Editorial board

Eric Min-yang Wang, National Tsing Hua University, Taiwan, ROC
Chia-Fen Chi, National Taiwan University of Science and Technology, Taiwan, ROC
Sheue-Ling Hwang, National Tsing Hua University, Hsinchu, Taiwan, ROC
Eui S. Jung, Korea University, Seoul, Korea
Mitsuyuki Kawakami, Tokyo Metropolitan Institute of Technology, Tokyo, Japan
Lihua He, Peking University Health Science Center, Beijing, China
Xianghong Sun, Chaoyang District Institute of Psychology, Chinese Academy of Sciences, Beijing, China
Chiuhsiang J. Lin, Chung Yuan Christian University, Taiwan, ROC
Dyi-Yih Michael Lin, I-Shou University, Taiwan, ROC
Koya Kishida, Takasaki City University of Economics, Takasaki-city, Japan
Ian Gibson, Ergotec, Ashfield, Australia
Kwan S. Lee, Hongik University, Seoul, Korea
Kee Yong Lim, Nanyang Technological University, Singapore
Min Yong Park, Hanyang University, Seoul, Korea
Akihiko Seo, Fukui Medical University, School of Medicine, Fukui, Japan
Antonios Vitalis, Massey University, Palmerston North, New Zealand
Youlian Hong, Chinese University of Hong Kong, Hong Kong
Richard So, University of Science and Technology Clear Water Bay, Hong Kong
Simon Yeung, Hong Kong Polytechnic University, Hong Kong

Asian Journal of Ergonomics is published biannually by the Pan-Pacific Council on Occupational Ergonomics. Dept. of Ergonomics. IIES, UOEH, 1-1, Iseigaoka, Yahatanishi-ku, Kitakyushu, 8078555, JAPAN. Annual subscription rates are: US$20 for PPCOE members; US$40 for individual; and US$100 for institutions. Subscriptions outside Hong Kong are requested to pay by bank draft payable to the Pan-Pacific Council on Occupational Ergonomics. All correspondence regarding subscriptions should be sent to: Dr. Alan Chan, Treasurer of PPCOE, Department of MEEM, City University of Hong Kong, 83 Tat Chee Avenue, Kowloon, Hong Kong (meachan@cityu.edu.hk)

Copyright © 2001, Pan-Pacific Council on Occupational Ergonomics. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, micro filming, recording, or otherwise, without permission from the publisher.
Contents

Development and Evaluation of Bus Seat Dimension to Improve the Fit and Comfort of Malaysian Bus Drivers
M.Y. Rosnaha, Y. M. Shahira, M.T. Samsul Baharib, W.C. Zaharahb

Data entry task in mobile computing: effects of vibration, display colour, and user age
Zulquernain Mallick

Cognitive performance of grass trimmers in noisy conditions – the effect of user age
Zulquernain Mallick

Correlation of job satisfaction with job characteristics, job organization and environmental factors in two Malaysian automobile factories
S.Z. Dawal, Z. Taha, Z. Ismail

Chronic Exposure Index Model to Assess Ergonomic Risk Factor Related to Upper Extremity Musculoskeletal Disorders
Seyyed Ali Moussavi-Najarkola

Laboratory Study of Factors Affecting Sitting Comfort and Discomfort
M.G. Mohamed Thariq, Weining Fang, Lijian Zhang, Harsha Munasinghe

A study of ergonomic factors contributing to the occurrence of occupation related musculo-skeletal problems in garment workers
Senthil Kumar R.K, Bobby Joseph, Padmanaban sekaran, Sulekha, Kurian Zachariah, Rajalakshmi Hariharan

Redesign of a hand pallet truck by integrating ergonomics analysis and quality function deployment
Isa Halim, Abdul Rahman, Wan Fadhli
Development and Evaluation of Bus Seat Dimension to Improve the Fit and Comfort of Malaysian Bus Drivers

M.Y. Rosnaha*, Y. M. Shahira1, M.T. Samsul Baharib2, W.C. Zaharahb2

1 Department of Mechanical and Manufacturing Engineering, Faculty of Engineering,  
2 Department of Community Health, Faculty of Medicine and Health, University Putra Malaysia,  
43000 UPM, Serdang, Selangor, Malaysia

Abstract

A bus seat design that increases the comfort of the drivers may help to reduce their fatigue and to increase their alertness, thus reducing the accident rate. Commercial vehicles in Malaysia are imported, but the fit between their dimensions and those of the Malaysian population has not been studied. The objective of this study is to use anthropometry to design a seat that is appropriate for Malaysian bus drivers. This study uses qualitative methods including observation and a survey to collect the data. Anthropometric data were used to propose the recommended seat design. The current and recommended seat designs were simulated to analyse the comfort of the seat for bus operators and comparisons were made. In simulations of the current seat dimensions with the drivers’ anthropometric dimensions, the Rapid Upper Limb Assessment (RULA) score showed that the design of the seat must be modified to accommodate the range of dimensions of the population of Malaysian bus drivers. The proposed seat design based on the anthropometric dimension of the bus drivers showed a lower RULA score, indicating that considering ergonomics in the design of the seat can increase the comfort, safety and health of the drivers, and also the safety of the passengers.

Keywords: Bus seat design, Malaysian, anthropometry, comfort, biomechanics, work-related musculoskeletal disorder

1. Introduction

Bus driving is characterized by psychological and physical stresses. Most severe are the stresses of traffic in big cities, because of the heavy traffic and frequent stops. In most transit companies, the drivers must, in addition to driving responsibilities, handle tasks such as selling tickets, observing passenger loading and unloading and providing information to passengers. Psychological stresses result from the

* Corresponding author: rosnah@eng.upm.edu.my, Phone: 03-89466342
responsibility for the safe transport of passengers, scant opportunity to communicate with colleagues and the pressure to keep to a fixed schedule. Rotating shift work is also psychologically and physically stressful. Ergonomic shortcomings in the driver’s workstation increase physical stresses [1].

Musculoskeletal disorders (MSDs) are among the leading causes of occupational injury and disability, with back pain the most common reason for the filing of workers’ compensation claims. Back pain accounts for about 25% of all disability claims and for about 40% of absences from work. In the United States, in 1990, the cost of back pain was estimated to be between $50 billion and $100 billion [2].

Strong evidence exists that musculoskeletal disorders are associated with workplace physical factors and non-work related characteristics. The workplace physical factors include heavy physical work, lifting and forceful movements, awkward postures, whole-body vibration, and static work postures. Static work postures of prolonged standing, sitting, and sedentary work are isometric positions where very little movement takes place. These postures are typically cramped or inactive and cause static loading on the muscles [3].

In studies of back pain among professional drivers, postural stress, muscular effort and long-term exposure to whole-body vibration were consistently associated with driving motor vehicles for extended periods of time [4]. Even in non-driving postures, bus drivers reported back and neck pain more frequently than workers in other professions [5].

This paper presents the development of bus seat design parameters for Malaysian bus drivers as an engineering intervention to improve their comfort and health.

1.1. Bus driving posture

Analysis of driving postures used by bus drivers should consider biomechanical factors, and ensure that all driving tasks are conducted within a comfortable reach range. The posture of the seated person depends on the design of the seat itself, on individual sitting habits, and on the work performed.

The primary interest in the bus operator’s workstation is the relationship between the operator’s seat, steering column and wheel, and pedals. Bus operators are required to interact and maintain constant contact with each of these components. It is the use and combination of these components that influence the operator’s posture [6].

The driver’s seat is fitted into a cramped space because the vehicle is usually designed to maximise the number of passenger seats. The design of the driver’s workstation must not only consider the tasks performed by the driver but also the physical characteristics of the driver and the accommodations required that permit the full range of seat adjustments [2].

The biomechanical considerations of seated postures include those of the spine, arms, and legs. The muscles at the back of the thighs influence the relative position of the spine and pelvis. The location and slope of the work area influence the
position of the neck, shoulders, and upper extremities. Therefore, along with the seat itself, the work to be performed must be considered [6], [7].

A body position or posture is considered appropriate if the weight of an individual’s body is transmitted to the seat with the least possible stress on the body [8]. The weight of the head, the trunk, and the thighs are borne by the headrest, backrest, and seat pan; the weight of the lower legs and feet is transmitted to the floor, suitable footrest, or in the case of a bus operator’s workstation, the foot pedals.

1.2. MSDs among Malaysian bus drivers

The prevention of musculoskeletal disorders is achieved by interventions, which reduce the probability and severity of injuries. Ergonomic design may reduce the incidence of compensable back pain by up to one-third [9].

In a study [10] of MSDs among 308 Malaysian bus drivers, the most common complaint (63.2%) was lower back pain while driving, followed by neck pain (54.3%), upper back pain (41.8%), and shoulder pain (30.7%), (Figure 1). Elbow pain occurred least frequently.

The bus drivers also attributed their discomfort to the vibration of the vehicle. Vibration comes most commonly from the steering wheel (43%), followed by the seat (31%), the gear-shift (15%) and the pedal (11%), (Figure 2). Thus, in designing the seat, the need to reduce vibration must also be considered.

![Figure 1. Frequencies of musculoskeletal complaints of the drivers surveyed](image_url)
Saporta [2] suggested that to minimize musculoskeletal stresses, the seat should be designed such that:

1. It permits shifting or changing of posture
2. It has a large adjustable back support;
3. The seat surface should be accommodating, but not spongy, to accommodate the forces transmitted to it; and
4. Seat height and angle should be easily adjusted.

All of these features can contribute to good seating posture.

1.3. Anthropometry data and design

Measurement of people’s physical characteristics and abilities (anthropometry) provides information that is essential to guide appropriate design of occupational and non-occupational environments, as well as for the design of consumer products, clothing, tools and equipment [11] and to resolve the dilemma of ‘fitting people to machines’ [12]. Anthropometry allows evaluation of the suitability of vehicle design for drivers [13]; designs that conform to users’ sizes in one country may not be appropriate in other countries in which the users may be smaller or larger, so users may choose to modify the designs unilaterally [14].

2. Methods

2.1. Sampling and observation

In this study, the average dimensions for the seat pan, backrest and steering wheel were calculated from a sample of three buses. The layout of the seat and the suspension system used were also observed. The seat design of the samples was assumed to be typical of the buses used in the Malaysian cities.
2.2. Anthropometry data of bus drivers

A cross-sectional study was conducted to measure the anthropometric dimensions of Malaysian Commercial Vehicle Bus Drivers (Table 1). A total of 176 bus drivers from seven bus depots in the Klang Valley serving the capital city participated in the study. Twelve anthropometric parameters were measured using Martin’s type anthropometer; however, only ten were relevant to the seat design:

- buttock-popliteal depth; (1)
- sitting eye height; (2)
- weight; (3)
- shoulder height; (4)
- elbow-rest height; (5)
- knee height; (6)
- popliteal height; (7)
- hip breadth; (8)
- buttock-knee depth, (9)
- and lumbar support height.(10)

2.3. Body part symptom survey

Twenty five drivers who used these seats were interviewed to identify any musculoskeletal pain that might be related to the design of the seat used. A body part symptom figure was used based on the sitting posture; drivers were asked to indicate the body parts experiencing problems, i.e., neck and head, shoulder, upper back, arm and hand, lower back, thigh, knee and ankle and leg. The frequency of the response for each part was calculated.

2.4. Modeling and evaluating the seat design

Seat designs were then modeled using CATIA software version V5R14. The CATIA software was used to design and simulate the current and recommended seat using the anthropometric dimensions of the bus drivers. The Rapid Upper Limb Assessment (RULA) tool available in the software was used to give a quick assessment of the potential problems that bus drivers may encounter with each seat design and to justify the need for a better seat design.

2.4.1. RULA analysis

RULA [15] is an ergonomic technique for evaluating individuals’ exposures to postures, forces and muscle activities that have been shown to contribute to Repetitive Strain Injuries (RSIs). Use of this ergonomic evaluation approach results
in a risk score between one and seven, where higher scores signify greater levels of apparent risk. RULA analysis examines the following risk factors: number of movements, static muscle work, force, working posture, and time worked without a break. RULA evaluates stress on each body part; the level of severity suggests which features of the chair should be modified to make it more comfortable.

2.4.2. Current seat measurement

Several measurements were taken on the current seat (Figure 3).

3. Results

3.1. Sampling and Observation

The seats in the three buses sampled, none had armrests, headrests or seatbelts. Armrests support the arms and prevent or reduce arm, shoulder, and neck fatigue. The headrest supports the weight of the head to reduce amount of stress on the body. Therefore adding armrests and a headrest should reduce fatigue among bus drivers. However, the lack of a seat belt simply showed a disregard for safety.

3.2. Body part Symptom survey

The respondents for this study were mostly (12) 31-40 years old and had worked as bus drivers for an average of 5-7 years. Of the 25 respondents, 18 indicated that they experience some musculoskeletal problems and 16 of these indicated that these problems first occurred after they had become drivers. In 23 of the workers, the most frequent problems were in the lower back, followed by pain in the neck or head (21), in the ankle or leg (20), in the thigh (17) and in the arm or hand (15). This result is consistent with that of the larger survey. Based on interviews and chair design observation, possible causes of the prevalent problems were identified (Table 1).

3.4. Current Seat measurement

The measurements the current seat (Table 3) will be compared with the relevant anthropometric data to recommend a new seat design.
Development and Evaluation of Bus Seat Dimension to Improve the Fit and Comfort of Malaysian Bus Drivers

Figure 3. Seat dimensions measured.
(a. seat pan height, b. seat width, c. seat depth, d. backrest height, e. backrest width and g. lumbar support height, f. angle of inclination.)

Table 1. Summary of complaints and possible causes

<table>
<thead>
<tr>
<th>Driver Complaints</th>
<th>Observation of Seat Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower back</td>
<td>Absent or improper lumbar support</td>
</tr>
<tr>
<td>Neck/head</td>
<td>No headrest</td>
</tr>
<tr>
<td>Ankle/Leg</td>
<td>Inadequate support; Inadequate leg room</td>
</tr>
<tr>
<td>Thigh</td>
<td>Seat height is not adjustable</td>
</tr>
<tr>
<td>Arm/hand</td>
<td>No armrest</td>
</tr>
</tbody>
</table>

Table 2. Mean and standard deviation anthropometric.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stature</td>
<td>164.63</td>
<td>5.57</td>
</tr>
<tr>
<td>Weight</td>
<td>72.31</td>
<td>11.88</td>
</tr>
<tr>
<td>Eye height</td>
<td>115.28</td>
<td>4.57</td>
</tr>
<tr>
<td>Shoulder height</td>
<td>98.54</td>
<td>4.06</td>
</tr>
<tr>
<td>Elbow-rest-height</td>
<td>64.37</td>
<td>3.31</td>
</tr>
<tr>
<td>Knee height with shoes</td>
<td>52.79</td>
<td>3.06</td>
</tr>
<tr>
<td>Knee height without shoes</td>
<td>50.15</td>
<td>2.48</td>
</tr>
<tr>
<td>Popliteal height with shoes</td>
<td>43.06</td>
<td>2.53</td>
</tr>
<tr>
<td>Popliteal height w/o shoes</td>
<td>40.88</td>
<td>2.27</td>
</tr>
<tr>
<td>Elbow breadth</td>
<td>47.03</td>
<td>5.06</td>
</tr>
<tr>
<td>Hip breadth</td>
<td>35.23</td>
<td>4.11</td>
</tr>
<tr>
<td>Buttock-to-popliteal depth</td>
<td>43.47</td>
<td>3.04</td>
</tr>
<tr>
<td>Buttock-to-knee depth</td>
<td>54.10</td>
<td>3.37</td>
</tr>
<tr>
<td>Lumbar support height</td>
<td>42.50</td>
<td>9.16</td>
</tr>
</tbody>
</table>

Note: N=25, Units are in centimeters except for weight (kg).
Table 3. Measurements of current seat

<table>
<thead>
<tr>
<th>Seat dimension</th>
<th>Current measurement (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Seat pan</strong></td>
<td></td>
</tr>
<tr>
<td>Height</td>
<td>470-530</td>
</tr>
<tr>
<td>Width</td>
<td>440</td>
</tr>
<tr>
<td>Adjustability</td>
<td>Yes</td>
</tr>
<tr>
<td>Depth</td>
<td>500</td>
</tr>
<tr>
<td><strong>Backrest</strong></td>
<td></td>
</tr>
<tr>
<td>Height</td>
<td>500</td>
</tr>
<tr>
<td>Width</td>
<td>400</td>
</tr>
<tr>
<td>Lumbar support</td>
<td>200</td>
</tr>
<tr>
<td>Inclination</td>
<td>10°-15°</td>
</tr>
<tr>
<td><strong>Steering wheel</strong></td>
<td></td>
</tr>
<tr>
<td>Adjustability</td>
<td>Yes</td>
</tr>
<tr>
<td>Diameter</td>
<td>500</td>
</tr>
<tr>
<td>Height</td>
<td>600</td>
</tr>
</tbody>
</table>

3.5. Redesigning the current seat

3.5.1. Seat pan

Seat height:

Seat height for the current seat ranged from 470 mm to 530 mm. In general, the optimal seat height for many purposes is close to the popliteal height and where this cannot be achieved a seat that is too low is preferable to one that is too high. For many purposes, the 5th percentile female popliteal height represents the best compromise [16]. Based on the Malaysian bus driver’s anthropometrics data [10], for the 5th and 95th percentile popliteal height, the seat height should be 370 mm to 480 mm.

Seat depth:

The current seat depth is 500 mm. If the seat depth is greater than the buttock-popliteal length, the user cannot engage the backrest effectively without unacceptable pressure on the backs of the knees and problems with standing up and sitting down will also increase. The lower limit of seat depth is less easy to define. A depth as little as 300 mm will still support the ischial tuberosities and may well be satisfactory in some circumstances [16]. Therefore, based on the Malaysian anthropometrics data obtained, the seat depth should be 380 mm by referring to the 5th percentile male popliteal-buttock depth.

Seat width:

To support the buttocks, a width that is some 25 mm less on either side than the
maximum breadth of the hips is all that is required. Hence 350 mm will be adequate. However, clearance between armrests must be adequate for the largest user. The hip breadth of the 95th percentile male will be considered [16]. Since the current seat width is 440 mm, it is acceptable because the 95th percentile male Malaysian hip breadth for the bus drivers is 420 mm.

3.5.2. Backrest

The backrest parameters consist of backrest height, width, lumbar support and backrest inclination angles. The current backrest height is 500 mm. A medium-level backrest should be used to support the upper back and shoulder regions [16]. For support to the mid-thoracic level, the overall backrest height should be about 500 mm, and for full shoulder support about 650 mm (95th percentile male values rounded up). Whatever its height, preferably and sometimes essentially the backrest should be contoured to the shape of the spine, and in particular to give positive support to the lumbar region in the form of a convexity or pad. Based on the 95th percentile male sitting shoulder height, the height of the backrest should be 660 mm.

The backrest width of current seat is at 400 mm. The seat back width should allow users to be supported without arm interference. The shape should be convex from top to bottom to conform to the normal lordosis, and should be concave from side to side to conform to human anatomy and support the occupant in the seat [7]. Thus the 95th percentile male elbow-to-elbow breadth measurement of 560 mm is recommended to give full support for the back.

The high complaint of lower back pain is most probably due to the lack of lumbar support. Repeated high muscle activity in the lumbar region fatigues the lumbar muscles, so that the subjectively sensed fatigue is reported here [17]. The lumbar support should be placed in the lumbar region to achieve a more normal lordotic curvature when in the seated posture. To provide as much comfort as possible, the support should be adjustable in both height and size, and large enough to accommodate a wide range of users [2].

