	338 s

each time. It is inconceivable to check the length or width of one blade, decide where to grind and identify imperfect parts in order to match the size of the other blade in such short time. What can be inferred from the eye camera footage is that when the artisan is comparing the two blades, he is not verifying how much one blade needs to be polished in order for its width and length to match those of the other blade. Instead, the shapes of both blades already almost fit when put together, and it appeared that he was only checking by sight in order to make slight adjustments. For this purpose, it is possible that 1 or 2 s of comparison was sufficient.

How is it possible that the artisan could produce a pair of scissors whose left and right blades can grip and cut fabrics without even a smallest error, without using any measuring instrument and moreover when he compared the two blades by laying one on the other in order to match their width and length only for a few seconds. According to the interview with the artisan, he adjusts the blades with assuming the final alignment to match in the end, even at the point of the forging process. Therefore, the two blades gradually come to match without requiring adjustment during the *Namatogi* step, and they match perfectly in the end. This comment can be understood by the fact that the artisan grinded the left and right blades alternately during the *Namatogi* step, 11 times for the blade gripped by lower fingers and 9 times for the blade gripped by a thumb accurately, instead of focusing on the production of one blade.

Moreover, even though it does not appear that he was grinding the two blade alter-natively in regular pace, it was in fact clarified that the total polishing time of the blade gripped by lower fingers was 355 s and the total grinding time for the blade gripped by a thumb was 338 s. Therefore, he was grinding the left and the right blade alternatively for almost the same amount of time, and it can be said that his comment that the two blades are gradually being matched is proven.

However, the remaining problem is what the artisan expressed as “the right way”. We are yet to extract this expression as a concrete technique. It is possible that the quality and amount of skill that is contained in this “right way” could be immeasurable. This is a typical example of tacit knowledge. In this study, the footage from the eye camera was shown to the artisan during the interview. Until the video was shown, the artisan himself could not answer how often the two scissors blades are compared and how long he spends on the comparison at all. This means that the artisan himself is unable to verbalize his own process.

5 Conclusion

In this study, the focus was on the *Namatogi* step, which is one of the steps within in the second main stage of the So-hizukuri processing method. We attached an eye camera to the artisan and researched his line of sight in order to elucidate the skill to produce two blades that perfectly come across without any smallest error, which is characteristic to his scissors. As a conclusion, it was clarified that the artisan did not use a measuring instrument even once, nor did he use one blade as a standard for the other blade to be matched. Instead, it was clarified that he employed a method to gradually finish the scissors by working on the two blades alternately, resulting in the left and right blades accurately coming across at the completion of the process.

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Investigation on Effect of Mattress Hardness on Sleep Comfort of Middle-Aged and Old Women

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Abstract. By investigating the effect on mattresses with different hardness on sleep comfort of the middle-aged and old women, the paper provides reference and basis for designing and purchasing a mattress for the middle-aged and old women. In the experiment, 46 middle-aged and old women aged 40–65 years finish subjective user's experience evaluation and a body pressure distribution test. The comprehensive research results indicate that: 1. Mattress hardness has a significant impact on the mattress comfort; 2. The objective body pressure distribution test result is consistent with the subjective user`s experience and evaluation result; 3. The middle-aged and old women generally prefer mattress with moderate and higher hardness value; 4. Shoulder comfort is related to head pressure intensity and back peak pressure, waist comfort is related to pressure intensity of whole body and back peak pressure; and hip comfort is related to back peak pressure, back peak pressure intensity and head pressure intensity.