In the current seat design, the lumbar support is not adjustable. The lumbar support should be large enough to accommodate a wide range of users [2]. The lumbar support range of the 5th and 95th percentile anthropometric data was 180 mm to 280 mm.

The most important factor in reducing low back stress is the inclination angle of the seat back. The height and inclination of the seat pan combined with the position, shape, and inclination of the backrest influence the resulting seated posture [2]. A backrest inclination of about 110° from horizontal is considered appropriate posture [16], but greater inclination may be desirable by the user. The backrest tilt angle adjustment should be independent so that it has little or no effect on the front seat height or angle. Furthermore, increasing the angle between trunk and thighs improves lordosis. The backrest inclination for current seat is approximately in the range of 10-15° from the vertical seat reference point. Thus, no changes are required.
3.5.3. Armrests

Since the current seat was not provided with an armrest, it should be considered as an option. Armrests might give additional postural support and be an aid to standing up and sitting down [16]. They also support the arms to prevent or reduce arm, shoulder, and neck fatigue. A gap of perhaps 100 mm between the armrest and the seat back may, therefore, be desirable. An elbow rest that is somewhat lower than sitting elbow height is probably preferable to one that is higher, if a relaxed posture is to be achieved. An elbow rest at 200-250 mm above the seat surface is generally considered suitable.

The height of the armrest was set at the 5th percentile male elbow-rest height at 600 mm from floor level and approximately 210 mm above the seat surface. The adjustability of the armrest is proposed to accommodate the 95th percentile male as well. Therefore the range of the adjustable armrest would be 210 mm-230 mm above the seat surface. The armrests should be designed such that drivers can move them out of the way if they so prefer.

3.5.4. Headrest

A headrest is also proposed in the new design because it can help reduce fatigue in the neck and head muscles. The headrest will help to align the eye-view of drivers. Without a headrest, the neck muscles are used to align the eye-view of drivers and this contributes to fatigue of the driver’s neck after driving for a period of time. The headrest should be adjusted to a minimum of 50 mm up and down from the top of the seat backrest and a minimum of 40º forwards from the vertical to fully support the user’s head [2]. By using the 95th percentile male sitting eye height as guidance, the headrest dimension is proposed with adjustable height and its inclination range based on the literature.

The recommended seat design has numerous differences from the current seat (Table 4).

3.6. Simulation results

Seat designs were drawn using CAD, then exported into CATIA and integrated with a 3-D human model. The 3-D human model (manikin) was edited using the Malaysian bus drivers’ anthropometry data. All missing data were calculated using the ratio scaling method by referring to the Japanese population. Thus, the manikin in the software represents the Malaysian bus drivers’ population. The human is located on the seat using the H-point and Seat Reference point (SRP) relationship [18].

The bus operation task was simulated under kinematics constrains and adjustable components were located iteratively until the human-workstation model satisfied ergonomic principles such as visibility, reach, and comfort. A comparison was made for both seats (for a 5th percentile male (Figure 4) and for a 95th
Development and Evaluation of Bus Seat Dimension to Improve the Fit and Comfort of Malaysian Bus Drivers

percentile male (Figure 5)).

In the simulations, the current seat showed that it does not provide adequate backrest support for the 5th percentile male because existing seat pan is 500 mm long, but the 5th percentile popliteal-buttock depth is only 386 mm.

**Table 4. Summary of recommended seat design parameters (mm, except where noted)**

<table>
<thead>
<tr>
<th><strong>Seat dimension</strong></th>
<th><strong>Current</strong></th>
<th><strong>Recommended</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Seat pan</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height</td>
<td>470-530</td>
<td>370-480 (5th-95th%ile popliteal height)</td>
</tr>
<tr>
<td>Width</td>
<td>440</td>
<td>440 (95th%ile hip breadth + &lt; 25mm all round)</td>
</tr>
<tr>
<td>Adjustability</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Depth</td>
<td>500</td>
<td>380 (5th%ile buttock-popliteal length)</td>
</tr>
<tr>
<td><strong>Backrest</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height</td>
<td>500</td>
<td>660 (95th%ile sitting shoulder height)</td>
</tr>
<tr>
<td>Width</td>
<td>400</td>
<td>560 (95th%ile elbow-elbow breadth)</td>
</tr>
<tr>
<td>Lumbar support</td>
<td>200</td>
<td>180-280 (5th-95th%ile lumbar support height)</td>
</tr>
<tr>
<td>Inclination</td>
<td>10°-15°</td>
<td>10°-15° (literature)</td>
</tr>
<tr>
<td><strong>Armrest</strong></td>
<td>NA</td>
<td>210-230 (5th-95th%ile sitting elbow height above seat surface)</td>
</tr>
<tr>
<td><strong>Headrest</strong></td>
<td>NA</td>
<td>50 mm up/down</td>
</tr>
</tbody>
</table>

**Figure 4.** Comparison of current seat and recommended seat design for 5th percentile

**Figure 5.** Comparison of current seat and proposed seat for 95th percentile male bus drivers
Also, an extra leg support is required for the current seat, indicating that the seat is too high for the 5th percentile drivers. When support for the leg is inadequate, the pressure distribution on the thighs increases. Blood circulation is restricted and this contributes to thigh fatigue. Leg support is critical to better distribute and reduce the load on the buttocks and the back of the thighs. The weight of the lower legs should not be supported by the front part of the thighs resting on the seat. Pressure applied to the front part of the thighs, the portion close to the knees, can result in swelling of the legs and pressure on the sciatic nerve [18].

3.7. RULA analysis

The results of the RULA analysis for the 5th and 95th percentile for the final score of posture for current seat is 3 (Tables 5 and 7), whereas for the recommended seat, the score is 2 (Tables 6 and 8).

<table>
<thead>
<tr>
<th>Table 5. The RULA analysis for posture of current seat (5th percentile)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Arm and wrist analysis</strong></td>
</tr>
<tr>
<td>Upper arm position</td>
</tr>
<tr>
<td>Forearm position</td>
</tr>
<tr>
<td>Wrist position</td>
</tr>
<tr>
<td>Wrist twist</td>
</tr>
<tr>
<td>Posture score</td>
</tr>
<tr>
<td>Muscle use</td>
</tr>
<tr>
<td>Force/load</td>
</tr>
<tr>
<td>Wrist and arm</td>
</tr>
<tr>
<td><strong>Final score</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 6. The RULA analysis for posture of proposed seat (5th percentile)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Arm and wrist analysis</strong></td>
</tr>
<tr>
<td>Upper arm position</td>
</tr>
<tr>
<td>Forearm position</td>
</tr>
<tr>
<td>Wrist position</td>
</tr>
<tr>
<td>Wrist twist</td>
</tr>
<tr>
<td>Posture score</td>
</tr>
<tr>
<td>Muscle use</td>
</tr>
<tr>
<td>Force/load</td>
</tr>
<tr>
<td>Wrist and arm</td>
</tr>
<tr>
<td><strong>Final score</strong></td>
</tr>
</tbody>
</table>
Development and Evaluation of Bus Seat Dimension to Improve the Fit and Comfort of Malaysian Bus Drivers

Table 7. The RULA analysis of current seat (95th percentile)

<table>
<thead>
<tr>
<th>Arm and wrist analysis</th>
<th>Score</th>
<th>Neck, trunk and leg analysis</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper arm position</td>
<td>2</td>
<td>Neck position</td>
<td>4</td>
</tr>
<tr>
<td>Forearm position</td>
<td>2</td>
<td>Trunk position</td>
<td>3</td>
</tr>
<tr>
<td>Wrist position</td>
<td>1</td>
<td>Legs</td>
<td>1</td>
</tr>
<tr>
<td>Wrist twist</td>
<td>1</td>
<td>Posture score</td>
<td>3</td>
</tr>
<tr>
<td>Posture score</td>
<td>3</td>
<td>Muscle use</td>
<td>0</td>
</tr>
<tr>
<td>Muscle use</td>
<td>0</td>
<td>Force/load</td>
<td>0</td>
</tr>
<tr>
<td>Force/load</td>
<td>0</td>
<td>Neck, trunk and leg</td>
<td>3</td>
</tr>
<tr>
<td>Wrist and arm</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final score</td>
<td></td>
<td></td>
<td>3</td>
</tr>
</tbody>
</table>

Table 8. The RULA analysis for posture of proposed seat (95th percentile)

<table>
<thead>
<tr>
<th>Arm and wrist analysis</th>
<th>Score</th>
<th>Neck, trunk and leg analysis</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper arm position</td>
<td>1</td>
<td>Neck position</td>
<td>4</td>
</tr>
<tr>
<td>Forearm position</td>
<td>2</td>
<td>Trunk position</td>
<td>1</td>
</tr>
<tr>
<td>Wrist position</td>
<td>1</td>
<td>Legs</td>
<td>1</td>
</tr>
<tr>
<td>Wrist twist</td>
<td>1</td>
<td>Posture score</td>
<td>2</td>
</tr>
<tr>
<td>Posture score</td>
<td>2</td>
<td>Muscle use</td>
<td>0</td>
</tr>
<tr>
<td>Muscle use</td>
<td>0</td>
<td>Force/load</td>
<td>0</td>
</tr>
<tr>
<td>Force/load</td>
<td>0</td>
<td>Neck, trunk and leg</td>
<td>2</td>
</tr>
<tr>
<td>Wrist and arm</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final score</td>
<td></td>
<td></td>
<td>2</td>
</tr>
</tbody>
</table>

4. Discussion

The problems identified from the body part symptom survey can be attributed to the design of the chairs used. The low back pain is probably caused by the lack of lumbar support in the chairs which should be placed in the lumbar region to achieve a more normal lordotic curvature when in the seated posture. To provide as much comfort as possible, the support should be adjustable in both height and size [2].

The lack of a headrest may have contributed to the neck and head pains experienced by the respondents. The headrest, full-size backrest, and the seat pan should receive the weight of the head, the trunk, and the thighs [2].

Problems in the ankle, leg and thighs occurred probably due to inadequate support of the legs caused by incorrect seat height. Leg support is critical to better distribute and reduce the load on the buttocks and the back of the thighs. The weight of the lower legs should not be supported by the front part of the thighs resting on the seat. Pressure applied to the front part of the thighs; can result in swelling of the legs and pressure on the sciatic nerve [7].

More than half of the drivers were not happy with the height of the current seat.
The seat height adjustment of the current seat was not in working order. This may have caused the drivers not able to accommodate their legs adequately. If the seat is too low, the knee flexion angle becomes large and the weight of the trunk is transferred to the seat pan surface over a small area at the ischial tuberosities [7]. The large knee and hip angles soon become uncomfortable, and the spine is flexed as the pelvis rotates backwards. When the seat is too high, the feet do not reach the floor, so the pressure on the back of the thighs becomes uncomfortable. Individuals tend to slide forward to the front of the seat. This allows the feet to be supported, but the seat back is not used properly to support the back. The seat height should be adjustable so that the feet can rest firmly on the floor with minimal pressure beneath the thighs.

Although only 15 respondents reported pain in their arm and hand, an armrest is important in providing support for the arm and in reducing fatigue to the arm, shoulder and neck. A seat should allow for relaxation of the muscles not required for the task as well as for intermittent relaxation of those that are [19].

More than half of the drivers complained that the leg room is inadequate. Adequate leg room is essential for the operator to adopt a satisfactory posture. The leg room was found to be constrained by the steering wheel. Drivers were observed to have difficulty sitting in the seat smoothly because of inadequate leg room between the seat and steering wheel. The lateral leg room must give clearance for the thighs and knees [17]. For vertical leg room, in some circumstances will be determined by the knee height of a tall user (95th percentile). A more relevant measurement would be to consider the thigh clearance above the highest seat height position using the 95th percentile male popliteal height and thigh thickness. The knee clearance is determined by buttock-knee length (95th percentile male) from the back of a fixed seat. Forward leg room is rather more difficult to calculate.

According to the literature, a RULA score of 3 or more indicates that further investigation is needed and that change may be required. With the recommended seat, the final score was reduced to 2 (Tables 6 and 8). This indicates that the posture is acceptable if it is not maintained or repeated for long periods of time.

Therefore, from the simulation results, the recommended seat design is acceptable because it can help reduce drivers’ fatigue while driving, especially in improving the posture of the arm and wrist and for the trunk and legs. A more comfortable seat will increase the performance of the bus drivers. However, though the overall score for the posture has improved, the score was 4 for the neck position of the 95th percentile in both the current and recommended seat design, and this is cause for concern. Further investigation must be conducted out to identify further the cause of this problem.

5. Conclusions and recommendations

A seat designed based on anthropometry of the users showed has better ergonomics than the current seat. RULA analysis indicated that the new seat is more comfortable than the current seat. The next step is to fabricate the seat and test it using bus drivers in a real environment. The dimensions of the recommended seat
parameters (Table 4) will accommodate 90 percent of Malaysian bus driver’s population and it can probably be used as a guide in designing the driver’s seat for other Asian bus drivers. The importance of designing using the anthropometric dimensions of the users has been shown in several studies [11, 12, 13, 14].

However the study has been limited to bus drivers in one region. A bigger sample which includes other regions may provide more accurate anthropometry data. Also different buses may have different seat designs that should be evaluated.

Though the use of RULA maybe subjective, it has been used in many studies to direct attention to design shortcomings. Due to its rapid assessment, potential problems can be identified earlier and actions taken much faster.

Also, the simulation was carried out only between the seat and the bus drivers. Bus driving is more complicated because it entails the various interactions with the dashboard, steering wheel and other aspects of driving in which the posture of the bus drivers maybe affected and compromised. The effect of these interactions on posture must also be studied.

References


Paquet, V. and Feathers, D., 2004. An Anthropometric study of manual and
powered wheelchair users. Int. J. of Industrial Ergonomics, 33, pp.191-204.

Rosnah Mohd. Yusuff

Dr. Rosnah Mohd. Yusuff is an Associate Professor in the Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, Universiti Putra Malaysia. She obtained her first degree from the University of Iowa, USA and her Masters degree from the same University in Industrial Engineering and Management and her PhD from Universiti Putra Malaysia in Manufacturing Systems. Her research areas of interest are ergonomics in systems and product design, msds, and in industrial engineering and management. She is currently an executive council member of Pan Pacific Council on Ergonomics, a council member of the Malaysian society of Engineering and Technology editorial committee of Asian Journal of Ergonomics and Asian journal of Science and Technology in Production and Manufacturing Engineering (AIJSTPME). She also represents Malaysia in South East Asia network of Ergonomics (SEANES).
Mohd Shahir Yahya

Mr. Mohd Shahir Yahya is currently a lecturer at Universiti Tun Hussein Onn Malaysia. He received his bachelor’s degree in Mechanical (Industrial) Engineering from Universiti Teknologi Malaysia and Masters degree in Manufacturing System Engineering from Universiti Putra Malaysia. He is also a graduate member of Board of Engineer Malaysia. He has conducted and supervised research projects covering several areas of ergonomics. His current research interest is on application of ergonomics in product design.

Shamsul Bahri Mohd Tamrin

Shamsul Bahri Mohd Tamrin is a senior lecturer working in the Faculty of Medicine and Health Sciences, Universiti Putra Malaysia with 11 years experienced in the field of industrial hygiene and ergonomics. His research areas of interest are in industrial hygiene and ergonomics. He received his Bachelor in Doctor Veterinary Medicine from Universiti Putra Malaysia and MS degree in Public Health from Universiti Kebangsaan Malaysia. He obtained his PhD in Occupational & Environmental Health from Mie University, Japan.

Wan Chik Zaharah Wan Hassan

Wan Chik Zaharah Wan Hassan graduated with a Masters degree from Universiti Putra Malaysia and received her Bachelor degree in Civil & Structural Engineering from Universiti Kebangsaan Malaysia in Selangor. Her research interests are in occupational ergonomics, work posture risk analysis (MSDs), affective human factors design, industrial hygiene, occupational safety & health management system, environment and civil engineering.
Data entry task in mobile computing: effects of vibration, display colour, and user age

ZULQUERNAIN MALLICK*

Department of Mechanical Engineering, Jamia Millia Islamia, New-Delhi-110025 (India)

Abstract

Mobile computing devices are expected to become more ubiquitous in the near future. This study attempts to quantify the influence of text and background (text/background) colours in laptop displays on the accuracy of data entry operators in an automobile. The accuracy of input by operators was quantified under varying levels of vehicular vibrations and combinations of text and background colour. Data entry accuracy was significantly affected by vehicular vibration and text/background colour of the laptop display. The findings suggest that designs of off-desktop computers should consider vibration-induced stresses that occur when users enter data while riding in a vehicle, and that proper text/background colour combinations should be chosen.

Keywords: Vehicular vibration, Data entry, Text/background, driving environment, age

1. Introduction

The use of Visual Display Units (VDUs) is increasing rapidly, and recently emerging technologies based on Wireless Application Protocol (WAP) like lap-tops and palmtops are expected to be commonly used in future Human Computer Interaction (HCI). Such systems will be widely used in mobile settings, so the capacity of such systems to meet user needs must be evaluated ergonomically in mobile HCI environments.

Designing user interfaces for off-desktop computing, like mobile computing on laptop and similar devices faces many challenges. Effective interfaces for text input and data entry are surprisingly difficult to design. Text writing constitutes one of the most frequent computer user tasks. The need for an effective interface for entering text off the desktop has driven numerous inventions in text entry, although

* Corresponding author: zmallick2002@yahoo.co.in, Phone: 091-11-26981259
most have not been properly evaluated using either theoretically or empirically.

Several factors may affect user performance when using VDUs for data entry or to search for items on the screen. These factors include vibration, the color of the text and the background, and user age. Therefore, these factors must be considered when designing devices for use in mobile settings.

The colours of the text and of the background (text/background) on a display affect user performance, especially in desktop and lap-top type computing systems. The text/background colours on a display affect user performance, especially in desktop and lap-top type computing systems. Users prefer a high contrast between text and background colour (Ling and Shaik 2002). Appropriately-chosen colours can also help convey information quickly. The readability of text increases with luminance contrast between the text and background colors (Shieh and Lin 2002) and users can find targets more quickly as color difference between the text and background increases (Wang et al. 2002). Normally, mobile computing is done during the day time; sunlight may cause glare, so a dark background and white text may be the best option.

Older people enter data more slowly than middle-aged and younger people (Khan 2002). People of different ages use computing systems in mobile environments, so possible age-related effects on task completion should be assessed, but little work has been done to do so. In tasks that require divided attention, performance of the task involved was significantly affected by age (Salthouse, 1982; Kaulser 1982). Younger subjects perform better than older subjects (Burke et al. 1980), and the time required to allocate attention increases with age (Madden 1992). The objective of this study was to quantify the combined effects of vibration, colour of text and background, and user age on users’ accuracy while entering data in a mobile environment.

2. Methods

2.1. Subjects

Forty-two male subjects’ different ages participated in this study; all had normal vision either with or without the aid of glasses, and none had any history of neuromuscular disorders. The subjects chosen had almost the same amount of experience with working on lap-computers in a stationary (zero-vibration) environment. The subjects selected were divided into three groups: 18-32, 33-47 and 48-62 years old. Each group included 14 subjects. Users’ input speed was measured as the number of characters entered per minute without spaces (NCEPMWS); to avoid any temporal effect that might affect subjects’ performance, data were recorded at approximately the same time of day throughout the experiment.

2.2. Stimuli and experimental task

A lap-top computer (Armada 1500, Compaq) was employed in all experiments.
The sensor of the vibration level meter was kept at a specially designed platform which did not affect the impact of vibration and the display was kept in front of the experimenter to allow him to constantly monitor the level of vibration.