Keywords: Middle-aged and old women · Body pressure distribution · Mattress hardness · Comfort · User's experience

1 Introduction

Mattress is essential bedding for human sleep, and its comfort greatly affects the quality of people's rest, while mattress hardness is an important factor affecting the comfort of mattresses [1], and mattresses with different hardness can lead to different body pressure distributions on shoulders, waist and hips when people rest in supine position. Relevant domestic and foreign research institutes carry out researches on mattress pressure comfort. Buckle et al. [2] evaluated mattress comfort by using human body pressure and subjective user's experience, and they thought that the mattress tested was more comfortable than the wooden reference surface; DeVocht [3] thought that the maximum pressure was related to the body weight of subject; by analyzing the body pressure distribution characteristics of four different types of mattresses by DeVocht et al., it was

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found that the pressure distributions of human body on the mattresses with different hardness were significantly different [4]; and for domestic mattress researches, Professor Shen Liming et al. from Nanjing Forestry University studied, with the use of human body pressure distribution, the relationship between human body characteristics such as age, body type, sex, etc. and spring mattress [5–7]. The use of the measuring system of human body pressure distribution allows the visually acquisition of the pressure distribution of human body on the mattress, under the ideal condition, the pressure distribution of human body is evenly distributed, the muscle is relaxed and finally the purpose of rest is achieved. Therefore, the human body pressure distribution is a visual evaluation method to measure whether the mattress customization is reasonable [8].

2 Research Objects and Methods

2.1 Experimental Subject

Mattress. Four palm mattresses with different hardness were selected, and their harness values were 0.54, 1.04, 1.56, 2.3 and 3.3 respectively. For information on mattresses to be tested, see Table 1.

Table 1. Information on mattress to be tested

S/N	Name	Hardness value
1	Palm mattress	3.30
2	Palm mattress	2.30
3	Palm mattress	1.56
4	Palm mattress	1.04
5	Palm mattress	0.54

Study Subject. The study subjects in the experiment were middle-aged and old women (aged 40–65 years). The actual total number of persons participating in research of this project was 46, wherein 15 were corpulent (body mass index BMI > 24), 18 were moderate (21 < BMI < 24), and 13 were slender (BMI < 21). For the specific information on subjects, see Table 2.

Table 2. Basic information on subjects

BMI grouping	Number of persons	Age (years)	Height (cm)	Weight (kg)	BMI
BMI < 21	13	50.50 ± 6.70	160.10 ± 4.00	47.80 ± 3.20	18.70 ± 6.70
BMI 21–24	18	55.40 ± 5.90	156.20 ± 5.40	55.50 ± 4.50	22.70 ± 0.90
BMI > 24	15	53.30 ± 5.90	154.20 ± 6.10	65.60 ± 12.50	27.50 ± 4.20
Total number of persons	46	53.33 ± 6.48	156.60 ± 5.80	56.70 ± 10.50	23.10 ± 4.30

2.2 Research Method

Body Pressure Distribution Test. By testing the pressure data for key parts of human body sleeping in the supine position, the body pressure distribution characteristic parameters for human body sleeping in the supine position were obtained, and in combination of the method of evaluating mattress comfort from the subjective user's experience of subjects, the body pressure comfort parameter range for the key parts of human body in the sleeping status were defined. In the research, the pressure data and subjective experience evaluation were obtained by mainly testing five key parts of the human body sleeping in the supine position, and the five parts were the contact area between the final edge of occipital bone in the head part and the horizontal plane, the contact area between the final edge of thoracolumbar spine and the horizontal plane, the contact area between the final edge of lumbosacral spine and the horizontal plane, the contact area between the final edge of gastrocnemius and the horizontal plane, and the contact area between the final edge of calcaneus and the horizontal plane. The main pressure parameters to be tested include force (F), connect area (CA), peak force (PF) and peak pressure (PP). The key parts of the human body were on the basis of the characteristic region contacting with the horizontal plane when lying in the supine position, and the definitions were as below:

- Position 1: The contact area between the final edge of occipital bone in the head part and the horizontal plane;
- Position 2: The contact area between the final edge of thoracolumbar spine and the horizontal plane;
- Position 3: The contact area between the final edge of lumbosacral spine and the horizontal plane;
- Position 4: The contact area between the final edge of gastrocnemius and the horizontal plane,
- Position 5: The contact area between the final edge of calcaneus and the horizontal plane

Test Purpose. Tekscan mattress pressure sensor was used to measure body pressure of the subject under the steady state when lying on mattresses with different hardness.