The mean value of the angle between eye level and the centre of the screen of the lap-top for all the subjects was kept at approximately 15° (SD = 3.16°). The temperature of the vehicle was maintained at approximately 26 ± 3 °C. While performing the experimental task the level of vibration in the driving environment was kept at a specified value by constantly monitoring the level of vibration in the x, y and z directions and running the vehicle at the appropriate speed.

Before the actual experiment in the test vehicle, a trial session was arranged; this was done for two purposes. The first purpose was to familiarize the subjects with the experimental procedure; the second was to determine the reaction of the subject in connection with the recorded text input in the audio-cassette that was replayed during the experimental session. Subjects did not adapt easily to this style of stimulus presentation style; therefore one experimenter sat beside of the subject and read the text to be entered. Out of 42 subjects 32 preferred this style of stimulus presentation but requested slow speed reading so that the text entry task could be completed without difficulty. Subjects were required to sit on the vehicle seat (without back rest) with the two hands on the keyboard (as was observed to be the practice of the end-users) while working on VDUs. Before performing the experimental task (data entry), the subject sat in the vehicle at a prespecified level of vibration for 60 minute and then the stimulus was presented to him. Each text entry task required 10 minutes. After completion of the task at each level of vibration separately, the content entered was saved with the name of the subject and later downloaded later to check it for errors. Subjects were allowed to rest for 30 min between successive trials; during this period they were isolated from the driving environment. Two text/background color employed in this experiment: black characters on white background and white characters on black background. The experimental task was repeated for both text/background colour combinations.

2.3. Experimental Set-up

Experimental investigations were carried out in a real life driving environment on a passenger car (Waja) manufactured in Malaysia. This particular type of car was chosen because ~ 65% of Malaysian people use this car. This car has a 1597-cc S4PH 4-cylinder 16-valve DOHC engine that has a maximum power of 82 kW at 6000 rpm, a maximum torque of 148 Nm at 4000 rpm, and a multi-point fuel injection system. The bore of this engine is 76.0 mm and its stroke is 88.0 mm. The front suspension uses a MacPherson strut with a stabilizer bar; the rear suspension uses Multilink with stabilizer bar. The car is 4465 mm long, 1740 mm wide, 1420 mm high and has a wheelbase of 2600 mm. Its maximum speed is 190 km/h.

The experimental setup (Figure 1) was comprised several sub-systems: a vibration level meter (Brue & Kjaer Deltatron, Type 4504), a 12-volt battery for energizing the amplifier (Brue & Kjaer, Type 2260), a digital lap-top Armada 1500 (Compaq).
2.4. Error and error handling

Another important dimension to consider in such experiments is the error rate. What matters is the effective speed, or speed after correction. Different methods of handling errors can be used; each has different implications to the text input study result. Some leave errors in the text and report them separately (MacKenzie and Zhang, 1999). Others do not allow errors, e.g. the testing program will not proceed until the correct character is entered (Zhai et al., 2002). Yet others require the participants to correct their errors, and measure their effective speed including error correction. The amount of time needed to correct errors depends on the design of the error correction mechanism; hence no set rules exist to compare tradeoffs between error and speed. Typing accuracy is defined as the percentage of characters correctly typed. In this experiment, error was counted on the basis of characters typed correctly. For example:

- Given Text: Please come to meet me at the play ground where match will be played.
- Entered Text: Please come to meet me at the flat ground where match well be played.

The given sentence has 55 characters without spaces and the entered text has two errors, one in the word ‘Please’ and the second in the word ‘Play’. Therefore the error rate is \((2/55) \times 100 = 3.63\%\) and typing accuracy is \((100 - 3.63) = 96.37\%\).

Data entry task performance is often measured in words per minute (WPM). In the present research performance of operators were measured in NCEPMWS. This style was adopted to nullify the subjects’ habit of leaving single or double spacing between words while performing data entry task.

![Figure 1](image-url). Schematic diagram of experimental set-up employed in all the experimental investigations undertaken in the present work without vibration (zero level) and vibration with vibration levels of 0.85 and 1.65 \(m/s^2\) in the HCI environment.
2.5. Measurement of vibration

For vibration measurement the evaluation procedure ISO 2631-1: 1997 was adopted. A tri-axial accelerometer (Deltatron Type 4505, Bruel & Kjaer) was mounted on the test vehicle seat to register the vibration level. This accelerometer has a detection range of 5 m/s$^2$ to 7500 m/s$^2$ and a frequency range of 1 Hz to 1000 Hz. This instrument can make simultaneous measurements in X, Y and Z directions. The vibration level meter was calibrated in the X, Y and Z directions before measurement. To check the suitability of the basic evaluation method, the crest factor was calculated for X, Y and Z directions. According to ISO 2631-1 (1997), the crest factor is defined as the modulus of the ratio of the maximum instantaneous peak value of the frequency-weighted acceleration signal to its root-mean-square (rms) value. The crest factor values for the X, Y and Z directions obtained were within the limit prescribed by ISO 2631-1 (1997). For vibration with crest factors $\leq 9$, the basic evaluation method is normally sufficient. The accelerometer was connected to a Whole Body Vibration front end (Bruel & Kjaer Type 2693) and this was connected to modular sound level meter (Bruel & Kjaer Type 2260) which was used for both data collection and display; data were later downloaded to a PC for further analysis. Total equivalent vibration was calculated using ISO 2631-1 (1997) recommendations. The vibration levels were measured with respect to the standard biodynamic coordinate system (Figure 2). Equivalent vibration level means the average power of the vibration measured in a specific period of time and was derived from the equivalent noise level of the sound level meter.

\[
\text{Total equivalent vibration} = \sqrt{\left(\frac{a_{wx}}{1.4}\right)^2 + \left(\frac{a_{wy}}{1.4}\right)^2 + \left(\frac{a_{wz}}{1}\right)^2}
\]

(1)

Where:

$a_{wx}$, $a_{wy}$ and $a_{wz}$ are the weighted rms acceleration values in the X, Y and Z directions respectively, and the factor 1.4 is the ratio of the longitudinal to the transverse acceleration limits for the frequency range in which humans are sensitive.

The total vibration varied from 0.30 m/s$^2$ to 1.75 m/s$^2$ (Table 1). The vibration levels for the present study were set at 0, 0.85 or 1.65 m/s$^2$. Zero vibration occurred only when the vehicle was not moving. Measurements at this level were necessary to determine the base line NCEPMWS value of the subjects.

Figure 2. Whole body vibration biodynamic coordinate system for a seated subject
3. Results

Three experiments were conducted to study the effect of experience level on data entry task performance.

3.1. Experiment 1

In this experiment, the subjects of 48-62 years of age were tested for the data entry task performance under varying levels of vibration and text/background color combination (Figure 3).

Analysis of variance (ANOVA) (Table 2) implied that the effects of vibration and color combination of the text and background, and the interaction of these two factors, were statistically significant.

The significant interaction between the vehicular vibration level and the text/background color combination necessitated an analysis of the simple main effects; the result (Table 3) indicated that level of vibration interacted significantly with text/background color combination only at 0.85 m/s² and 1.65 m/s² for (48-62 year-old) subjects in the real driving environment. However, the same was not true in case of vibration level under the varying levels of text/background color combination, i.e., black characters on white background and white characters on black background. The mathematical relationship between NCEMWS for varying levels of vibration under the influence of particular text/background color combination was explored for subjects of age group 45-55 Years and the following models were obtained:

\[
(CE)_{B1} = 50.86 - 5.01V \\
(CE)_{B2} = 68.72 - 8.24V
\]

Where \((CE)_{B1}\) and \((CE)_{B2}\) represent characters entered per minute without spaces for text/background color combinations B1 (black characters on white background) and B2 (white characters on black background), and \(V\) is the value of vibration considered in this study (0, 0.85 m/s² and 1.65 m/s²).

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>(F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Subjects (S)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Within Subjects</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A (Vibration)</td>
<td>1015.19</td>
<td>9</td>
<td>507.59</td>
<td>8.32</td>
</tr>
<tr>
<td>A x S (Error I)</td>
<td>1097.64</td>
<td>18</td>
<td>60.98</td>
<td></td>
</tr>
<tr>
<td>B (Text/ background color)</td>
<td>686.72</td>
<td>1</td>
<td>686.72</td>
<td>10.94</td>
</tr>
<tr>
<td>B x S (Error II)</td>
<td>564.75</td>
<td>9</td>
<td>62.75</td>
<td></td>
</tr>
<tr>
<td>A x B</td>
<td>660.20</td>
<td>2</td>
<td>330.10</td>
<td>6.02</td>
</tr>
</tbody>
</table>

Table 2. Analysis of variance of vibration effects when operators (48-62 Years) performed the data entry task under varying levels of vibration and text/background color combination.
Data entry task in mobile computing: effects of vibration, display colour, and user age

Figure 3. Comparison of operators performance (in NCEPMWS) for varying levels of vibration and text/background color combination for subjects of age group 48-62 Years (B1: black character on white background, B2: white character on black background)

Figure 4. Comparison of operators’ performance (in NCEPMWS) for varying levels of vibration and text/background color combination for subjects of age group of 33-47 Years. (B1: black character on white background, B2: white character on black background)

Table 3. Analysis of Simple Main Effects when Subjects (48-62 Years) Performed the Data Entry task at varying levels of text/background color combination under varying levels of equivalent vehicular vibration

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>SS</th>
<th>Df</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>B (Text/background color combination)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At A1 (vibration level 1)</td>
<td>26.70</td>
<td>1</td>
<td>26.70</td>
<td>0.97</td>
</tr>
<tr>
<td>At A2 (vibration level 2)</td>
<td>138.20</td>
<td>1</td>
<td>138.20</td>
<td>5.02*</td>
</tr>
<tr>
<td>At A3 (vibration level 3)</td>
<td>168.48</td>
<td>1</td>
<td>168.48</td>
<td>6.12*</td>
</tr>
<tr>
<td>B x S (Error)</td>
<td>495.54</td>
<td>18</td>
<td>27.53</td>
<td></td>
</tr>
<tr>
<td>A (Vibration Level)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At B1 (White character on black background)</td>
<td>35.42</td>
<td>2</td>
<td>17.71</td>
<td>0.87</td>
</tr>
</tbody>
</table>

3.2. Experiment 2

In this experiment, the 33-47 year-old subjects were tested for the data entry task performance under varying levels of vibration and text/background color
combination (Figure 4). ANOVA (Table 4) implied that the effects of vibration and color combination of the text and background, and the interaction of these two factors, were statistically significant.

The significant interaction between the vehicular vibration level and the text/background color combination necessitated an analysis of the simple main effects; results (Table 5) indicated that level of vibration interacted significantly with text/background color combination only at 1.65 m/s² for subjects (aged 33-47 years) in the real driving environment. However, the same was not true in case of vibration level under the varying levels of text/background color combination, i.e., black character on white background and vice versa. The mathematical relationship between NCEPMWS for varying levels of equivalent vibration under the influence of particular text/background color combination was explored for age group of 33-47 years; the following models were obtained:

\[
(\text{CE})_{B1} = 89.72 - 25.24V
\]

\[
(\text{CE})_{B2} = 98.86 - 30.81V
\]

Where variables are defined as for Eqs. (2) and (3).

Table 4. Summary of ANOVA pertaining to the studies of vibration effects when operators (33-47 years old) performed the data entry task under varying levels of vibration and text/background color combination

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Subjects (S)</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Within Subjects</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A (Vibration)</td>
<td>1165.74</td>
<td>2</td>
<td>582.87</td>
<td>9.32*</td>
</tr>
<tr>
<td>A x S (Error I)</td>
<td>1125.72</td>
<td>18</td>
<td>62.54</td>
<td></td>
</tr>
<tr>
<td>B (Text/background color)</td>
<td>471.93</td>
<td>1</td>
<td>471.93</td>
<td>8.12*</td>
</tr>
<tr>
<td>B x S (Error II)</td>
<td>523.08</td>
<td>9</td>
<td>58.12</td>
<td></td>
</tr>
<tr>
<td>A x B</td>
<td>777.16</td>
<td>2</td>
<td>388.58</td>
<td>7.18*</td>
</tr>
<tr>
<td>A x B x S (Error III)</td>
<td>974.16</td>
<td>18</td>
<td>54.12</td>
<td></td>
</tr>
</tbody>
</table>

![Figure 4. Comparison of operator’s performance (in NCEPMWS) for varying levels of vibration and text/background color combination for subjects of age group of 33-47 Years. (B1: black character on white background, B2: white Character on black background)](image-url)
Table 5. Analysis of Simple Main Effects when Subjects Performed the Data Entry task at varying levels of text/background color combination under varying levels of vehicular vibration for subjects of age group of 33-47 Years.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>B (Text/background color combination)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At A1 (vibration level 1)</td>
<td>30.18</td>
<td>1</td>
<td>30.18</td>
<td>1.24</td>
</tr>
<tr>
<td>At A2 (vibration level 2)</td>
<td>87.13</td>
<td>1</td>
<td>87.13</td>
<td>3.58</td>
</tr>
<tr>
<td>At A3 (vibration level 3)</td>
<td>300.84</td>
<td>1</td>
<td>300.84</td>
<td>12.36</td>
</tr>
<tr>
<td>BX S (Error)</td>
<td>438.12</td>
<td>18</td>
<td>24.34</td>
<td></td>
</tr>
<tr>
<td>A (Vibration Level)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At B1 (White character on black background)</td>
<td>82.66</td>
<td>2</td>
<td>41.33</td>
<td>1.89</td>
</tr>
<tr>
<td>At B2 (Black character on white background)</td>
<td>71.73</td>
<td>2</td>
<td>35.86</td>
<td>1.64</td>
</tr>
<tr>
<td>AX S (Error)</td>
<td>393.66</td>
<td>18</td>
<td>21.87</td>
<td></td>
</tr>
</tbody>
</table>

3.3. Experiment 3

In this experiment, the young subjects (18-32 years old) were tested for the data entry task performance under varying levels of vibration and text/background color combination (Figure 5).

ANOVA (Table 6) implied that the effect of vibration was statically significant, the effect of text/background color not statistically significant, and the interaction between the vibration and text/background was statistically significant.

The significant interaction between the vehicular vibration level and the text/background color combination necessitated an analysis of the simple main effects; results (Table 7) indicated that level of vibration interacted significant with text/background color combination only when vibration was 0.85 m/s$^2$ and 1.65 m/s$^2$. However, the same was not true in case of vibration level under the varying levels of text/background color combination, i.e. black character on white background and vice versa. The mathematical relationship between the number of characters entered per minute without spaces for varying levels of vibration under the influence of particular text/background color combination was explored for subjects of age group 18-32 Years and model obtained is as follows

$$(CE)_{B1} = 103.82 - 30.24V$$  \hspace{1cm} (6)

$$(CE)_{B2} = 98.27 - 14.54V$$  \hspace{1cm} (7)

Where symbols have the same meanings as in Eqs. (2) and (3).
Figure 5. Comparison of operators performance (in NCEPMWS) for varying levels of vibration and text/background color combination for subjects of age group 18-32 Years. (B1: lack character on white background and white character on black background)

Table 6. Summary of the analysis of variance (ANOVA) pertaining to the studies of vibration effects when operators (18-32 Years) performed the data entry task under varying levels of text/background color combination

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between S&lt;sub&gt;t&lt;/sub&gt;</td>
<td>2006.78</td>
<td>2</td>
<td>1003.39</td>
<td>15.27*</td>
</tr>
<tr>
<td>Within S&lt;sub&gt;t&lt;/sub&gt;</td>
<td>64.45</td>
<td>1</td>
<td>64.45</td>
<td>1.24</td>
</tr>
<tr>
<td>A (Vibration)</td>
<td>1182.78</td>
<td>18</td>
<td>65.71</td>
<td></td>
</tr>
<tr>
<td>A X S&lt;sub&gt;t&lt;/sub&gt; (Error I)</td>
<td>467.82</td>
<td>9</td>
<td>51.98</td>
<td></td>
</tr>
<tr>
<td>B (Text/background color)</td>
<td>1115.12</td>
<td>2</td>
<td>557.56</td>
<td>10.98*</td>
</tr>
<tr>
<td>AXB</td>
<td>914.04</td>
<td>18</td>
<td>50.78</td>
<td></td>
</tr>
</tbody>
</table>

Table 7. Analysis of Simple Main Effects when Subjects Performed the Data Entry task at varying levels of text/background color combination under varying levels of vehicular vibration for subjects of age group 18-32 Years.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>B (Text/background color combination)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At A1 (vibration level 1)</td>
<td>91.76</td>
<td>1</td>
<td>91.76</td>
<td>2.64</td>
</tr>
<tr>
<td>At A2 (vibration level 2)</td>
<td>683.03</td>
<td>1</td>
<td>683.03</td>
<td>19.65</td>
</tr>
<tr>
<td>At A3 (vibration level 3)</td>
<td>408.77</td>
<td>1</td>
<td>408.77</td>
<td>11.76</td>
</tr>
<tr>
<td>BX S&lt;sub&gt;t&lt;/sub&gt; (Error)</td>
<td>625.66</td>
<td>18</td>
<td>34.76</td>
<td></td>
</tr>
<tr>
<td>A (Vibration Level)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At B1 (White character on black background)</td>
<td>167.12</td>
<td>2</td>
<td>83.56</td>
<td>3.23</td>
</tr>
<tr>
<td>At B2 (Black character on white background)</td>
<td>63.12</td>
<td>2</td>
<td>31.56</td>
<td>1.22</td>
</tr>
<tr>
<td>AXS&lt;sub&gt;t&lt;/sub&gt; (Error)</td>
<td>465.66</td>
<td>18</td>
<td>25.87</td>
<td></td>
</tr>
</tbody>
</table>
4. Discussion

People of different ages perform different kinds of computer related tasks in mobile settings; the results of this study reveal that people of different ages are not equally efficient in performing data entry in a mobile setting. The level of vibration significantly affects operators’ data-entry performance. Several studies have reported the effect of vibration on readability task but vibration’s effect on data entry task performance appears not to have been explored. Reduction in reading performance is dependent on the vibration frequency with a maximum reduction of visual acuity at a frequency of 12.5 Hz (Ishitake 1998). Subjects aged from 19-26 years had difficulty in recognizing characters and graphic patterns containing horizontal lines, and developed eyestrain in the presence of 5-Hz sinusoidal single and dual axis (vertical and lateral) whole-body vibration (Griefahn et al. 2000).

Another major finding of the present work is that the text/background color combination has a significant effect on operators’ data-entry performance. Similar results were reported by Wang et al. (2002) who reported that subjects’ searching performance while reading a display improved when the color difference between text and background increased, and by Shieh and Lin (2000), who indicated that visual identification performance and subjective preferences increased as the luminance contrast of the between text and background colors.

The polarity of the contrast is also important. Polarity is positive when dark letters are displayed on light backgrounds and negative in the reverse case. Displays with a positive polarity are easier to read than those with negative polarity because positive-polarity displays typically have higher luminance than negative-polarity displays (Buchner et al. 2009). Readibility of text presented on computer screens (e.g. on websites) is better when the overall display luminance level is high, as in positive polarity displays (dark letters on light background). The interaction between jump length and color combination of a reading display also has a significant effect on subjects’ reading performance (Wang and Chen 2003).

Another major finding of the present work is that the interaction of vibration with color combination is statistically significant. In the mobile environment the level of light is reasonably high because sunlight enters without any hindrance. Light falling on the screen may be source of glare and because the screen of the lap-top cannot maintain a definite viewing angle due to vehicle vibration, the combined effect of the vibration and text/background color combination may affect the performance of the operator. Subjects performed data entry tasks more successfully when white text was displayed on a black background (B2) than in the reverse case; this may be a result of the glare effect.