Test Requirement. Subject was required to keep the supine position, with both legs naturally separating and both arms crossed at the chest, as shown in Fig. 1.

Number of Tests. Subject randomly selected five mattresses with different hardness to carry out the body pressure test.

Testing Process. After subject lay down, calibration was carried out on body weight of subject, and carried out the pressure value test for 25 s consecutively (200 frames in total, 0.125 s/frame, with collection frequency of 8 Hz).

The human body pressure on the mattress was divided into the following eight parts, i.e. head, neck, back, waist, hips, thighs, calves and feet as well as the whole body. Five parameters of force, peak force, pressure, peak pressure and connect area were obtained

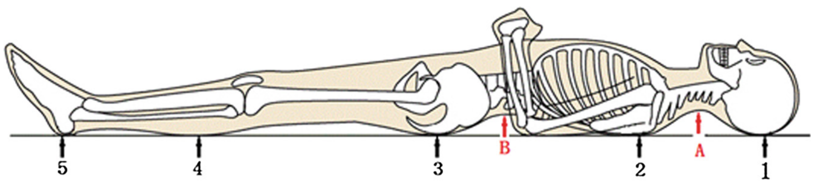

Fig. 1. Schematic diagram for five key parts of human body when lying in supine position

respectively, and the effective average of different parts and parameters in the whole testing process was obtained (Fig. 2).

Fig. 2. Mattress pressure sensor for testing and test photo

On the basis of characteristic areas contacting with the horizontal area when lying in the supine position, different parts of human body were defined as below:

- Head: Skull to occipital bone (Fig. 3: area 1–2)
- Neck: Occipital bone to the seventh cervical vertebra (Fig. 3: area 2–3)
- Back: The seventh cervical vertebra to the twelfth thoracic vertebra (Fig. 3: area 3–4)
- Waist: The first lumbar vertebra to the fifth lumbar vertebra (Fig. 3: area 4–5)
- Hips: The fifth lumbar vertebra to hip stripe (Fig. 3: area 5–6)
- Thighs: Hip stripe to popliteal space (Fig. 3: area 6–7)
- Calves and feet: Popliteal space to planta pedis (Fig. 3: area 7–8)

Subjective Comfort Experience. The subjects randomly selected five mattresses with different hardness to carry out user’s experience on sleeping, they carried out different

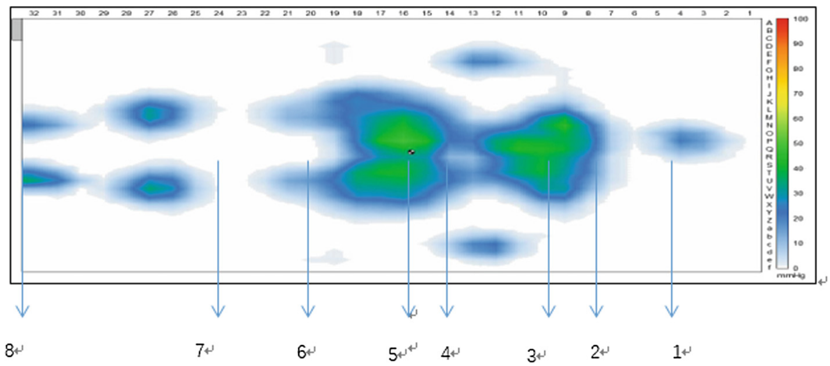

Fig. 3. Schematic diagram of mattress pressure zone

forms of experience according to the actual sleeping positions at home during the process for not less than 3–5 min, and then completed the subjective feeling evaluation after experiencing all the mattresses. The subjective comfort during the experience process was rated into five classes according to the actual feeling, including the rating of comfort experience in different parts of human body (Table 3).