References


Khan, Z. A., 2000. Ergonomic investigation on human performance in HCl environment involving operations on desktop and laptop systems under the impact of organismic variable and noise-incursed stresses: Jamia Millia Islamia,


Zulquernain Mallick

Zulquernain Mallick received the B.Sc. degree in Mechanical Engineering and the M.Sc. degree in Industrial and production engineering from Aligarh Muslim University, Aligarh, India, in 1987 and 1989, respectively, and the Ph.D. degree from Jamia Millia Islamia, New Delhi, India, in 2002 in Mechanical Engineering. He is associated with the Department of Mechanical Jamia Millia Islamia, New Delhi. He has more than 60 publications in international and national conferences and journals and is the coauthor of one book titled “Engineering Materials and their Manufacturing”. 
Cognitive performance of grass trimmers in noisy conditions – the effect of user age

Zulquernain Mallick*

Department of Mechanical Engineering, Jamia Millia Islamia, India

Abstract

Operators engaged grass trimming using backpack type trimmers encounter high levels of noise generated by the machine. This study determined that workers’ cognitive ability was significantly affected by task difficulty index, amount of user experience, and noise level. The interaction between difficulty index and noise level was also significant. The findings suggest that grass trimmers must be protected from cognitive degradation by applying suitable devices or reducing the noise level.

Keywords: Novices, Intermediate, Experienced. Reaction Time, Noise

1. Introduction

Noise is recognized as a serious health problem in modern societies (Ising and Kruppa, 2004; Muzet, 2002). Direct effects of noise on various human cognitive abilities have been demonstrated, including long-term memory, mental arithmetic ability, and ability to complete visual tasks (Cohsen, 1981; Hockey, 1970; Jerison, 1959). The level of noise necessary to produce adverse effects greatly depends upon the type of task (Suter, 1991). Human abilities to perform simple tasks remain unaffected at noise level as high as 115 dB or above, whereas their ability to perform more complex tasks can be reduced even at much lower noise levels.

The effects of noise on humans depend on its spectral frequency and the duration of exposure. High-frequency sound is more disruptive than low-frequency sound, and intermittent noise can reduce performance more than continuous noise of equivalent energy. The concept of a maximum daily noise dose can be used to correctly assess noise-induced effects. A practical approach to assessing the noise health hazard is to use the index dBA (Burns and Robinson, 1970). OSHA has specified 90 dBA as the maximum permissible exposure to continuous noise in an

* Corresponding author: zmallick2002@yahoo.co.in, Tel: +091-11-26981259
8-hour shift.

Age related decrements in performance of sustained attention tasks have been reported (Parasuraman and Giambara, 1990), and although the allocation of attention across trials is similar for young and older subjects, time required to allocate attention increases with age (Madden, 1992). Dual task situation reaction time for older subjects is greater than that of younger ones (McDowd and Craik, 1988). No significant age effect occurs when tasks require divided attention (Somberg and Salthouse, 1982). The presence of vibrations in a working environment stresses workers and leads to poor task performance, particularly in visual tasks, motor tasks and cognitive tasks.

Gasoline-engine grass trimming machines are widely used in Malaysia for cutting grass along roadsides and on agricultural land. These machines generate noise of 132 to 138 dBA, which exceeds OSHA guidelines. One likely outcome of exposure to this level of noise for 5 to 6 hours daily is a decrease in the cognitive ability of the workers involved in this profession. Cognitive ability and mental well-being of operators in any profession is very important. Numerous people are involved in this profession and ensuring workers’ safety from all points of view is an employer’s obligation. This study was conducted to quantify the effects of noise exposure on workers’ cognitive ability and to suggest possible ways to mitigate them. The results will help employers to protect their employees.

2. Methods

2.1. Subjects

Ninety subjects contract workers who trim grass along highways were tested, 30 each of Novice (experience, a few months), Intermediate (experience ≤ 2 years), and Experienced (experience ≥ 5 years) operators. None of the subjects had any neuromuscular disorder. Subjects were divided into two age groups: 25-40 years (mean 31.4 years; SD 4.92 years) and > 40 years (mean 47.8 years; SD 4.60 years).

2.2. Grass cutting and noise

Gas-engine grass trimming machines are widely used in Malaysia for cutting long grass along roadsides and general agricultural land. A gas-powered backpack type (Tanaka SUM 328SE, appendix B) grass trimmer generates a large amount of noise while in operation. Workers involved in this profession work for about 8 hours a day and are exposed to noise levels of 116-145 dBA. The noise level was measured using a sound level meter (Bruel & Kjaer Observer Type 2260), which is also a data storage and display device. Data were downloaded to a personal computer for further analysis. This sound level meter was calibrated before the experiment. Figure 1 shows the example of observation taken for level of noise with the sound level meter (Figure 1). Noise level was also recorded on an audio cassette. This was done for the purpose of playing the audio cassette in a simulated
environment to conduct the experiment.

2.3. Personal interview

Before the actual experiment personal interview was conducted to qualitatively assess noise-induced effects on the grass trimmers. Workers were questioned about such matters as the feeling of annoyance, quality of sleep, whether they were well-rested after sleep, and enjoyment of leisure time. Workers were also asked their age, the period for which they had worked as grass trimmers, and whether they were had health problem before entering in the profession. Only those who reported no health complaints before entering in this profession were used in the experiment. Workers who had been grass trimmers for more than five years or so mostly reported sleep disturbances, irritability, inability to fully enjoy leisure time, not feeling fresh even after sleep. These complaints were less frequent in workers who had been grass trimmers for less than two years. New workers did not report such effects.

2.4. Difficulty Index

Three difficulty indices were defined in this study: level 1 (one possible response); difficulty; index 2 (two possible responses) and level 3 (three possible responses).

![Figure 1. Observation sheet showing example of noise level during grass trimming operation](image-url)
2.5. Noise levels

In a preliminary study to determine the level of noise to which operators were subjected while trimming grass, the level of noise varied from 116 dBA to 145 dBA; therefore the noise levels in this experiment were set at 116, 126, 136 and 145 dBA.

2.6. Experimental set-up

Experiment was conducted in a 4.9 x 4.6 x 2.9 m (L x W x H) room. The temperature was maintained approximately at 25 ± 2° C. Light reflection from windows and doors was eliminated. When the room was closed, it was acoustically sealed from the outside environment. A human response measurement system (Figure 2) was used to measure reaction times in milliseconds. Circuit-1 and Circuit-2 were part of the experimental set-up that included LEDs of different colors.

2.7. Stimuli and general experimental procedure

Circuit-1 and Circuit-2 (Figure 2) were fabricated specially for this experiment on two plastic boards and were placed in front of the subjects when they were required to perform the experimental task. Circuit-1 was used for presenting the stimuli to the subjects, and Circuit-2 was used to measure their responses. Before the actual experimentation, a pilot study was undertaken. During this study, each subject was briefed about the objective of the experiment, and the methods used. Subjects were instructed to adopt a normal sitting posture while performing the experimental task. Each subject was given a training session to familiarize him with the experimental procedure.

Figure 2. Schematic diagram of the experimental setup
Three tasks were assigned, which had different levels of difficulty. In all tasks, subjects were required to switch on the same color of LED at Circuit-2 by observing the glowing LED and its color at Circuit-1. In the simplest task (Difficulty Index 1), subjects were required to observe the color of the LED on Circuit-1, and to light the LED on Circuit-2 that had the same color; this trial provided a simple reaction time.

In the second task (Difficulty Index 2) two LEDs of different color were lit on Circuit-1, and subjects were required to switch on an LED of one of the two colors on Circuit-2. In the third task (Difficulty Index 3) three LEDs of different color were lit and subjects were required to switch on an LED of one these colors on Circuit-2. The locations of the LEDs on Circuit-2 were clearly labeled. Subjects were trained during a trial session to switch on the appropriate LED. All reaction times (in milliseconds) and user errors were measured using an electronic device designed and developed for this purpose (Appendix A) However subjects committed a negligible number of errors (<2%). After the subject had taken his seat, the following steps were followed in order for both the training and experimental sessions.

Step 1: A Start signal was given to the subject.
Step 2: The stimulus was presented to the subjects by the experimenter.
Step 3: The subject responded by switching on the appropriate LED on Circuit-2.
Step 4: The reaction time was recorded by the experimenter.

The experiment was conducted for three categories of subjects: Novice, Intermediate and Experienced workers. The noise during grass trimming operation in a real environment was recorded on an audio-cassette. The pre-recorded noise was subsequently played in the experimental chamber during the experiments. The noise level was maintained at a pre-specified value. Training was rigorous for older subjects so that they were made fully aware of the experimental procedure.

2.8. Experimental Design

In all the three studies undertaken in the present work, human performance (dependent variable) was measured in milliseconds for reaction time, choice reaction time and choice reaction time for difficulty index three. Independent variables were difficulty index, noise levels and subject age category. A three-factor repeated-measures analysis of variance (ANOVA) was used to analyze the data.

3. Results

Three experiments were conducted to study the effect of age on cognitive performance of subjects.
3.1. Experiment 1

In this experiment, the effect of age on cognitive performance was investigated under varying levels of difficulty index and noise levels for Novices. ANOVA (Table 1) implied that subject age and difficulty index had statistically significant effects on subject performance.

The relationship between the reaction time and noise was linear (Figures 3, 4), with regression equations as follows.

**Notation**

\[ RT_{(DI)i} \] reaction time at difficulty index \( i \)

\( B \) noise level

**Age-group 1 (Novices)**

\[ RT_{(DI)1} = 500 + 0.4 B \] (1)

\[ RT_{(DI)2} = 600 + 0.31 B \] (2)

\[ RT_{(DI)3} = 675 + 0.45 B \] (3)

**Age group2 (Novices)**

\[ RT_{(DI)1} = 575 + 0.36 B \] (4)

\[ RT_{(DI)2} = 650 - 0.13 B \] (5)

\[ RT_{(DI)3} = 694 + 0.48 B \] (6)

**Table 1.** ANOVA Results when subjects performed the cognitive task (Novices)

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Between Subjects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age group (A)</td>
<td>1</td>
<td>1221495.41</td>
<td>69.37</td>
<td>0.01</td>
</tr>
<tr>
<td>Subjects within groups (Error 1)</td>
<td>12</td>
<td>17607.80</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Within Subjects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Noise levels (B)</td>
<td>3</td>
<td>51205.10</td>
<td>0.933</td>
<td>0.32</td>
</tr>
<tr>
<td>A x B</td>
<td>3</td>
<td>11686.46</td>
<td>0.21</td>
<td>0.78</td>
</tr>
<tr>
<td>B x Subjects within groups (Error 2)</td>
<td>36</td>
<td>54825.21</td>
<td></td>
<td>0.01</td>
</tr>
<tr>
<td>Difficulty index (C)</td>
<td>2</td>
<td>3093389.23</td>
<td>101.41</td>
<td>0.00</td>
</tr>
<tr>
<td>A x C</td>
<td>2</td>
<td>3650.89</td>
<td>0.11</td>
<td>0.87</td>
</tr>
<tr>
<td>C x Subjects within groups (Error 3)</td>
<td>24</td>
<td>30501.67</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B x C</td>
<td>6</td>
<td>4558.09</td>
<td>0.374</td>
<td>0.88</td>
</tr>
<tr>
<td>A x B x C</td>
<td>6</td>
<td>1390.42</td>
<td>0.11</td>
<td>0.91</td>
</tr>
<tr>
<td>B x C x Subjects within groups</td>
<td>72</td>
<td>12187.67</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.2. Experiment 2

In this experiment, the effect of age on cognitive performance was investigated under varying levels of difficulty index and noise levels for Intermediate- subjects. ANOVA (Table 2) implied that the effects of age, difficulty-index, noise and interaction between noise and difficulty-index all significantly affected reaction time.
Table 2. ANOVA Results when subjects performed the cognitive task (Intermediates)

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Subjects</td>
<td>13</td>
<td>9153.71</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age Groups (A)</td>
<td>1</td>
<td>122183.41</td>
<td>73.56</td>
<td>0.01</td>
</tr>
<tr>
<td>Subjects within groups (Error 1)</td>
<td>12</td>
<td>16607.80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Within Subjects</td>
<td>154</td>
<td>23083.95</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Noise levels (B)</td>
<td>3</td>
<td>512051.10</td>
<td>9.33</td>
<td>0.02</td>
</tr>
<tr>
<td>A x B</td>
<td>3</td>
<td>11686.46</td>
<td>0.21</td>
<td>0.78</td>
</tr>
<tr>
<td>B x Subjects within groups (Error 2)</td>
<td>36</td>
<td>54825.21</td>
<td></td>
<td>0.01</td>
</tr>
<tr>
<td>Difficulty index (C)</td>
<td>2</td>
<td>3993389.23</td>
<td>130.92</td>
<td>0.00</td>
</tr>
<tr>
<td>A x C</td>
<td>2</td>
<td>3450.89</td>
<td>0.11</td>
<td>0.87</td>
</tr>
<tr>
<td>C x Subjects within groups (Error 3)</td>
<td>24</td>
<td>30301.34</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B x C</td>
<td>6</td>
<td>45589.03</td>
<td>3.74</td>
<td>0.03</td>
</tr>
<tr>
<td>A x B x C</td>
<td>6</td>
<td>1390.42</td>
<td>0.11</td>
<td>0.91</td>
</tr>
<tr>
<td>B x C x Subjects within groups</td>
<td>72</td>
<td>12187.67</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The significant interaction between the noise level and the difficulty index necessitated an analysis of the simple main effects (Table 3) which indicated that the level of noise was statistically non-significant at all three levels of the difficulty index. However, difficulty index was found to have a significant effect at all four levels of noise. The relationship between the reaction time and noise level was linear (Figures 5, 6).

**Age-group 1 (Intermediate)**

\[
\text{RT}_{(D1)}^{(C1)} = 629.12 + 0.98 B \quad (7)
\]
\[
\text{RT}_{(D1)}^{(C2)} = 800 + 0.18 B \quad (8)
\]
\[
\text{RT}_{(D1)}^{(C3)} = 750 + 1.20 B \quad (9)
\]

**Age group2 (Intermediate)**

\[
\text{RT}_{(D1)}^{(C1)} = 796 + 0.28 B \quad (10)
\]
\[
\text{RT}_{(D1)}^{(C2)} = 840 + 0.48 B \quad (11)
\]
\[
\text{RT}_{(D1)}^{(C3)} = 495 + 4.80 B \quad (12)
\]

Table 3. Analysis of simple Main Effect when Subjects Performed the Cognitive Task at Varying levels of Difficulty Index Under Different Levels of Age group (Novices)

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>B (Noise level)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At C1 (Difficulty level 1)</td>
<td>3</td>
<td>8432.13</td>
<td>0.15</td>
<td>0.90</td>
</tr>
<tr>
<td>At C2 (Difficulty level-2)</td>
<td>3</td>
<td>98523.34</td>
<td>1.53</td>
<td>0.19</td>
</tr>
<tr>
<td>At C3 (Difficulty level-3)</td>
<td>3</td>
<td>99878.90</td>
<td>1.65</td>
<td>0.20</td>
</tr>
<tr>
<td>C (Difficulty Index)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At B1 (Noise level-1)</td>
<td>2</td>
<td>213432.57</td>
<td>5.87</td>
<td>0.02</td>
</tr>
<tr>
<td>At B2 (Noise level-2)</td>
<td>2</td>
<td>466578.86</td>
<td>11.67</td>
<td>0.01</td>
</tr>
<tr>
<td>At B3 (Noise level-3)</td>
<td>2</td>
<td>653098.10</td>
<td>12.54</td>
<td>0.01</td>
</tr>
<tr>
<td>At B4 (Noise level-4)</td>
<td>2</td>
<td>674098.29</td>
<td>15.23</td>
<td>0.00</td>
</tr>
</tbody>
</table>
3.3. Experiment 3

In this experiment, the effect of age on cognitive performance was investigated under varying levels of difficulty index and noise for experienced subjects. ANOVA (Table 4) implied that the effects of age, difficulty-index, noise and the interaction between noise levels and difficulty-index all were statistically significant.
Table 4. ANOVA Results when subjects performed the cognitive task (Experienced workers)

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Df</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Subjects</td>
<td>13</td>
<td>9973.91</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age Groups (A)</td>
<td>1</td>
<td>181023.41</td>
<td>113.79</td>
<td>0.00</td>
</tr>
<tr>
<td>Subjects within groups (Error 1)</td>
<td>12</td>
<td>15907.70</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Within Subjects</td>
<td>154</td>
<td>29085.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Noise levels (B)</td>
<td>3</td>
<td>614051.10</td>
<td>13.31</td>
<td>0.01</td>
</tr>
<tr>
<td>A x B</td>
<td>3</td>
<td>10986.41</td>
<td>0.23</td>
<td>0.98</td>
</tr>
<tr>
<td>B x Subjects within groups (Error 2)</td>
<td>36</td>
<td>46100.21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Difficulty index (C)</td>
<td>2</td>
<td>544389.23</td>
<td>135.74</td>
<td>0.00</td>
</tr>
<tr>
<td>A x C</td>
<td>2</td>
<td>5450.89</td>
<td>0.13</td>
<td>0.66</td>
</tr>
<tr>
<td>C x Subjects within groups (Error 3)</td>
<td>24</td>
<td>40101.33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B x C</td>
<td>6</td>
<td>71589.93</td>
<td>5.97</td>
<td>0.02</td>
</tr>
<tr>
<td>A x B x C</td>
<td>6</td>
<td>1270.41</td>
<td>0.10</td>
<td>0.99</td>
</tr>
<tr>
<td>B x C x Subjects within groups</td>
<td>72</td>
<td>11977.69</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5. Analysis of simple Main Effect when Subjects Performed the Cognitive Task at varying levels of Difficulty Index Under Different Levels of noise (Experienced workers)

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>B (Noise level)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At C1(Difficulty level 1)</td>
<td>3</td>
<td>8892.13</td>
<td>4.50</td>
<td>0.04</td>
</tr>
<tr>
<td>At C2(Difficulty level-2)</td>
<td>3</td>
<td>98953.34</td>
<td>5.65</td>
<td>0.02</td>
</tr>
<tr>
<td>At C3(Difficulty level-3)</td>
<td>3</td>
<td>899878.90</td>
<td>16.9</td>
<td>0.01</td>
</tr>
<tr>
<td>C (Difficulty Index)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At B1 (Noise level-1)</td>
<td>2</td>
<td>513936.27</td>
<td>53.87</td>
<td>0.00</td>
</tr>
<tr>
<td>At B2 (Noise level-2)</td>
<td>2</td>
<td>899578.86</td>
<td>95.67</td>
<td>0.00</td>
</tr>
<tr>
<td>At B3 (Noise level-3)</td>
<td>2</td>
<td>987998.10</td>
<td>112.54</td>
<td>0.00</td>
</tr>
<tr>
<td>At B4 (Noise level-4)</td>
<td>2</td>
<td>1374098.29</td>
<td>156.23</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Significant interaction between the noise levels and the difficulty index necessitated an analysis of the simple main effects (Table 5) which indicated that the level of noise was statistically significant at all three levels of the difficulty index, and that the same was true in case of the difficulty index under varying levels of noise. The relationship between the reaction time and noise was linear (Figures 7, 8).