Table 3. Rating criteria for user's experience of subjective comfort

Rating	1	2	3	4	5
Feeling	Very uncomfortable	Uncomfortable	Ordinary	Comfortable	Very comfortable

2.3 Data Processing and Analysis

Standardized Processing of Data. People with different body weight might result in different pressure values, which were in direct proportion to body weight, therefore standardized processing is adopted.

1. Processing of force value: 100% was set for the whole body, and the force value/the value of the whole body*100% was adopted for the other parts;
2. Processing of peak force: The maximum value of each part was set to be 100%, and the peak force value/maximum*100% was adopted for the other parts;
3. Processing of pressure values: The maximum value of each part was set to be 100%, and the pressure value/maximum*100% was adopted for the other parts;
4. Processing of peak pressure: The maximum value of each part was set to be 100%, and the peak pressure value/maximum*100% was adopted for the other parts; and
5. Processing of connect area: 100% was set for the whole body, and the connect area value/the value/ whole body*100% was adopted for the other parts.

Data Analysis The data statistical analysis was conducted with SPSS21.0. The difference (the data is expressed as: average value ± standard deviation) between mattresses with different hardness was compared by using one-way ANOVA (statistical quantity: 46 persons, and the statistical value refers to the standardized value); and multiple regression was used to determine the relationship between mattress test value and subjective feeling value of mattress (the statistical value refers to the original value after deleting abnormal values). The significance level was defined as $\alpha < 0.05$.

3 Experimental Results and Analysis

3.1 Subjective Comfort Experience for Mattresses with Different Hardness

Table 4 indicates the comfort rating for each part of human body on the mattresses with different hardness. The comfort difference of shoulder, waist and hips (with significance level < 0.05) between mattresses with different hardness was compared by using one-way ANOVA: ① As for shoulder comfort, there is significant difference between No. 1 mattress and No. 3, 4 and 5 mattresses, between No. 2 mattress and No. 3 and 4 mattresses, as well as between No. 3 mattress and No. 1, 2 and 5 mattresses; and ② The significant difference in waist comfort and hips comfort has consistency, No. 1 mattress has significant difference from No. 3 and 4 mattresses, No. 2 mattress has significant difference from No. 3 and 4 mattresses, No. 3 mattress has significant difference from No. 1, 2 and 5 mattresses, and No. 4 mattress has significant difference from No. 1, 2 and 5 mattresses.

Table 4. One-way ANOVA for comfort of mattresses with different hardness

Mattress	Hardness	Comfort index		
		Shoulder	Waist	Hips
1	3.30	3.04 ± 1.20^{cde}	3.26 ± 1.20^{cd}	3.33 ± 1.30^{cd}
2	2.30	3.37 ± 1.10^{cd}	3.28 ± 1.00^{cd}	3.26 ± 0.90^{cd}
3	1.56	3.91 ± 0.80^{abe}	3.85 ± 1.00^{abe}	4.04 ± 0.90^{abe}
4	1.04	3.83 ± 0.80^{ab}	3.80 ± 0.90^{abe}	3.92 ± 0.90^{abe}
5	0.54	3.48 ± 1.10^{ac}	3.33 ± 1.10^{cd}	3.22 ± 1.20^{cd}

Note: The significance level is less than 0.05. a, b, c, d and e stand for mattresses 1, 2, 3, 4 and 5 respectively, and when a, b, c, d and e are marked, it indicates that there is significant difference in comfort between this mattress and the compared mattress. For example: Shoulder comfort c d e of No. 1 mattress indicates that there is significant difference in shoulder comfort between No. 1 mattress and No. 3, 4 and 5 mattresses.