Regression equations describing the relationship between noise level and reaction time for age-groups 1 and 2 were:

**Age group-1 (Experienced workers)**

\[
\text{RT}_{(D1,1)} = 750 + 0.48 B \quad (13)
\]

\[
\text{RT}_{(D1,2)} = 465 + 3.8 B \quad (14)
\]

\[
\text{RT}_{(D1,3)} = 500 + 5.01 B \quad (15)
\]

**Age group-2 (Experienced workers)**

\[
\text{RT}_{(D2,1)} = 745 + 0.60 B \quad (16)
\]

\[
\text{RT}_{(D2,2)} = 485 + 3.91 B \quad (17)
\]

\[
\text{RT}_{(D2,3)} = 395 + 6.08 B \quad (18)
\]
Cognitive performance of grass trimmers in noisy conditions
- the effect of user age

Figure 7. Relationship between reaction time and noise levels for different levels of difficulty index for subjects of age-group 1 (Experienced workers)

Figure 8. Relationship between reaction time and noise levels for different levels of difficulty index for subjects of age-group 2 (Experienced workers)

4. Discussion

Research into the possible adverse effects of agricultural tools on operators’ cognitive ability is still in its infancy. This study looked into possible ill-affects on operators’ mental ability when the gasoline-powered grass-cutting machine produced loud noise. Cognitive tasks when performed in a noise-induced stressful environment lead to many kinds of ill-affects, including long- and short-term memory loss, inability to concentrate, and sleep disturbances.

Finding of the present work indicated that the age of the subject has significant
effect on his cognitive performance while completing simple and choice reaction
tasks. Operators of grass trimming machines face a number of stresses including
high noise level exposure for long periods, and the heat of the sun. Perhaps the
simultaneous effects of these two environmental stressors affect the mental ability of
operators. Body reflexes slow with age; therefore these affects are more pronounced
with increasing age coupled with long exposure to grass trimmer noise. This
conclusion is supported by several published reports. Dose-response relationships
have been detects between aircraft noise exposure, nervousness and mental health
(Miyakita et al, 1998). Several studies have described morphological changes in the
frontal and temporal cortex with ageing (Adams, 1987; Bartzokis et al, 2001; Jernigan
et al, 2001 and Liu et al, 1996). The time required to allocate attention to two or more
tasks has been reported to increase with age (Madden 1992). In a dual task situation,
reaction time of older subjects was greater than that of younger ones(McDowd and
Craik, 1988).

The present work also indicated that the difficulty index level of a cognitive
task had a highly significant on response time; this result needs to be studied further.
Grass trimmer operators are exposed to highly noisy work environment; this study
suggests that long exposure to noise high levels might impair their cognitive ability.
In a recent review, Griefahn (2002) highlighted the crucial question of whether a link
occurs between sleep disturbances related to environmental noise exposure and
human performance deterioration the next day. These results are in conformity with

5. Conclusion

Based upon the results in the present study the following conclusions were
drawn.

1. Age had significant effect on time required to complete cognitive tasks.
2. In cognitive tasks, time required to complete the task increased with its
difficulty
3. In cognitive tasks, noise generated during the grass trimming operation
significant increased time required to complete the tasks.
4. The interaction between noise and task difficulty was significant.
5. The time required to complete the tasks was affected by noise levels,
regardless of whether the subjects were Novice, Intermediate or
Experienced grass cutters.

Appendix A

This appendix describes the structure and function of the device used to present
the stimuli and to measure the subject’s response time (Figure A). The user's
reaction time was measured as the duration between observing a lit LED, and pressing a button. This duration was accurately measured using Timer 0, and the computed value is displayed on two, 7-segment LED displays.

We set up a finite state machine to control the operation of the circuit. The machine has five states, with multiple paths between some of the states. A global integer variable controls the current state. Timer 0 is used to provide a 1-ms in conjunction with the interrupt handlers.

The random number generating routine has been recycled, but slightly modified to produce integers between 1000 and 10000, which is used as the random wait time (in milliseconds), before lighting the LED.

![Logic diagram of the system used for reaction time measurement](image)

Figure A. Logic diagram of the system used for reaction time measurement

The microcontroller can use two classes of interrupts, known as low-priority and high-priority interrupts. For most applications and devices, only one class of interrupts is necessary. Under normal operation, the microcontroller starts execution at program memory location 0. When interrupts are in use, two additional addresses in program memory have special meaning.

When an interrupt occurs, the processor jumps the program counter to one of two interrupt handlers, which are specific locations in program memory. The high-priority interrupt handler starts at program memory location 0x8, and the low-priority interrupt handler starts at program memory location 0x18. Normally, memory is insufficient to store the complete interrupt handling code in these locations, so a goto instruction is often used to branch to somewhere else in the program memory.

The PIC18F452 includes four timing devices on-chip, with many features and options to customize their operation. For this experiment, we used Timer 0. This is a 16-bit counter/timer, with internal/external clock inputs, variable edge-detection settings, and an 8-bit programmable pre-scaler.
In 16-bit mode, Timer 0 has two registers that store the current count, TMR0L and TMR0H. The high byte is latched, so reading from and writing to TMR0L performs the same operation between TMR0H (the latched register) and the actual register.

Another important feature of Timer 0 is the ability to pre-set the count to customize the time to interrupt. This is done by loading the upper byte of the desired value into TMR0H, and writing the lower byte of the desired value into TMR0L.

In this device, Timer 0 is set up for 16-bit mode with a pre-scaler of 1. This is done by writing the value 0x80 into the T0CON register. We also must enable global interrupts and the Timer 0 interrupt. We will be loading a starting count of 60543 = 0xEC7F into the TMR0 registers. We must load this value at the start of the program, and every time an interrupt occurs. This value corresponds to a very accurate timer period of 1 ms.

The output to the LED display is handled with PORTC for the 8 data lines, and PORTD pins 0 & 1 for the digit select lines. We enable output for these ports and clear their values at the start of the program. The LED is connected to RB0, and the switch is connected to RB7.

At initial power-on, the device's displays should be blank. When the switch is first pressed, the device waits a random duration, between 1 and 10 seconds. If the user presses the switch before the LED is turned on, the error code E0 is displayed. When the device has waited for the specified duration, the LED is turned on and the device starts the timer. If the users do not press the switch within the next 999 ms, the error code E1 is displayed. Assuming the user pushes the switch within 999 ms, the processor waits 1 s before displaying the user's reaction time. The number displayed is only two digits, and the digits are simply the most significant digits of the milliseconds count.

A software-controlled finite state machine has been implemented for this device. A global integer value is used to control the finite state machine. Here is a summary of the states:

STATE 0: Display digits, wait for button press, then proceed to state 1.
STATE 1: Wait for button release, generate random wait time, then proceed to state 2.
STATE 2: Enable Timer 0; wait for random time, or until premature button press, which leads to state 5. If the random time expires, set the LED and reset the timer to upward counting mode, then proceed to state 3.
STATE 3: Wait for button press (go to state 5), or timer reaches 999 milliseconds (go to state 4); turn on LED.
STATE 4: Wait one second to display results, update display digits, and then proceed to state 5;
STATE 5: Display digits, wait for button release, then return to state 0;
References


Zulquernain Mallick

Zulquernain Mallick received the B.Sc. degree in Mechanical Engineering and the M.Sc. degree in Industrial and production Engineering from Aligarh Muslim University, Aligarh, India, in 1987 and 1989, respectively, and the Ph.D. degree from Jamia Millia Islamia, New Delhi, India, in 2002 in Mechanical Engineering. He is associated with the Department of Mechanical Jamia Millia Islamia, New Delhi. He has more than 60 publications in international and national conferences and journals and is the coauthor of one book titled “Engineering Materials and their Manufacturing”.
Correlation of job satisfaction with job characteristics, job organization and environmental factors in two Malaysian automobile factories

S.Z. Dawal∗, Z. Taha¹, Z. Ismail²

¹ Department of Engineering Design and manufacture, University of Malaya, Kuala Lumpur, Malaysia
² Department of Civil Engineering, University of Malaya, Kuala Lumpur, Malaysia

Abstract

The relationship between job satisfaction, job characteristics, job organization and environmental factors in two automotive industries in Malaysia were analyzed using surveys and questionnaires to query 170 male subjects. Job satisfaction was significantly correlated with worker assessments of job organization and the physical work environment. Skill variety, a factor of job characteristic, was found to be the most significant factors that influence job satisfaction for both factories.

Keywords: Job Satisfaction, Job Characteristics, Environmental Factors, Job Organization, Automotive Industries

1. Introduction

Many factors affect job satisfaction (Bowen et al, 1994, DeSantis and Durst, 1996 and Gaesser & Whitbourne, 1985). Although numerous studies on the effect of job satisfaction in industries exist, findings were often specific to the particular investigation, and to date mainly consider individual components of the physical environment (Clegg et al, 1997).

Nadin et al, 2001 stated that many researchers have suggested a number of workplace design strategies to improve the quality of the workplace. On the other hand, little attention is given to the actual process of workplace design (Oldham, 1996). Clegg, 1995 suggested that methods should be developed to facilitate this process; and to do so, a more thorough understanding is needed about how various factors affect industrial job satisfaction. Workplace design research can make progress by applying what is already known and by asking a more comprehensive

∗ Corresponding author: sitiawiahmd@um.edu.my, Tel: 03-79675251, Fax: 03-79675330
set of research questions (Holman et al., 2002). An approach to the design of workplaces that is human centered is needed. This approach should adequately incorporate factors that contribute to the effectiveness of workplace design.

Therefore, the aim of this study is to discover new insights into factors that affect job satisfaction in automotive industries in Malaysia. The primary objective of this paper is to investigate how job satisfaction is affected by job characteristics, job environment and job organization. The methods used to address the objective include questionnaire design, observation, measurements, and data collection.

2. Method

In this survey, the job diagnostic survey (JDS) (Hackman and Oldham 1974) was used as a tool to diagnose job characteristics, job environment and job organization. The questionnaires used consist of a set of multiple-choice items that use a seven-point Likert scale (Rodeghier, 1996). The relationships between job satisfaction and the tested factors were analyzed statistically using correlations.

2.1. The Survey

The questionnaires were distributed to the subjects individually. Two automotive manufacturing industries (“Auto1” and “Auto 2”) were involved in the survey; 170 male subjects (ages 18 to 40 years) completed the survey.

2.2. The Questionnaires

The questionnaires were organized into five sections covering:

(a) General background data: age, gender, years of employment, marital status and education levels.
(b) Job characteristics factors: skill variety, task identity, task significance, autonomy and feedback from the work.
(c) Environmental factors: air temperature, humidity, noise and light.
(d) Job organization: job rotation, work method, training, problem solving and goal setting.

The five job characteristics factors tested were defined according to Hackman and Oldham (1974) as follows:

- Skill variety: The degree to which a job requires a variety of different activities which involve the use of a number of different skills and talents.
- Task identity: The degree to which a job requires completion of a “whole” and identifiable piece of work.
Correlation of job satisfaction with job characteristics, job organization and environmental factors in two Malaysian automobile factories

- Task significance: The degree to which a job has a substantial impact on the lives or work of other people, whether in the immediate organization or in the external environment.
- Autonomy: The degree to which the job provides the employee substantial freedom, independence and discretion in scheduling the work and in determining the procedures to complete it.
- Feedback from job: The degree to which completing work activities required by the job results in the employee obtaining direct and clear information about the effectiveness of his or her performance.

The four environmental factors tested were defined as follows:
- Air temperature and humidity. Environmental factors such as temperature and humidity can have important effects on psychological parameters such as level of arousal and motivation (Parsons, 2000). The questionnaire developed to assess thermal comfort adopts the definitions of Parson (2000) as “the condition of mind which expresses satisfaction with the thermal environment”. The reference to “mind” indicates that satisfaction is a subjective measure. However, warmth discomfort has been shown to be related to the stickiness caused by un-evaporated perspiration (Parsons, 2000). Therefore, questions regarding thermal comfort addressed satisfaction and comfort. Temperature and relative humidity were measured at each workstation.
- Noise and Light. Noise levels can also affect worker satisfaction. The term comfort is not usually used when assessing the effect of noise on the occupants of the buildings. In practice, annoyance levels are the most useful criterion (Parsons, 2000). Therefore, questions regarding noise addressed annoyance and comfort. Noise levels were measured in decibels (dB) throughout the workstations and were expressed as averages.
- Light can cause both discomfort and positive sensations (Parsons, 2000). Questions regarding light addressed satisfaction and the degree of comfort in seeing the work task. Light levels (in lux) were measured throughout the workstations.

The organization factors such as workers’ participation in job related decision self-regulation and worker autonomy can affect job satisfaction (Das, 1999). The questionnaire addressed respondents’ perception of these factors. However, before initiating the questionnaire session and as a reference for the analysis, the management was first interviewed and a checklist was made. The study intends to determine how the respondents felt about the tasks being organized, the type of procedures being used, and the related work being loaded.

Five job organization factors tested in this study were defined as follows:
- Job rotation. Job rotation allows workers to rotate among jobs to increase variety (De Jong, 1989). This technique has been widely used to increase the competence of workers and to reduce monotony (Helander, 1995). The objective of job rotation is to broaden an employee’s experience and to train backup staff to allow the company to cope with worker vacations and
illnesses, and also with periods of increased production (The ergonomics group, 1986).

- Work method. Work method describes how tasks are being organized (Rouse et al., 1991). Methods include the procedures, instructions and documentation that defines how manufacturing steps or processes are accomplished (Quirk, 1999).
- Training. Training is the systematic development of worker skills. Individuals need knowledge and skills to perform adequately on a given task (Stammers and Patrick, 1975).
- Problem solving. Problem solving describes how the workers handle work related problems by giving them the resources and authority to do so (Ugboro and Obeng, 2001).
- Goal setting. Goal setting is the process of developing, negotiating and formalizing the targets or objectives that an employee is responsible for accomplishing (Umstod et al., 1976).

2.3. The analysis

The data were analyzed for correlations using the Spearman rank order correlation. To test the reliability of each question in the survey, reliability of factors tested in the survey was quantified using Cronbach’s $\alpha$. This statistic is derived from the average correlations of all items on the scale, which will measure the internal consistency of the test scores. As a rule of thumb, values that are greater than 0.70 will indicate that the questions are reliable.

3. Results

The results were divided into several sections covering general background data, reliabilities measures, and correlations of job satisfaction with job characteristics, environment and job organization factors.

3.1. General background data

Of the 170 respondents, 120 were from Auto1 and 50 were from Auto2. Eighty percent of respondents in both companies hold “Malaysian Certificate of Education” (SPM) equivalent to “O” levels; while others hold SPM certificate together with other skill certificates.

Respondents in Auto1 were older and more experienced than those in Auto2. The respondents from Auto1 were 23 to 40 years old (mean = 31.3, s.d. = 3.9; 83% $\geq$ 26 years) with a mean of work experience of 10.6 years (s.d. = 3.8); those from Auto2 were 18 to 27 years old (mean = 22.6, s.d. = 2.1; 10% $\geq$ 26 years) with a mean of work experience of 2.6 years (s.d. = 1.8). In Auto1, 69% were married, but in Auto2 only
13% were married. Ages were normally distributed but work experience was not. Work experience for Auto1 was negatively skewed but work experience for Auto2 was positively skewed. At Auto1, 90% of the respondents from Auto 1 had worked for there for more than 5 years, but at Auto2, only 10% had worked there for more than 5 years. These demographic differences between the plants may occur because Auto1 was established before Auto2.

3.2. Reliabilities measure

Cronbach’s α was derived from the average correlations between the Likert-scale assessments of all pairs of items (Rodeghier, 1996). Out of twenty-eight reliability measures in both companies, 18 had $\alpha > 0.7$, 9 had $0.6 < \alpha < 0.7$ and one had $\alpha = 0.5$ (Table 1). Therefore, the reliability measures were high for job factors in both companies, especially for skill, task identity, autonomy and feedback ($0.69 < \alpha < 0.88$).

3.3. The correlation coefficient

Job satisfaction was significantly ($p < 0.01$) correlated with several job characteristics, environment and job organization (Figures 1 to 3). Eight factors had strong significant correlation in with job satisfaction Auto 1: skill variety, task identity, autonomy, light, job rotation, work method, training and goal setting. Four factors had strong significant correlation with job satisfaction in Auto 2: skill variety, humidity, job rotation and work method.

<table>
<thead>
<tr>
<th>Tested Factors</th>
<th>Auto1, $n = 120$</th>
<th>Auto2, $n = 50$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Job factors:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skill</td>
<td>0.77</td>
<td>0.79</td>
</tr>
<tr>
<td>Task identity</td>
<td>0.76</td>
<td>0.69</td>
</tr>
<tr>
<td>Task significance</td>
<td>0.61</td>
<td>0.63</td>
</tr>
<tr>
<td>Autonomy</td>
<td>0.72</td>
<td>0.69</td>
</tr>
<tr>
<td>Feedback</td>
<td>0.86</td>
<td>0.88</td>
</tr>
<tr>
<td><strong>Environmental factors:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perception of temperature</td>
<td>0.72</td>
<td>0.69</td>
</tr>
<tr>
<td>Perception of humidity</td>
<td>0.64</td>
<td>0.86</td>
</tr>
<tr>
<td>Perception of noise</td>
<td>0.76</td>
<td>0.67</td>
</tr>
<tr>
<td>Perception of light</td>
<td>0.78</td>
<td>0.64</td>
</tr>
<tr>
<td><strong>Job organization factors:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Job rotation</td>
<td>0.83</td>
<td>0.83</td>
</tr>
<tr>
<td>Work method</td>
<td>0.89</td>
<td>0.88</td>
</tr>
<tr>
<td>Training</td>
<td>0.83</td>
<td>0.50</td>
</tr>
<tr>
<td>Problem solving</td>
<td>0.69</td>
<td>0.79</td>
</tr>
<tr>
<td>Goal setting</td>
<td>0.90</td>
<td>0.82</td>
</tr>
<tr>
<td>Job satisfaction</td>
<td>0.89</td>
<td>0.82</td>
</tr>
</tbody>
</table>
Figure 1. Correlations of job satisfaction with five job factors

Figure 2. Correlations of job satisfaction with four environmental factors

Figure 3. Correlations of job satisfaction with job organization factors
Correlation of job satisfaction with job characteristics, job organization and environmental factors in two Malaysian automobile factories

4. Discussion

4.1 Effects of job characteristics on job satisfaction

The study detected significant positive correlations between job satisfaction and several job characteristics. This result was in agreement with those of empirical studies by Hackman and Oldham (1974) and Umstod et al., (1976). In this study, the correlations of job satisfaction with job characteristics were stronger than those observed by Hackman and Oldham (1974), possibly because the present study considered only automotive industries.

One outstanding result was that job satisfaction was significantly correlated with skill in both companies. Generally, more than 80% of respondents agreed that they utilized moderate to very much skill. Based on this finding, they tend seem to appreciate skill variety, and this variety has a greater influence on job satisfaction than other job factors. Hackman and Oldham, (1974 and 1976) stated that skill, task identity and task significance are psychological factors that help workers see their work as meaningful. However, results from this study suggest that skill variety had greater effect on that matter than did other factors.

Das (1999), Hackman and Oldham (1974, 1976) had stated that job satisfaction was one of the outputs that could be determined by job factors in a work-design model, and the result obtained from this study support the above statement. The result obtained showed that job factors were predictors of job satisfaction in workplace design. Therefore the design of future workplaces should emphasize job enrichment to increase the beneficial effects of those factors.

4.2. Effects of environmental factors on job satisfaction

Significant positive correlations occurred between job satisfaction and perception of all environmental factors (Figure 2). The outstanding correlation for Auto1 was perception of light and for Auto2 was perception of humidity.

The correlations of job satisfaction with perception of temperature were about the same for both companies, but the correlation of job satisfaction with perception of humidity factor was higher in Auto2 than in Auto1. Average temperature and humidity were slightly higher in Auto2 (32.2°C and 60.2 RH) than in Auto 1 (31°C and 69.1 RH). The heat index (Steadman, 1979) calculated using these measurements places Auto 2 in the transition from “hot” to “very hot”, and place Auto1 in the “very hot” band. The assembly line in Auto 2 is in the middle of the factory, whereas that in Auto 1 was located near openings (doors and windows) which allow additional heat from forklifts and vehicles to influence the working environment. These results show that workers’ perception of their environment corresponds to the measurements. The results were consistent with Parson’s (2000) definition of thermal comfort as a condition of mind which expresses satisfaction with the thermal environment.
The correlation between job satisfaction and perception of light was higher in Auto1 than in Auto2. Average light intensity was also higher in Auto1 than in Auto2. The higher correlation in Auto1 could be due to high average light measurement because light can cause either discomfort or positive sensations (Parsons 2000) that affect respondents’ job satisfaction. Light levels in both factories were within the 500-1000 lux standard of IES (IES 1979) which were appropriate for medium assembly factory.

The correlation of job satisfaction with perception of noise factor was slightly higher in Auto1 than in Auto2. Average noise measurements were lower in Auto1 than in Auto2. This explains why this correlation is higher in Auto1 than in Auto2. Psychological responses to noise can also produce effects on mental health and emotional state, especially if the noise adds to an already stressful environment (Parsons 2000).

The results indicated that environment conditions, especially temperature, humidity, noise and light affect job satisfaction in automotive industries. The management of both companies should attempt to optimize temperature, humidity and noise because measurements of these factors are outside the comfortable boundary and respondents are not satisfied with them. Standard environmental conditions (including temperature, humidity, noise, and light) for automotive industries in Malaysia must be revised to maintain workers’ health physically and mentally, thereby increasing productivity and job satisfaction as well as performance.

4.3. Effects of job organization of job satisfaction

Significant positive correlations were observed between job satisfaction and job organization factors. In Auto1, job satisfaction was strongly correlated with job rotation, work method, training and goal setting showed strong correlations with job satisfaction, but only intermediate correlation with problem solving. In Auto2, job satisfaction showed intermediate correlations with most job organization factors, except for the training factor, for which the correlation was low. The correlations for all factors were higher in Auto1 than Auto2.

The significant correlation between job satisfaction and job rotation and work method are rarely discussed because most research focuses more on worker’s performance and productivity (Vroom and Deci, 1970; The ergonomics group 1986). In this study, a significant positive correlation was observed between job satisfaction and both job rotation and work method. This result is in agreement with Amrine et al. (1993) who stated that reducing the time spent performing boring and monotonous jobs could improve job satisfaction. This result is also consistent with the findings by Gaziolu and Tansel (2002) and Hamermesh (1997) who found that job satisfaction is significant and positively correlated with training opportunity. This correlation was higher in Auto1 than in Auto2. Respondents in Auto2 reported many opportunities for training because most of them were new employees, based on their ages and experiences. Therefore, the results indicated that increasing training opportunities will increase job satisfaction; similar conclusions were

Significant positive correlations were observed between job satisfaction and goal setting in both companies: more than 90% of the workers were satisfied with their companies’ goal setting. This result indicates that management should consider the capabilities and limitations of individual subordinates before establishing goals.

Fifty percent of the respondents in Auto2 felt that the management was serious in encouraging them to be involved in problem solving. This increased their job satisfaction as much as did other factors. In contrast, only 40% respondents in Auto1 felt the same way; this led to lower job satisfaction compared to other factors in Auto1. The results supported the findings by Ugboro and Obeng (2001) that involving workers in problem solving increases job satisfaction.

The findings indicated that job satisfaction is affected by job rotation, work method, training, goal setting and problem solving. More than 70% of the respondents in both companies were satisfied with the implementation of job rotation, work method, problem solving and goal setting. In contrast, more than 80% of the respondents in Auto1 felt that they have moderate to adequate training and only 55% of the respondents in Auto2 felt the same way. In addition about 30% of workers in Auto2 felt that they have training opportunities, but only 5% respondents in Auto1 felt the same way. Management therefore should emphasize training opportunity, because the result reflected a decrease in job satisfaction with too much training in Auto2. Moderate to adequate training will lead to higher job satisfaction (Gaziolu and Tansel, 2002).

4.4. Effects of age, work experience and marital status on job satisfaction

The correlations between job satisfaction, job characteristics and job organization factors are higher in Auto1 than in Auto2 (Figures 1 and 3). One possible explanation is that older, married and more experience workers in Auto1 were more satisfied with their work than the younger, single and less experienced workers in Auto2.

Job satisfaction was correlated with worker age. Studies in five different countries prove that older workers are more satisfied than their younger counterparts (Kaya 1995). The results also supported findings by Janson and Martin (1982) and McCaslin and Mwangi (1994) who found that older employees have higher job satisfaction than younger ones, and those by Lee and Wilbur (1985) which suggested that job satisfaction increases with age. One explanation for such a finding is that older employees are more able to adjust their expectations to the characteristics of their work (DeSantis and Durst 1996). The lack of job satisfaction amongst younger workers may cause them to be more mobile and seek new jobs. If this occurs in Auto2, the plant will experience a shortage of skilled and experienced workers.

Work experience is only one of the many aspects related to length of employment that can be correlated with perceived job satisfaction. Bowen et al. (1994), McCaslin and Mwangi (1994), Manthe (1976), Boltes et al. (1995) and Bertz
and Judge (1994) found that overall job satisfaction increased as the years of experience increased.

The level of worker education was the same in both companies. However, marital status was very different in the two companies. Older, married and more experienced workers had higher levels of job satisfaction and are more committed than the younger, single and less experienced men; furthermore, younger, single and less experienced workers may still be deciding on a career and this may interfere with job satisfaction and organizational commitment (Bowen et al. 1994).

Literature on the relationship between work, marital status and family has shown a spillover effect between both domains. Most of the spillover studies have investigated how work or career satisfaction affects one’s personal life. Benin and Nienstedt (1985) that job satisfaction influenced marital happiness and that the effects of job satisfaction and fulfillment interacted with the effects of marital happiness in producing overall happiness.

Research on relationships between work satisfaction and marital characteristics is extensive and is primarily found in literature on marital satisfaction, work identity and satisfaction, and dual-career couples (Blair 1998, Ray 1990, Gaesser & Whitbourne 1985). These studies suggested that career and family lives are mutually entangled, and that to understand strain in one domain, information on both facets of an individual’s life is necessary (Ludlow & Salvat 2001). Therefore further research should be conducted into this interaction.

5. Conclusion

This study found that job satisfaction was significantly correlated with job characteristics, environment, and job organization:

1. Skill variety had an outstanding effect on job satisfaction in automotive industries.
2. The strength of the correlation between job factors and job satisfaction was influenced by age, work experience and marital status.
3. Job satisfaction was significantly correlated with environmental and job organization factors.
4. The environmental factors affect job satisfaction and the strength of the correlation is influenced by the workers’ surroundings, depending on the function of the building.

Reference


Correlation of job satisfaction with job characteristics, job organization and environmental factors in two Malaysian automobile factories

Siti Zawiah Md Dawal
Siti Zawiah Md Dawal is an associate professor at the Department of Engineering Design and Manufacture, University of Malaya, Kuala Lumpur, Malaysia. She is also the current Head of Department. Her research interests are industrial ergonomics, work design survey, and manufacturing system. She received the M. Sc degree in manufacturing system engineering from University of Warrick, UK and the Ph.D. degree in industrial ergonomics from University of Malaya.

Zubaidah Ismail
Zubaidah Ismail is an associate professor at the Department of Civil Engineering, University of Malaya, Kuala Lumpur, Malaysia. Her research interests include the field of ergonomics, structural dynamics, and contaminant transport. She received her M.A. degree in applied mathematics from Temple University, USA and the PhD degree in civil engineering from University of Malaya.

Zahari Taha
Zahari Taha is a professor at the Department of Engineering Design and Manufacture, University of Malaya, Kuala Lumpur, Malaysia. His research interests are in engineering design, manufacturing processes, and manufacturing automation and robotics. He received his B. Sc. from University of Bath, UK and PhD degree in dynamics and control of robots from University of Wales, UK.
Chronic Exposure Index Model to Assess Ergonomic Risk Factor Related to Upper Extremity Musculoskeletal Disorders

Seyyed Ali Moussavi-Najarkola

Dept. of Occupational Health, School of Medical Sciences, Shahid Beheshti of Medical University, Tehran, Iran

Abstract

To protect workers from upper extremity musculoskeletal disorders (UEMSDs) the Chronic Exposure Index (CEI) model is presented; this model simplifies assessment of risk factors associated with development of work-related UEMSDs. The CEI simultaneously considers ten variables that occur in repetitive tasks. In reproducibility tests inter-assessor and intra-assessor reliability of assessments (Cohen’s kappa and percentage agreement) were “acceptable”, and increased with the work experience of the assessors and the amount of training specific to the assessment criteria. The model was compared to the Occupational Repetitive Actions index and the Strain Index and gave comparable results; therefore CEI is reliable for assessing the need for intervention to modify working conditions to reduce the occurrence of UEMSDs, and for assessing changes in exposure and assessment items before and after ergonomic interventions. The model is also reliable, valid and applicable to a vast range of tasks and jobs.

Keywords: Comprehensive Exposure Index, CEI, UEMSDs, Repetitive Tasks, Risk Factors, Ergonomic Assessment

1. Introduction

Work-related musculoskeletal disorders (WMSDs) are significant health risks; they can cause significant reductions in worker productivity and increases in healthcare costs, so they are expensive to employers. Several approaches have been proposed to identify, quantify and evaluate risk factors that contribute to development of WMSDs (1).

WMSDs of the upper limbs are generally multi-factorial in character (2). This paper considers the most significant contributory risk factors, and presents a set of definitions, criteria and procedures that are useful to describe and, wherever possible, to evaluate work situations that can biomechanically, physiologically, and dynamically overload the upper limbs (3).
The aim of this paper is to describe a preliminary study of an assessment model for identifying tasks that can induce upper extremity musculoskeletal disorders (UEMDs), for preventing such disorders and protecting workers from such disorders, and for reducing the risk level of tasks to acceptable levels by redesigning hazardous tasks and automatically suggesting ergonomic design improvements.

In most existing risk assessment tools, contributory risk factors are considered individually instead of jointly and simultaneously (5-13). At least the most recent models tend to reproduce concepts and methods adapted to the NIOSH equation model for assessing manual material handling/lifting tasks (14).

The comprehensive exposure index (CEI) proposed here is a method for evaluating risk factors featuring repetitive tasks using the MMHs method (14), the stress index (SI) method (12), the Occupational Repetitive Actions (OCRA) method (10), the CEN (15) and Kilbom’s (16) investigations. The aim of the method is to identify a procedure for calculating a comprehensive exposure index for assessing UEMSDs. The CEI method seems to be the most complete exposure index that must be researched by parallel and subsequent study.

2. CEI model and its framework

The aim of the model was to fulfill the following requirements:

a) An index should be capable of assessing a manual material handling system for light hand activity in repetitive tasks.
b) The model should be capable of evaluating the risk of workers developing UEMSDs.
c) The model should consider all risk factors, including those that have not been considered in other models, including worker age, parts weight, and minor effective items.
d) Risk factors associated with work-related UEMSDs (such as force exertion, posture of upper limb, frequency, duration and speed of force exertion, task duration, part weight, recovery periods, age factor, and effective items) should considered simultaneously and jointly.
e) The model should present a risk classification system that allows identification of safe tasks and modification of hazardous tasks.
f) The model should automatically propose ergonomic designing solutions and classify tasks to identify those with different levels of risk.
g) The model should propose ways to diminish risk levels to the lowest level.
h) The model should be valuable as an index to assess risks to upper limbs.

To fulfill these requirements, this paper proposes the CEI model, which seems appropriate for assessing the risk of workers developing UEMSDs. The CEI is calculated as the product of ten parameters:

\[ CEI = \sum_{i=1}^{n} FE \times PU \times FF \times DF \times TD \times SF \times PW \times RP \times AF \times EI \]  

(1)
Chronic Exposure Index Model to Assess Ergonomic Risk Factor Related to Upper Extremity Musculoskeletal Disorders

where:

\[ i = \text{the number of tasks featuring risk factor producing upper extremity disorders during a work shift (1 \ldots n)} \]

\[ \text{FE} = \text{force exertion, weighted by a multiplier (Table 1)} \]

\[ \text{PU} = \text{posture of upper limbs, weighted by a multiplier (Table 2)} \]

\[ \text{FF} = \text{frequency of force exertion per minute, weighted by a multiplier (Table 3)} \]

\[ \text{DF} = \text{duration of force exertion in percent, weighted by a multiplier (Table 4)} \]

\[ \text{TD} = \text{task duration per day in hours, weighted by a multiplier (Table 5)} \]

\[ \text{SF} = \text{speed of force exertion, weighted by a multiplier (Table 6)} \]

\[ \text{PW} = \text{parts weight, which can be calculated by estimating weight of objects that must be handled or lifted and using corresponding multiplier factors (Table 7)} \]

\[ \text{RP} = \text{lack of recovery periods, calculated from the number of hours without adequate and sufficient recovery periods or rest intervals, weighted by a multiplier (Table 8)} \]

\[ \text{AF} = \text{age factor, weighted by a multiplier (Table 9)} \]

\[ \text{EI} = \text{effective items; these factors involve several items that have not been taken into consideration in nine previous items, weighted by a multiplier (Table 10).} \]

The CEI presents a score with a range indicating the severity of exposure and its level. Theoretically, the calculated comprehensive exposure index is interpreted on the basis of the following classification obtained from empirical studies and physiological, biomechanical, and epidemiological principles, which include:

**Level 1 (safe level or green zone):** A CEI score < 2; it indicates that situations are acceptable and that conditions do not need to be changed.

**Level 2 (uncertain level or yellow zone):** A CEI score of 2 to 4; it indicates that the incidence rate of UEMSDs is negligible, but that further investigations are needed and changes may be required.

**Level 3 (slight risk or orange zone):** A CEI score of 4 to 6; it indicates that incidence rate of UEMSDs is fairly high, and that engineering control measurements and corrections are required soon.

**Level 4 (significant risk level or red zone):** A CEI score of > 6; it indicates that incidence rate of UEMSD is high and thus that engineering control measurements and workstation redesign are required immediately.

### 3. Introduction of variables involved in calculating the CEI

For easier calculation of corresponding exposure index, the brief definitions and descriptions about variables involving in the CEI formula have been submitted.

**Table 1.** Parameter for obtaining the multiplier factor for force exertion (FE)
3.1. Force Exertion (FE)

FE can be defined as the amount of physical effort required to perform a task or maintain control of equipment (1, 2); it depends on the type of grip, the weight of the object, body posture, the type of activity, and the duration of the task (2). FE may depend on static or dynamic contractions (1). The need to exert force during work-related activities may be due to handling, lifting, lowering, moving or holding objects, or keeping them in a given position (3).

The required force for performing various occupational actions is a critical factor producing WMSDs. The rate of exerted load or force on hand muscles can exceed hundreds of pounds. FE can be estimated using the Borg CR-10 scale or by knowing the percent of Maximum Voluntary Contraction (%MVC) from Table 1, which was derived from the model of CEN investigation (15) and the SI method (12).

<table>
<thead>
<tr>
<th>Rating criterion</th>
<th>Light</th>
<th>Somewhat difficult</th>
<th>Difficult</th>
<th>Very difficult</th>
<th>Near maximal</th>
<th>Maximal</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean of force exertion perceived (according to Borg)</strong></td>
<td>0-2</td>
<td>3</td>
<td>4-5</td>
<td>6-7</td>
<td>8-10</td>
<td>10&lt;</td>
</tr>
<tr>
<td><strong>Mean of force exertion in % of MVC</strong></td>
<td>0-20</td>
<td>30</td>
<td>40-50</td>
<td>60-70</td>
<td>80-100</td>
<td>100&lt;</td>
</tr>
<tr>
<td><strong>Multiplier factor</strong></td>
<td>1</td>
<td>3</td>
<td>6</td>
<td>9</td>
<td>13</td>
<td>17</td>
</tr>
</tbody>
</table>

3.2. Posture of Upper Limbs (PU)

Prolonged exposure to repetitive forceful exertion of the hand and wrist, especially in awkward postures, is strongly associated with tendon and nerve damage at the wrist and hand (17). Awkward postures include repeated or prolonged reaching, twisting, turning and bending hands, working with hands or arms, holding fixed positions, working with wrist bent for 2 hours per day (4); pressing the upper limbs against a hard or sharp edge, which can result in placing too much pressure on nerves, tendons and blood vessels; and using the palm of hand as a hammer regularly, or typing while resting arms or wrists on the hard desk edge (1).

UEMSDs may be attributable to occupational, non-occupational and individual factors (2). In the CEI method, the posture of upper limbs includes those of the hand and fingers, wrist, forearm, elbow, arm, and shoulder. CEI assigns a score 4 for each of these parts and every part is divided into four awkward posture items. Thereby every part of the upper limbs can receive a maximal score of 4. The items which must be considered include (10):

- Hand & fingers: 1) Pinch grip
2) Tight grip  
3) Hook grip  
4) Palmar grip

- **Wrist:**  
  1) Flexion  
  2) Extension  
  3) Radial deviation  
  4) Ulnar deviation

- **Forearm:**  
  1) Supination  
  2) Pronation  
  3) Radial deviation  
  4) Ulnar deviation

- **Elbow:**  
  1) Supination  
  2) Pronation  
  3) Flexion  
  4) Extension

- **Arm:**  
  1) Abduction  
  2) Contracting arm for a long term  
  3) Turning inward  
  4) Turning outward

- **Shoulder:**  
  1) Abduction  
  2) Pulling forward  
  3) Pulling backward  
  4) Holding at higher than shoulder level for a long term

Finally, the multiplier factor for PU of upper limbs (Table 2) was extracted from (15) (16) using the SI method (12).

**Table 2.** Parameters for determining the multiplier factor for posture of upper limbs (PU)

<table>
<thead>
<tr>
<th>Rating criterion</th>
<th>Very good</th>
<th>Good</th>
<th>Fair</th>
<th>Bad</th>
<th>Very bad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Score of upper limb posture</td>
<td>≤ 4</td>
<td>5-8</td>
<td>9-12</td>
<td>13-16</td>
<td>&gt; 16</td>
</tr>
<tr>
<td>Multiplier factor</td>
<td>1</td>
<td>1.25</td>
<td>1.5</td>
<td>1.75</td>
<td>2.5</td>
</tr>
</tbody>
</table>

**Table 3.** Parameters for determining the multiplier factor for frequency of force (FF) exertion

<table>
<thead>
<tr>
<th>Frequency of force exertion per minute</th>
<th>&lt; 4</th>
<th>4-8</th>
<th>9-14</th>
<th>15-19</th>
<th>19 &lt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiplier factor</td>
<td>0.5</td>
<td>1</td>
<td>1.5</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

**Table 4.** Parameters for determining the multiplier factor for duration of force exertion (DF)
Repeating the same motions over and over again places stress on the muscles and tendons. The severity of risk depends on the frequency at which the action is repeated, the speed of the movement, the number of muscles involved and the required force (1, 3).