4 Body Pressure Distribution Analysis

4.1 Body Pressure Distribution Test Result

Force F. The percentage result for force of each part of human body on mattresses with different hardness indicated that (Table 5): 1. Head force of No. 3 mattress was

Table 5. Pressure test results for parts of human body (%)

Mattress (hardness)	1 (3.30)	2 (2.30)	3 (1.65)	4 (1.04)	5 (0.54)
Standard F of whole body	100	100	100	100	100
Standard F of head	6.91 ± 1.47	7.25 ± 1.22	7.27 ± 1.34	7.22 ± 2.11	6.85 ± 1.50
Standard F of neck	0.72 ± 0.44^{de}	0.79 ± 0.45^{de}	0.62 ± 0.39^{de}	0.42 ± 0.44^{abc}	0.27 ± 0.31^{abc}
Standard F of back	38.06 ± 6.10	36.63 ± 6.33	37.33 ± 7.10	39.78 ± 11.43	39.44 ± 6.23
Standard F of waist	6.68 ± 1.85^{de}	6.38 ± 1.94^{de}	6.37 ± 1.92^{de}	5.28 ± 2.46^{abce}	2.95 ± 1.54^{abcd}
Standard F of hips	29.23 ± 5.39^{de}	30.09 ± 4.66^{d}	30.45 ± 5.10^{d}	34.55 ± 18.36^{abc}	33.97 ± 5.77^{a}
Standard F of thighs	6.09 ± 2.24^{de}	6.44 ± 2.34^{de}	5.65 ± 1.93^{e}	5.10 ± 2.87^{abe}	2.93 ± 1.90^{abcd}
Standard F of calves and feet	11.59 ± 3.47	11.39 ± 3.10^{e}	12.22 ± 3.11	12.82 ± 4.92	13.01 ± 3.70^{b}

maximum; 2. Neck force decreased with the increase in hardness of No. 2–5 mattresses; 3. Back force increased with the increase in hardness of No. 2–5 mattresses; 4. Waist force decreased with the increase in mattress hardness; and 5. Hip force increased with the increase in hardness of No. 1–4 mattresses.

According to one-way ANOVA, there is a significant difference (significance level is less than 0.05) in neck, waist, hip and thigh forces between the mattresses with different hardness. The specific difference is that: 1. Neck force percentage: There is significant difference between No. 1, 2 and 3 mattresses and No. 4 and 5 mattresses; 2. Waist force percentage: There is significant difference between No. 1, 2 and 3 mattresses and No. 4 and 5 mattresses as well as between No. 4 mattress and No. 5 mattress; 3. Hip force percentage: There is significant difference between No. 1 mattress and No. 4–5 mattresses, and between No. 2–3 mattresses and No. 4 mattress.

Connect Area CA. The percentage result for connect area of each part of human body on mattresses with different hardness indicated that (see Table 6): 1. The waist connect area of No. 3 mattress was maximum; 2. The head connect area decreased with the increase in mattress hardness; 3. The neck connect area among No. 2–5 mattresses decreased with the increase in mattress hardness; 4. The back and hip connect area increased with the increase in mattress hardness; and 5. The waist connect area decreased with the increase in hardness of No. 3–5 mattresses.

Table 6. Connect area test results for parts of human body (%)

Mattress (hardness)	1 (3.30)	2 (2.30)	3 (1.65)	4 (1.04)	5 (0.54)
Standard CA of whole body	100	100	100	100	100
Standard CA of head	6.38 ± 1.26^{de}	6.06 ± 1.06	5.97 ± 1.33	5.61 ± 1.17^{a}	5.86 ± 1.36^{a}
Standard CA of neck	$1.72 \pm 0.82^{d\cdot e}$	1.87 ± 0.74^{de}	1.61 ± 0.69^{e}	1.31 ± 0.83^{ab}	1.13 ± 0.82^{abc}
Standard CA of back	29.85 ± 4.66^{e}	30.68 ± 3.94^{e}	30.43 ± 5.22^{e}	31.60 ± 3.80^{e}	33.41 ± 3.54^{abcd}
Standard CA of waist	7.90 ± 1.64^{e}	7.80 ± 1.60^{e}	8.13 ± 1.64^{e}	7.61 ± 2.13^{e}	5.87 ± 2.29^{abcd}
Standard CA of hips	22.74 ± 5.31^{de}	22.94 ± 4.91^{de}	23.40 ± 4.44^{de}	25.45 ± 5.00^{abc}	26.76 ± 4.57^{abc}
Standard CA of thighs	12.31 ± 3.86^{e}	12.32 ± 3.63^{e}	11.61 ± 3.31^{e}	10.88 ± 4.08^{e}	8.05 ± 3.76^{abcd}
Standard CA of calves and feet	17.17 ± 3.67	16.78 ± 3.37^{e}	17.26 ± 3.69	16.78 ± 3.42^{e}	18.31 ± 3.45^{bd}