The success of the psychophysical approach to assessing the risk of manual handling tasks led to the application of this approach to analyzing the effects of repetitive motion of the hands and wrists (2). Repetitiveness can be used to characterize tasks for assessment. For this, a repetitive task for the upper limbs can be defined as an activity of at least an unbroken hour in which the subject repeats a similar series of relatively brief actions (4). Quantifying and assessing repetitiveness is a difficult task (18). The multiplier factor for FF (Table 3) was extracted from (15) (16) using the OCRA method (10).

### 3.4. Duration of Force Exertion (DF)

DF is the percentage of time that is spent exerting force per work cycle (3); it represents biomechanical and physiological stresses related to maintaining force exertion. Therefore, both the exertion cycle and average exertion time per cycle must be determined (1). Measuring average exertion cycle time requires observing workers performing a job for long enough to ensure that the observations correspond to job requirements (5). Average exertion cycle time is gained by dividing the number of counted force exertions by the length of the observation period (12).

From percent force exertion duration, the multiplier factor for DF (Table 4) was extracted from (15) and (16).

### 3.5. Task duration per day (TD)

TD (hours) represents the total time per day that a task is performed (3, 5); it represents the time that a person (muscles, tendons and ligaments) performs a specified task per a shift, rather than total shift length (12). The multiplier factor for task duration (Table 5) was extracted from (15, 16) using the SI method (12) and the OCRA method (10).

<table>
<thead>
<tr>
<th>Duration of force exertion (%)</th>
<th>&lt; 10</th>
<th>10-29</th>
<th>30-49</th>
<th>50-79</th>
<th>&gt; 79</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiplier factor</td>
<td>0.5</td>
<td>1</td>
<td>1.5</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 5. Elements for obtaining the multiplier factor for task duration (TD)
3.6. Speed of Force Exertion (SF)

SF is the observed velocity of a task; this speed is considered due to its effects on force exertion (12). As FE increases, the Maximum Voluntary contraction is diminished and range of EMG is increased (18). To achieve suitable working conditions, SF should be "Very slow", “Slow”, or “Fair” (12). The multiplier factor for speed of force exertion (Table 6) was obtained from (15) and (16) using the SI method (12).

3.7. Part Weight (PW)

Weight of the object (PW) is the most important characteristic of manual material handling; it is involved in producing UEMSDs and other cumulative Trauma disorders (14). In manual handling systems for assessing load on upper extremities, an object or load weight between 0.5 to 4 kg is the critical range for inducing alterations in the upper limb musculoskeletal system that can increase the incidence rate of UEMSDs (14). An object with weight > 4 kg stresses the neck, upper limbs and other upper parts of the body (18). The weighting factor for part weight (Table 7) was extracted from (19), (16) and (20).

Table 6. Elements for quantifying the multiplier factor for speed of force exertion (SF)

<table>
<thead>
<tr>
<th>Speed of force exertion</th>
<th>Very slow</th>
<th>Slow</th>
<th>Fair</th>
<th>Fast</th>
<th>Very fast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compared to MTM</td>
<td>≤ 80</td>
<td>81-90</td>
<td>91-100</td>
<td>101-115</td>
<td>115 &lt;</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Perceived speed</th>
<th>Extremely relaxed pace</th>
<th>Taking one’s own time</th>
<th>Normal speed of motion</th>
<th>Rushed, but able to keep up</th>
<th>Rushed and barely or unable to keep up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiplier factor</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1.5</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 7. Elements for quantifying the multiplier factor for part weight (PW)

<table>
<thead>
<tr>
<th>Part weight (kg)</th>
<th>&lt; 0.5</th>
<th>0.5-1</th>
<th>1-2</th>
<th>2-4</th>
<th>4 &lt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiplier factor</td>
<td>1</td>
<td>1.5</td>
<td>2</td>
<td>2.5</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 8. Elements for determining the multiplier factor for lack of recovery periods (RP)
Lack of enough recovery periods (hour) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8  
---|---|---|---|---|---|---|---|---|---
Multiplier factor | 1 | 1.25 | 1.5 | 1.75 | 2 | 2.25 | 2.5 | 2.75 | 3

Table 9. Elements for achieving the multiplier factor for age factor (AF)

<table>
<thead>
<tr>
<th>Age rating (year)</th>
<th>≤ 40</th>
<th>41-50</th>
<th>51-60</th>
<th>&gt; 60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiplier factor</td>
<td>0.6</td>
<td>0.8</td>
<td>0.9</td>
<td>1</td>
</tr>
</tbody>
</table>

3.8. Lack of Recovery Periods (RP)

A recovery period is defined as “period of time between or within cycles, during which no repetitive movements are carried out” (10). A recovery period consists of relatively long pauses after periods of mechanical movements; during these periods muscles can recovered metabolically (10). Lack of recovery periods can create oxygen debt and produce accumulation of lactic acid, which induces muscle fatigue (4). Therefore, providing formal and informal rest intervals between work cycles during tasks can prevent muscle fatigue and UEMSDs (1, 3, 5). The multiplier factor for lack of recovery period (Table 8) was derived from (15) and (16) using the OCRA method (10).

3.9. Age Factor (AF)

Age is the most important factor in force exertion and biomechanical models (18); it has a direct relationship with FE and Maximal Aerobic Capacity in hand activities (4). For example, a 40 year old person has the maximal power, but at later ages this capability and power decrease slowly (18). The age factor multiplier (Table 9) was obtained using the European Coal and Steel Community (ECSC) studies that quantified the effect of age on inducing and exacerbating UEMSDs (21, 22, 23).

3.10. Effective Item (EI)

EIs are factors that have indirect effects on the incidence rate of UEMSDs (10). These items may be present in repetitive tasks, but not necessarily or always (10). Their type, intensity and duration lead to an increased level of overall exposure to risk of developing UEMSDs (2). These items are considered to be relevant in the production and development of UEMSDs (3). They are always work-related, and must be considered when assessing risk exposure (5). For an item to be considered, it must have an association with UEMSD occurrence, so that it would have a collective impact rather than an individual impact (10). To obtain EI, a score of 1 is allocated to any item whenever that item is present (10).

- Extreme precision at working
Chronic Exposure Index Model to Assess Ergonomic Risk Factor
Related to Upper Extremity Musculoskeletal Disorders

- Unsuitable lighting (low or high)
- Exposure to heat
- Carelessly
- Economic problems
- Background of UEMSDs
- Localized compression on upper limb
- Lack of training
- Secondary job
- Reach limit
- Clearance
- Humidity
- Poor size or shape of parts
- Presenting vibration
- Exposure to cold

- Presenting noise
- Low experience
- Familiar problems
- Contact stress
- Sharpness of object surface
- Rapid twisting/turning movements
- Overtime
- Slippery level
- Poor packaged goods or poor handles
- Chemical components and poisons
- Hand-arm vibrations

Then, the scores are added and the corresponding multiplier factor is determined (Table 10), which was calculated from (15) and (16) studies using the OCRA method (10).

4. Development of the CEI

UEMSDs are generally agreed to be a multi-factorial occupational problem (24). Many epidemiological studies have linked development of UEMSDs to various risk factors (25, 26, 27, 28), which have been classified into physical (29), psychosocial/organizational (30, 31, 32), and individual (33) occupational risk factors.

Several ergonomic techniques have been developed to assess exposure UEMSD risk factors (34). Many of the posture–based observational techniques which have been provided are only strictly applicable in very limited circumstances and have shortcomings and limitations. Based on these findings and current techniques, a strategy and policy was developed to obtain a CEI which:

a) Is applicable to the complete range of manual tasks;
b) Provides an integrated assessment of various risk factors;
c) Provides an independent assessment of disorder risk to different body regions;
d) Provides an overall risk assessment which allows prioritisation of tasks and submits suggested action levels;
e) Facilitates effective targeting of controls by providing an indication the relative severity of different risk factors within a task;
f) Is suitable for use by workplace staff with minimal training and equipment;
g) Is quick and easy to use; and
h) Can identify high risk manual handling and repetitive tasks
Table 10. Elements for determining the multiplier factor for effective items (EI)

<table>
<thead>
<tr>
<th>Score of effective items</th>
<th>0</th>
<th>1-4</th>
<th>5-8</th>
<th>9-12</th>
<th>12 &lt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiplier factor</td>
<td>1</td>
<td>1.5</td>
<td>2</td>
<td>2.5</td>
<td>3</td>
</tr>
</tbody>
</table>

4.1. Applicability of the CEI

The proposed CEI model has been applied successfully in several studies performed by the author (unpublished reports); this success shows that it can be used in the study of many repetitive single or multiple tasks without any limitations. In most cases the aim of studies has been to identify and assess the risk factors of UEMSDs and injuries for individual employees. A more detailed and general purpose was to assay, measure and investigate the reliability and validity of various survey risk factors involving in calculating the CEI Score. The studies have been performed in different fields, including weaving and textile industries, manufacturing industries, carpentry, steel industry, post offices, service industry, electronic industry, shopping and marketing, agriculture and farming industry, tailoring and sewing, hair styling, baking, and bricklaying.

4.2. Reliability and validity tests of the CEI

4.2.1. Inter-observer reliability test of the assessment items

Inter-observer assessment reliability (Table 11) was assessed to identify possible sources of error in the reliability assessment test process. In this test, 31 various tasks were randomly selected from 31 different jobs involving manual handling tasks with varied part (load) weights. The ergonomic field study assessed static and repetitive tasks; highly repetitive tasks; repetitive tasks with low, moderate and high force exertions; sedentary or standing tasks; and non-repetitive tasks with low, moderate and high force exertions. Video-tape recordings were viewed in slow motion to confirm the assessment of the observer. Several pilot tests quantified that assessment durations of 5-7 minutes are sufficient to complete the assessment.
process by most observers. Twenty-five observers comprising of five general observers without any experience in ergonomic assessment tests, and 20 professional observers with 2, 4, 6 and 7-8 years’ experience in ergonomic assessment tests in ergonomics and occupational Health were selected randomly. The mean age of observers was 39.8 years (SD = 12.7, Range = 21-57). Excluding the five non-experienced observers, the average experience of observers was 4.9 years (SD = 3.2, Range = 2-8). The 25 observers were divided into five groups, and each observer in each group separately assessed the various tasks both in the field and using video-tape-recordings.

As assessment work experience increased, inter-observer reliabilities (both Cohen’s Kappa (35) and percentage agreement) in assessing items used in calculating the CEI score increased. According to the classification proposed by Landis and Koch (35), single and total percentage agreement for any item was > 60% and all kappa factors for strength of agreement were > 0.20 (“Fair” to “almost perfect” agreement). Percentage agreement in most items were either close to or > 60%; this agreement can be considered “acceptable” (35, 36, 37).

**Table 11.** Inter-observer reliability on assessment items as specified in the CEI

<table>
<thead>
<tr>
<th>Assessment Items</th>
<th>All observers Kappa</th>
<th>All observers % agreement</th>
<th>5 observers with no experience Kappa</th>
<th>5 observers with 2 yrs' experience % agreement</th>
<th>5 observers with 4 yrs' experience Kappa</th>
<th>5 observers with 6 yrs' experience % agreement</th>
<th>5 observers with 7-8 yrs' experience Kappa</th>
<th>5 observers with 7-8 yrs' experience % agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force exertion</td>
<td>0.46</td>
<td>80.1</td>
<td>0.36</td>
<td>76.1</td>
<td>0.39</td>
<td>77.4</td>
<td>0.43</td>
<td>79.5</td>
</tr>
<tr>
<td>Upper limb posture</td>
<td>0.45</td>
<td>82.5</td>
<td>0.29</td>
<td>71.3</td>
<td>0.31</td>
<td>81.6</td>
<td>0.36</td>
<td>83.3</td>
</tr>
<tr>
<td>Force frequency</td>
<td>0.47</td>
<td>86.8</td>
<td>0.33</td>
<td>61.5</td>
<td>0.41</td>
<td>63.6</td>
<td>0.43</td>
<td>67.2</td>
</tr>
<tr>
<td>Duration of force exertion</td>
<td>0.42</td>
<td>71.3</td>
<td>0.34</td>
<td>62.4</td>
<td>0.35</td>
<td>67.6</td>
<td>0.38</td>
<td>71.3</td>
</tr>
<tr>
<td>Task duration</td>
<td>0.35</td>
<td>70.1</td>
<td>0.28</td>
<td>63.8</td>
<td>0.31</td>
<td>67.6</td>
<td>0.35</td>
<td>69.6</td>
</tr>
<tr>
<td>Speed of force exertion</td>
<td>0.50</td>
<td>79.5</td>
<td>0.31</td>
<td>69.7</td>
<td>0.33</td>
<td>73.5</td>
<td>0.39</td>
<td>77.2</td>
</tr>
<tr>
<td>Parts weight</td>
<td>0.42</td>
<td>86.4</td>
<td>0.32</td>
<td>81.3</td>
<td>0.36</td>
<td>81.9</td>
<td>0.38</td>
<td>86.2</td>
</tr>
<tr>
<td>Lack of recovery periods</td>
<td>0.47</td>
<td>75.8</td>
<td>0.27</td>
<td>63.7</td>
<td>0.30</td>
<td>76.2</td>
<td>0.34</td>
<td>73.5</td>
</tr>
<tr>
<td>Age factor</td>
<td>0.81</td>
<td>94.8</td>
<td>0.65</td>
<td>85.2</td>
<td>0.73</td>
<td>89.5</td>
<td>0.79</td>
<td>97.3</td>
</tr>
<tr>
<td>Effective items</td>
<td>0.39</td>
<td>67.4</td>
<td>0.32</td>
<td>63.1</td>
<td>0.34</td>
<td>63.5</td>
<td>0.38</td>
<td>66.7</td>
</tr>
</tbody>
</table>
4.2.2. Intra-observer reliability test of the assessment items

Intra-observer reliability (Table 12) was assessed by having the same observers participate in a test-retest procedure in which they assessed the same 31 tasks twice in a 4-week interval. All kappa statistical analysis factors for all assessment items were > 0.60 ("substantial" to "almost perfect" agreement), and the test-retest agreements were all statistically significant ($\chi^2$ test.) These results indicate that agreement between assessments of the same factor by the same observer analyses can considered “acceptable” (35).

4.2.3. Validity test of the assessment items

A validity test was conducted in a laboratory study with the same observers assessing the same set of 31 various tasks by comparing the observers’ assessment of simulated tasks with computer-assisted 3D (dimensional) motion analysis utilizing the SIMI system (34,38,39,40). The same observers also participated in the field study by comparing observers’ assessment on the same set of 31 various tasks using analysis of video-tape recordings of the tasks. Agreements were quantified between observers’ assessment and video analysis of assessment items utilized in calculating the CEI score (Table 13). In the laboratory study, for all tasks and for all assessment items, the percentage agreements were close to or > 60%. In the field study, for all assessment items, the percentage agreements were > 70%. These agreements can be considered “acceptable” (35, 36, 37).

Table 12. Intra-observer reliability on assessment items as specified as in the CEI

<table>
<thead>
<tr>
<th>Assessment items</th>
<th>25 totally observers</th>
<th>5 observers without any experience</th>
<th>5 observers with 2 yrs’ experience</th>
<th>5 observers with 4 yrs’ experience</th>
<th>5 observers with 6 yrs’ experience</th>
<th>5 observers with 7-8 yrs’ experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force exertion</td>
<td>Kappa p*</td>
<td>Kappa p*</td>
<td>Kappa p*</td>
<td>Kappa p*</td>
<td>Kappa p*</td>
<td>Kappa p*</td>
</tr>
<tr>
<td></td>
<td>0.71 0.008 0.61 0.003</td>
<td>0.65 0.022 0.73 0.002</td>
<td>0.74 0.037 0.79 0.025</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper limb posture</td>
<td>0.81 0.031 0.73 &lt;0.001</td>
<td>0.77 0.011 0.80 0.001</td>
<td>0.83 0.001 0.89 0.001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Force frequency</td>
<td>0.77 0.006 0.69 0.001</td>
<td>0.71 0.008 0.77 0.033</td>
<td>0.80 0.011 0.85 0.005</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duration of force exertion</td>
<td>0.80 0.036 0.70 0.004</td>
<td>0.75 0.013 0.78 0.002</td>
<td>0.86 0.038 0.91 0.019</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Task duration</td>
<td>0.83 0.017 0.76 0.013</td>
<td>0.79 0.004 0.83 &lt;0.001</td>
<td>0.86 0.001 0.90 0.008</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed of force exertion</td>
<td>0.88 &lt;0.001 0.79 0.045</td>
<td>0.86 0.003 0.89 0.021</td>
<td>0.90 0.013 0.94 0.001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parts weight</td>
<td>0.79 0.028 0.71 0.017</td>
<td>0.74 0.014 0.78 0.001</td>
<td>0.79 0.039 0.96 0.005</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lack of recovery periods</td>
<td>0.81 0.007 0.69 0.021</td>
<td>0.77 0.005 0.79 0.016</td>
<td>0.83 0.001 0.89 &lt;0.001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age factor</td>
<td>0.82 0.003 0.72 0.002</td>
<td>0.76 0.001 0.81 0.023</td>
<td>0.86 0.003 0.93 0.041</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effective items</td>
<td>0.86 0.045 0.80 0.015</td>
<td>0.82 0.020 0.85 0.032</td>
<td>0.90 0.041 0.93 0.033</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: The letter p with asterisk (*) denotes the $\chi^2$ significant level.
Table 13. Agreement between observers’ assessment and detailed video analysis of assessment items as specified in the CEI

<table>
<thead>
<tr>
<th>Assessment items</th>
<th>Percentage agreement between observers’ assessment and SIMI analysis (laboratory study)</th>
<th>Percentage agreement between observers’ assessment and video analysis (field study)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force exertion</td>
<td>88.5</td>
<td>81.4</td>
</tr>
<tr>
<td>Upper limb posture</td>
<td>95.2</td>
<td>79.6</td>
</tr>
<tr>
<td>Force frequency</td>
<td>79.3</td>
<td>85.3</td>
</tr>
<tr>
<td>Duration of force exertion</td>
<td>93.2</td>
<td>88.1</td>
</tr>
<tr>
<td>Task duration</td>
<td>69.9</td>
<td>83.3</td>
</tr>
<tr>
<td>Speed of force exertion</td>
<td>77.5</td>
<td>89.4</td>
</tr>
<tr>
<td>Parts weight</td>
<td>89.3</td>
<td>73.6</td>
</tr>
<tr>
<td>Lack of recovery periods</td>
<td>71.3</td>
<td>82.4</td>
</tr>
<tr>
<td>Age factor</td>
<td>91.4</td>
<td>89.6</td>
</tr>
<tr>
<td>Effective items</td>
<td>75.1</td>
<td>83.2</td>
</tr>
</tbody>
</table>

4.2.4. Validity test of the CEI action levels

The same 25 observers assessed the same 31 tasks using the CEI. For comparison, the Occupational Repetitive Actions (OCRA) index (10) and the Strain Index (SI) (12) were also assessed. The purpose of the validity test was to develop, and then to verify an action recommended by the CEI model, so the observers determined and assessed the action levels of the CEI model by considering the need for ergonomic changes and further investigations. Finally, the CEI score and its action levels were compared to those of OCRA and SI, and Cohen’s kappa was used to quantify the strength of observers’ percentage agreements (Table 14). The kappa values for all action levels were > 0.60 (“substantial” to “almost perfect” agreement) and percentage agreements for all action levels were > 75%; these agreements can be considered “acceptable” (35, 36, 37).