According to one-way ANOVA, there is significant difference (significance level is less than 0.05) in neck, waist, hip and thigh connect areas between the mattresses with different hardness. The specific difference is that: ① Neck connect area percentage: There is significant difference between No. 1 and 2 mattresses and No. 4 and 5 mattresses, and between No. 3 mattress and No. 5 mattress; ② There is consistency for significance difference in back and waist connect area percentages; and between No. 1, 2, 3 and 4 mattresses and No. 5 mattress; and ③ There is significant difference in hip connect area percentage between No. 1, 2 and 3 mattress and No. 4 and 5 mattresses.

Pressure CP. The pressure test result of each part of human body on mattresses with different hardness indicated that (as shown in Table 7): 1. Pressure in the neck and the thighs parts decreased with the increase in mattress hardness; 2. Except for No. 3 mattress, back pressure of other mattresses decreased with the increase in mattress hardness; and 3. Waist and hip pressure of No. 3 mattress is minimum, and that of No. 5 mattress is maximum.

Table 7. Pressure test results for parts of human body (%)

Mattress (hardness)	1 (3.30)	2 (2.30)	3 (1.65)	4 (1.04)	5 (0.54)
Standard CP of whole body	100	100	99.99 ± 0.97	100	100
Standard CP head	79.25 ± 17.10^{abc}	82.16 ± 16.28^{a}	82.58 ± 14.76^{a}	85.69 ± 15.23^{a}	83.90 ± 16.37
Standard CP of neck	14.88 ± 5.90^{cde}	14.80 ± 6.74^{cde}	12.09 ± 6.17^{ade}	8.98 ± 4.49^{abce}	5.83 ± 3.58^{abcd}
Standard CP of back	76.55 ± 17.75^{ce}	70.82 ± 21.71	66.63 ± 21.42a	69.22 ± 19.47	67.47 ± 19.94^{a}
Standard CP of waist	41.17 ± 15.51^{cde}	37.57 ± 11.98^{de}	35.35 ± 20.02^{ade}	74.26 ± 20.98^{abce}	85.74 ± 19.92^{abcd}
Standard CP of hips	73.43 ± 16.44	76.03 ± 18.27^{d}	71.30 ± 20.41	74.26 ± 21.08^{b}	85.80 ± 19.90
Standard CP of thighs	24.51 ± 7.50^{de}	23.45 ± 7.27d^{e}	20.73 ± 6.65^{e}	19.56 ± 7.95^{abe}	14.75 ± 6.65^{abcd}
Standard CP of calves and feet	70.22 ± 6.82	69.72 ± 6.48	67.78 ± 7.40	69.59 ± 6.85	69.25 ± 7.91

According to one-way ANOVA, there is significant difference (significance level is less than 0.05) in pressure of neck, waist, hip and thigh parts between the mattresses with different hardness. The specific difference is that: ① Neck pressure percentage: There is significant difference between No. 1 and 2 mattresses and No. 3, 4 and 5 mattresses, between No. 3 mattress and No. 4 and 5 mattresses, and between No. 4 mattress and No. 5 mattresses; ② There is significant difference in waist pressure percentage between No. 1 mattress and No. 3, 4 and 5 mattresses, between No. 2 mattress and No. 4 and 5 mattresses, between No. 3 mattress and No. 1, 4 and 5 mattresses, and also between No. 4 mattress and No. 5 mattress; and ③ There is significant difference in hip pressure percentage between No. 2 mattress and 4 mattress.

Peak Force PF. The percentage result for peak force occupying whole body force of each part of human body on mattresses with different hardness indicated that (as shown in Table 8): 1. Peak force in the neck, waist and the thighs parts decreased with the increase in mattress hardness; 2. Except for No. 3 mattress, back peak force of other mattresses decreased with the increase in mattress hardness; and 3. Hip peak force of No. 3 mattress is minimum, and that of No. 5 mattress is maximum.

Table 8. Peak pressure test results for parts of human body (%)

Mattress (hardness)	1 (3.30)	2 (2.30)	3 (1.65)	4 (1.04)	5 (0.54)
Standard PP of whole body	100	100	99.96 ± 0.10	100	100
Standard PP of head	79.25 ± 17.10	82.16 ± 16.28	82.58 ± 14.76	85.69 ± 15.23	82.90 ± 16.37
Standard PP of neck	14.88 ± 5.91c[de]	14.80 ± 6.74[cde]	12.09 ± 6.17[abde]	8.98 ± 4.49[abce]	5.83 ± 3.58[abcd]
Standard PP of back	76.55 ± 17.75[ce]	70.82 ± 21.71	66.63 ± 21.42[a]	69.22 ± 19.47	67.47 ± 19.94[a]
Standard PP of waist	41.17 ± 15.51[cde]	37.57 ± 11.98[de]	35.35 ± 13.95[ade]	29.82 ± 14.22[abce]	19.02 ± 10.05[abcd]
Standard PP of hips	73.43 ± 16.44[e]	76.03 ± 18.27[e]	71.30 ± 20.02[e]	74.26 ± 20.98[e]	85.74 ± 19.92[abcd]
Standard PP of thighs	24.51 ± 7.50[cde]	23.45 ± 7.27[de]	20.73 ± 6.65[ae]	19.56 ± 7.95[abe]	14.75 ± 6.65[abcd]
Standard PP of calves and feet	73.45 ± 24.01	75.74 ± 17.86	77.14 ± 19.96	75.48 ± 20.46	69.93 ± 17.91

According to one-way ANOVA, there is significant difference (significance level is less than 0.05) in peak force of neck, waist, hip and thigh parts between the mattresses with different hardness. The specific difference is that (Table 8): 1. Neck pressure percentage: There is significant difference between No. 1 and 2 mattresses and No. 3, 4 and 5 mattresses, between No. 3 mattress and No. 4 and 5 mattresses, and between No. 4 mattress and No. 5 mattresses; 2. There is significant difference in waist pressure percentage between No. 1 mattress and No. 3, 4 and 5 mattresses, between No. 2 mattress and No. 4 and 5 mattresses, between No. 3 mattress and No. 1, 4 and 5 mattresses, and also between No. 4 mattress and No. 5 mattress; and 3. There is significant difference in hip pressure percentage between No. 2 mattress and No. 4 mattress.

Peak Pressure PP. The peak pressure test results of each part of human body on mattresses with different hardness indicated that (Table 9): 1. Peak pressure in the neck, waist and the thighs parts increased with the increase in mattress hardness; 2. Except back peak pressure for No. 3 mattress, other body pressure indexes increased with the increase in mattress hardness; and 3. Hip pressure of No. 3 mattress is minimum, and that of No. 5 mattress is maximum.

According to one-way ANOVA, there is significant difference (significance level is less than 0.05) in connect area of neck, waist, hip and thigh parts between the mattresses with different hardness. The specific difference is that: 1. Neck peak pressure percentage: There is also respectively significant difference between No. 1 and 2 mattresses and No. 3, 4 and 5 mattresses; 2. There is significant difference in waist peak pressure percentage between No. 1 mattress and No. 3, 4 and 5 mattresses, between No. 2 mattress and No. 4 and 5 mattresses, between No. 3 mattress and No. 1, 4 and 5

Table 9. One-way ANOVA of body pressure indicators

Mattress	Hardness	Body pressure indicators			
		CP head	PF back	PP whole body	PP back
1	3.30	0.21 ± 0.09^{cde}	6.96 ± 1.92^{de}	0.82 ± 0.24^{cde}	0.60 ± 0.16^{de}
2	2.30	0.249 ± 0.119^{de}	6.85 ± 1.80^{de}	0.93 ± 0.39^{de}	0.60 ± 0.15^{de}
3	1.56	0.27 ± 0.13^{ae}	7.24 ± 1.53^{de}	1.05 ± 0.47^{ae}	0.62 ± 0.13^{de}
4	1.04	0.31 ± 0.13^{ab}	8.59 ± 2.78^{abce}	1.14 ± 0.38^{abe}	0.75 ± 0.24^{abce}
5	0.54	0.34 ± 0.15^{abc}	10.06 ± 2.09^{abcd}	1.40 ± 0.45^{abcd}	0.87 ± 0.18^{abcd}

mattresses, and also between No. 4 mattress and No. 5 mattress; and 3. There is significant difference in hip peak pressure percentage between No. 1, 2,3 and 4 mattress and No. 5 mattress.

Correlation Analysis on Comfort and Body Pressure Distribution. Through stepwise regression correlation analysis, it is obtained that shoulder comfort is related to head pressure and back peak force; waist comfort is related to peak pressure of whole body and back peak force; hip comfort is related to back peak force, back peak pressure and head pressure. The regression equation is as follows:

$$\text{Shoulder comfort} = 3.517 + 1.918\text{CP Head} - 0.064\text{PF Back} \quad (1)$$

$$\text{Waist comfort} = 3.499 + 0.571\text{PP Whole body} - 0.076\text{PF Back} \quad (2)$$

$$\text{Hip comfort} = 3.745 - 0.58\text{PF Back} + 5.781\text{PP Back} + 1.592\text{CP Head} \quad (3)$$

The one-way ANOVA result between body pressure indicators indicates that, the higher the mattress hardness, the greater difference between body pressure indicators and other mattresses. For specific information, see Table 10.

5 Discussion and Conclusion

5.1 Discussion of Experimental Results

Comfort Comparison between Mattresses with Different Hardness. Among the mattresses with different hardness, the comfort ratings on shoulder, waist and hips of No. 3 mattress were the highest, and No. 4 mattress is secondly higher, which is consistent with the most comfortable mattresses selected by users. The comfort ratings on shoulder and waist of No. 1 mattress were the lowest, and the comfort rating on hips of No. 5 mattress was the lowest, according to reason analysis, it may be the reason that during sleep, shoulder and waist of the human body prefers slightly harder mattresses, and hips prefer slightly softer mattresses, thus it can be seen that sleep comfort for different parts of the human body has different requirements on mattress hardness, and in design of mattress hardness, the mattresses with different hardness can be designed in consideration of the parts of human body.

Force F and Contact Area CA. The force and connect areas of neck, waist and thighs decreased with the increase in mattress hardness, and the force and connect areas of head, back, hips, calves and feet increased with the increase in mattress hardness. It may because that neck, waist and the like are concave parts of physiological curvature, and force approximately decreases with the decrease in connect area. Back, hips, etc. are physiological complete sections, and force approximately decreases with the increase in connect area.

6 Conclusion

According to the research in the experiment, the following conclusions are preliminarily obtained:

1. Mattress hardness has significant effect on mattress comfort;
2. The middle-aged and old women among subjects generally prefer mattress with moderate hardness value;
3. It has comfort consistency in shoulder, waist and hips for mattresses with different hardness;
4. The subjective evaluation of mattress comfort and the relevant data analysis results of force distribution have consistency, and various force indexes for the mattresses with moderate hardness are within the moderate value range;
5. The subjective comfort in different parts of human body and the body force indicators have some relevance. Shoulder comfort is related to head pressure and back peak force; waist comfort is related to pressure of whole body and back peak force; and hip comfort is related to back peak force, peak pressure and head pressure.

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