Table 14. Agreement between observers’ assessment on verifying the CEI action levels

<table>
<thead>
<tr>
<th>CEI score</th>
<th>CEI action level</th>
<th>Equivalent SI score</th>
<th>Equivalent OCRA score</th>
<th>Observers’ assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 2</td>
<td>Acceptable</td>
<td>&lt; 3</td>
<td>&lt; 1</td>
<td>0.67</td>
</tr>
<tr>
<td>2-4</td>
<td>Investigate further</td>
<td>3-5</td>
<td>1-2</td>
<td>0.63</td>
</tr>
<tr>
<td>4-6</td>
<td>Investigate further and change soon</td>
<td>5-7</td>
<td>2-4</td>
<td>0.81</td>
</tr>
<tr>
<td>&gt; 6</td>
<td>Investigate further and change immediately</td>
<td>&gt; 7</td>
<td>&gt; 4</td>
<td>0.79</td>
</tr>
</tbody>
</table>

5. Conclusions
The CEI method is a new model for assessing exposure to various risk factors that can cause UEMSDs in repetitive tasks. The method utilizes concepts from the OCRA method (10), the SI method (12), CEN (15), Kilbom (16) and ECSC (21,22,23). A CEI score of < 2 must be achieved to prevent the incidence of UEMSDs. CEI can be used for classifying safe and hazardous tasks, and for proposing design solutions to correct awkward workplace situations. The model requires reliability and validation, particularly by means of a parallel and continuous study of induced UEMSDs in groups of exposed workers. CEI considers various risk factors. Parallel investigations are required to find more reasonable relationships between clinical effects and calculated index scores. Based on results obtained from tests, the model is found to be sensitive for assessing the interventions and changes in exposure and assessment items before and after ergonomic intervention. The model is also reliable, valid and applicable for a vast range of tasks and jobs. Assessment reliability, validity and exposure index applicability may improve if assessors’ training is improved. In test results the CEI model achieved “acceptable” inter-observer, intra-observer and validity agreement.

References


Winkel J, Mathiassen SE (1994). Assessment of physical workload in epidemiologic


**Seyyed Ali Moussavi-Najarkola**

Seyyed Ali Moussavi-Najarkola is Ph.D. of Occupational Health from Department of Occupational Health, School of Medical Sciences, Shahid Beheshti of Medical University (SBMU), Tehran, Iran. He have presented a new ergonomic risk assessment model for the assessment of risk factors associated with upper extremity musculoskeletal disorders (UEMSD) in repetitive tasks so-called "Comprehensive Exposure Index; CEI" model in the Asian Journal of Ergonomics.
Laboratory Study of Factors Affecting Sitting Comfort and Discomfort

M.G. Mohamed Thariq ¹*, Weining Fang ¹, Lijian Zhang ², Harsha Munasinghe ³

¹ Ergonomics Lab, State Key Laboratory of Rail Traffic Control and Safety, Beijing Jiaotong University, Beijing 100044, China
² Human Factors Specialist, General Dynamics Land Systems, 38500 Mound Rd, Sterling Heights, MI 48310, USA
³ Department of Architecture, University of Moratuwa, Sri Lanka

Abstract

A questionnaire was used to assess how sensations of sitting discomfort (physical) and comfort (emotional) factors affected the discomfort and comfort perceptions experienced by subjects while sitting in office chairs of three distinct designs. Body posture movements were recorded on video. Factor analysis validated the factor structure of comfort and discomfort. The results obtained by analysis of the body posture movements confirmed the results obtained in subjective ratings. Above moderate and higher levels of discomfort (physical) factors are dominant over higher levels of comfort (emotional) factors in the perception of discomfort and comfort. However, lower levels of discomfort factors and low to intermediate levels of comfort factors can co-exist. Various individual underlying factors have varying levels of effect on overall comfort and discomfort perceptions. The results indicate that relief is the strongest factor in perception of comfort in sitting. From the results obtained, it is suggested to investigate chair design features that may influence the feeling of relief in sitting.

Keywords: sitting, comfort need, comfort factors, discomfort factors, interactions

1. Introduction

Comfort is one of the main concerns in office seat design. Slater (1985) defines comfort as a pleasant state of physiological, psychological and physical harmony between a human and its environment. Scientific work in the design of seats has made a remarkable progress in providing comfortable seats. Comfort is influenced by several factors, including postural support provided to the body, contact

* Corresponding author: zmallick2002@yahoo.co.in, Phone: 091-11-26981259
pressure with the body, thermal and humidity characteristics of the seat and aesthetics.

Several studies indicate that comfort and discomfort are affected by distinctly different variables (Kleema, 1981; Kajimo et al., 1982). Zhang et al. (1996) identified the multidimensional properties of comfort and discomfort. Comfort is affected by well being factors (e.g. relaxation, impression) (Zhang et al., 1996; Helander and Zhang, 1997). Physical strain factors (e.g. muscle contraction, joint angles, and pressure distribution that produce feelings of pain and soreness) cause discomfort. A theoretical model (De Looze et al., 2003) recognizes discomfort and comfort as conceptually separate entities. The model identifies the underlying factors for comfort and discomfort at the human, seat and context levels. Zhang et al. (1996) postulated a two-stage hypothetical model, based on which comfort and discomfort need to be treated as different and complementary entities in ergonomic investigations. They noted that transition is possible from discomfort perception to comfort perception while sitting. Hence, different underlying factors at different levels may affect the range of perceived comfort and discomfort.

Several subjective and objective methods have been used to evaluate or predict seat comfort. Shackel et al. (1969) suggested that in sitting comfort assessment, the user’s subjective assessment should be the ultimate criterion. Subjective sitting comfort evaluation is a widely accepted method in ergonomic research, although the merits of subjective rating scale have been questioned (Annett 2002). Many practitioners and researchers assume that comfort and discomfort are two opposites on one continuum. Thus comfort and discomfort ranges from extreme comfort through a neutral state to extreme discomfort (e.g. Shackel et al, 1969).

On the other hand, Helander and Zhang (1997) argued that comfort and discomfort can be quantified and measured independently. Further they stated that a multi-dimensional chair evaluation checklist that they developed produced consistent results in field studies. They concluded that the multi-dimensional checklist can be used for practical evaluation of sitting comfort and discomfort. Kyung, et al., (2007) recommended using discomfort ratings to measure basic qualities of seats with the objective of prevention of pain, and to use comfort ratings to measure more subtle qualities of seats with hedonomic objectives.

Hancock and Pepe (2005) showed that discomfort and comfort are at different stages of needs, the latter being placed at a higher stage than the former. Preliminary evidence indicated that the influences of the two stages may overlap (Zhang 1992). To further explain the two stage concept, Helander and Zhang (1997) suggested that when physical strain factors (biomechanical factors) are present, the contribution of well-being factors to overall sensation of comfort diminishes. They further stated that discomfort factor has a dominant effect in comfort perception. These citations indicate that underlying factors of sitting comfort and discomfort interact. The important outcome of the two stage concept was the development of a multi-dimensional checklist to evaluate comfort and discomfort on separate scales.

The checklist used by Helander and Zhang (1997) assumed that, in sitting comfort measurement, different levels of sensations can be produced by each individual underlying factor. The explanation of how various individual sitting comfort factors (e.g., impression, relaxation) and discomfort factors (e.g., pain,
fatigue) at their different levels interact to produce perception of comfort and discomfort in sitting is lacking in the literature. Hence the goal of the present study was to investigate the interaction effects of various underlying sitting comfort and discomfort factors on comfort and discomfort perception under laboratory conditions.

2. Method

2.1. Subjects

Twenty male and female students from the Beijing Jiaotong University participated in the study. Permission to conduct the study was obtained from the Head of the relevant Division. Subjects selected were in good health and reported no past or present musculoskeletal problems. Their consent to participate in the study was obtained. Their stature and weight were measured (Table 1), and their name, age, and sex was obtained.

2.2. Chairs and workstation

Three different types of adjustable office chair were tested (Figure 1); the chairs selected to be different in dimensions and appearance to represent the different sensations produced by the chairs (Vergara and Page, 2002). A workstation was set up with a personal computer, an office table and an adjustable chair. All of the workstation components were taken from existing office furniture and equipment inventories. In the work station, only the chair was changed during the experiment.

Table 1. Heights, weights, and ages of the experimental subjects

<table>
<thead>
<tr>
<th>Characteristics of subjects</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean (S.D.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (mm)</td>
<td>155</td>
<td>179</td>
<td>167.94 (6.99)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>46</td>
<td>97</td>
<td>59.40 (12.65)</td>
</tr>
<tr>
<td>Age</td>
<td>19</td>
<td>22</td>
<td>20.45 (0.76)</td>
</tr>
</tbody>
</table>

Figure 1. Chair types and workstation used in the experiment
2.3. Task and Time

In this study, participants performed a typing task while sitting in one of the seats. Fernandez and Poonawala (1998) concluded that before performing an ergonomic evaluation of a chair, the user should perform his or her task in the chair for at least 3 h. Discomfort and postural shifts are known to increase considerably after a 2-h work period (Liao and Drury, 2000). Fatigue may accumulate over 40 min of work (Hening et al., 1989). Considering these findings, a total work period of 1.5 h was used for this study.

2.4. Posture and movement measure (video recording)

Subjective methods are useful when they are combined with objective methods (Eklund and Corlett, 1985; Lepoutre et al., 1985). Therefore, record the body posture movements on video then used the body posture movement method to test our subjective conclusions. Movements may be dictated either by the task requirements or by a physiologically driven needs to change sitting position; they can therefore be a measure of discomfort (Graf et al., 1995). We assumed that these measures are an indirect measure of sitting discomfort. Videos of the subjects recorded them sitting between the camera and a vertical background board with grid lines. The video camera was placed on the sagittal plane of the seat. The board with grid lines was perpendicular to the video camera.

2.5 Questionnaire survey (use of rating scales)

2.5.1 Variables measured

Factors such as pain and fatigue are usually used in chair evaluation studies (Wilder et al., 1994 and Vink et al., 1994). For this study, discomfort factors such as pain and fatigue were taken based on the study by Zhang et al (1996). Pain usually consists of localized physical suffering associated with bodily disorder (as a disease or an injury), or a basic bodily sensation induced by an unpleasant stimulus and is characterized by physical discomfort (as pricking, throbbing, or aching), which and typically leads to evasive action (Merriam-Webster dictionary). Fatigue is defined as weariness from bodily or mental exertion (Dictionary.com Unabridged). Pain in different body regions (i.e. neck, upper back, mid back, lower back, upper leg and lower leg, upper arm, lower arm, and wrist) were assessed. Based on the findings of Zhang et al (1996), comfort factors measured were impression, relaxation, and relief. Kolcaba and DiMarco (2005) defined relief as the state of having a discomfort mitigated or alleviated. Relaxation can be considered as a loosening or slackening of body or mind (American Heritage Stedman's Medical Dictionary). Impression is defined as an effect, a feeling, or an image retained as a consequence of experience (American Heritage Dictionary of Idioms). Overall comfort perception and
discomfort perception were also measured as two separate variables (Helander and Zhang, 1997). Measurements of all these variables were obtained using rating scales in the questionnaire.

Subjective feelings of pain, fatigue, impression, relaxation and relief produced by different chairs were assumed to take different levels. Similarly, perceived overall comfort and discomfort in sitting was also assumed to take different levels. Levels of these sensations are usually measured using subjective rating scales (e.g. Shackle et al., 1969; Helander and Zhang, 1997).

2.5.2 Questionnaire

Two types of questionnaires were used: a general questionnaire that consisted of a few questions to obtain participant’s names, age, and sex and other pertinent data; and a rating questionnaire that consisted of separate statements for each variable rated; for example “I feel low back pain” and “I feel relaxed”. Each statement was rated on a seven-point rating scale from 1: ‘not at all’, to 7: ‘extremely’. The questionnaires were written in Chinese script.

2.6 Procedure

Subjects were given a brief introduction about the study. All participants were requested to test each chair for a 1.5-h period in the laboratory workstation. Each subject evaluated all three chairs, one per day. The subjects were given full explanation on how to use the adjustability features in the case of adjustable chairs. The subjects were asked to adjust the chair height at the beginning of the assessment until it fit them. During the typing sessions, the subjects did not perform chair adjustments.

Typing software NCEcaikbttop free version (V 2.3 Chinese) was used for typing. Text with sufficient length was selected so that subjects would not run short of text during the experiment. The typing text was displayed on the monitor and subjects were asked to read and type it. The 1.5-h period was divided into three 30-min sessions: typing session 1(5 min instruction, 25 min typing), typing session 2 (5 min break 1, 25 min typing), and typing session 3 (5 min break 2, 25 min typing). Subjects remained sat at their workstation during entire test. In all three sessions, the subject was recorded on video. Subjects were asked to complete the rating questionnaire at the end of each typing session. Subjects were provided with a diagram of body parts to assist them in specifying the sites of pain.

At the end of the testing period, the general questionnaire was given to each participant and finally stature and weight were measured.

2.7 Data Analysis

Video recording was reviewed and detectable posture changes were counted
for analysis. The posture change frequency (i.e., the number of posture changes per minute) was calculated. The questionnaire survey data and the posture change frequency data were analyzed using SPSS version 13.0 software.

3 Results and Discussions

3.1 Factor separation

We verified the factor structure of sitting comfort and discomfort before investigating the interactions between underlying factors of sitting comfort and discomfort. The factor analysis was conducted with Varimax rotation to separate main factors for data collected using rating questionnaires; the results separated the underlying factors rated in the questionnaires into two main factors (Table 2). Factor 1 (discomfort factor) consists of neck pain, upper back pain, mid back pain, low back pain, upper leg pain, lower leg pain, upper arm pain, lower arm pain, wrist pain, and fatigue. Factor 2 (comfort factor) consists of impression, relaxation, and relief. This result confirmed the factor structure obtained by Zhang et al. (1996) and Helander and Zhang (1997). The results obtained were also similar to those obtained in classroom settings by Thariq and Munasinghe (under review).

3.2 Chair and time effect

MANOVA was conducted to identify the Chair, Time, and Chair x Time interaction effects on comfort and discomfort factors, as well as on overall comfort and discomfort perception (Table 3).

Table 2. The results of factor analysis

<table>
<thead>
<tr>
<th>Underlying factors of sitting comfort and discomfort</th>
<th>Factor 1 (discomfort factor)</th>
<th>Factor 2 (comfort factor)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neck pain</td>
<td>0.797</td>
<td>-0.213</td>
</tr>
<tr>
<td>Upper back pain</td>
<td>0.810</td>
<td>-0.186</td>
</tr>
<tr>
<td>Mid back pain</td>
<td>0.715</td>
<td>-0.384</td>
</tr>
<tr>
<td>Low back pain</td>
<td>0.622</td>
<td>-0.372</td>
</tr>
<tr>
<td>Upper leg pain</td>
<td>0.725</td>
<td>-0.398</td>
</tr>
<tr>
<td>Lower leg pain</td>
<td>0.701</td>
<td>-0.283</td>
</tr>
<tr>
<td>Upper arm pain</td>
<td>0.640</td>
<td>-0.156</td>
</tr>
<tr>
<td>Lower arm pain</td>
<td>0.712</td>
<td>0.076</td>
</tr>
<tr>
<td>Wrist pain</td>
<td>0.733</td>
<td>0.015</td>
</tr>
<tr>
<td>Fatigue</td>
<td>0.730</td>
<td>-0.093</td>
</tr>
<tr>
<td>Impression</td>
<td>0.072</td>
<td>0.784</td>
</tr>
<tr>
<td>Relax</td>
<td>-0.277</td>
<td>0.723</td>
</tr>
<tr>
<td>Relief</td>
<td>-0.232</td>
<td>0.839</td>
</tr>
</tbody>
</table>
3.2 Chair and time effect

MANOVA was conducted to identify the Chair, Time, and Chair x Time interaction effects on comfort and discomfort factors, as well as on overall comfort and discomfort perception (Table 3).

Chair type had no significant effects on discomfort factors or on discomfort perception. Helander and Zhang (1997) found that biomechanical discomfort factors (e.g. pain) increased as a function of time of day, and that chair design did not seem to matter. Discomfort perception and all discomfort factors were significantly affected by sitting Time. The Chair x Time interaction effect did not significantly affect overall discomfort factors or discomfort perception. The results suggest that discomfort perceived in this study was caused by the passage of time while sitting. These results are similar to those obtained by Helander and Zhang (1997); they believed that the time dependency is a fatigue effect.

Chair effect had no significant effect on relaxation and relief but a significant effect on impression. Further, the results showed that the overall comfort perception was not significantly affected by the chair. These result may suggest that a significant chair effect on impression (comfort factor) alone may not be sufficient to rate the chair as comfortable. However, Helander and Zhang (1997) obtained significant chair effects for all comfort factors measured. In a study under class room settings conducted by Thariq and Munasinghe (under review), impression, relaxation and relief were affected by chair type. The present experiment was conducted in 1.5-h session whereas the study under class room settings was conducted for 3-h time periods. In the class room experiment by Thariq and Munasinghe (under review), relaxation and relief were affected by the time, but relaxation and relief were unaffected by the time factor in the present experiment. Therefore the duration effect may be the possible reason for the chair effects not being significant except for impression.

Overall comfort perception and comfort factors (impression, relax and relief) were unaffected by the Time or the Chair x Time interaction in the present study. This indicates that comfort perception as well as impression, relaxation, and relief did not change over time while sitting. Similar results were obtained by Helander and Zhang (1997) for time the Time and Chair x Time interaction effects on comfort factors.

In a separate analysis (data not presented), age and gender did not affect comfort factors, discomfort factors, overall comfort or discomfort. This means that age and gender effects are immaterial in comfort and discomfort perception while sitting, although this conclusion may be due to the fact that all subjects tested were of a limited age range and were university students who were all used to sitting and carrying out similar type of activities. We also analyzed the effects of overall comfort and discomfort on typing speed and accuracy because these values may indicate the level of typing skills between subjects; we observed no significant effects.
Table 3. MANOVA for the chair type, Time and Chair Type x Time interactions effects, p values were given in the table (p); values p < 0.05 are significant.

<table>
<thead>
<tr>
<th>Items</th>
<th>Chair Type (p)</th>
<th>Time (p)</th>
<th>Chair Type x Time (p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discomfort factors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neck pain</td>
<td>0.082</td>
<td>0.000</td>
<td>0.982</td>
</tr>
<tr>
<td>Upper back pain</td>
<td>0.232</td>
<td>0.000</td>
<td>0.832</td>
</tr>
<tr>
<td>Mid back pain</td>
<td>0.269</td>
<td>0.000</td>
<td>0.973</td>
</tr>
<tr>
<td>Low back pain</td>
<td>0.215</td>
<td>0.000</td>
<td>0.990</td>
</tr>
<tr>
<td>Upper leg pain</td>
<td>0.144</td>
<td>0.001</td>
<td>0.952</td>
</tr>
<tr>
<td>Lower leg pain</td>
<td>0.153</td>
<td>0.006</td>
<td>0.378</td>
</tr>
<tr>
<td>Upper arm pain</td>
<td>0.206</td>
<td>0.000</td>
<td>0.914</td>
</tr>
<tr>
<td>Lower arm pain</td>
<td>0.640</td>
<td>0.003</td>
<td>0.882</td>
</tr>
<tr>
<td>Wrist pain</td>
<td>0.916</td>
<td>0.002</td>
<td>0.986</td>
</tr>
<tr>
<td>Fatigue</td>
<td>0.759</td>
<td>0.000</td>
<td>0.662</td>
</tr>
<tr>
<td>Comfort factors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Impression</td>
<td>0.013</td>
<td>0.598</td>
<td>0.803</td>
</tr>
<tr>
<td>Relaxation</td>
<td>0.925</td>
<td>0.851</td>
<td>0.630</td>
</tr>
<tr>
<td>Relief</td>
<td>0.976</td>
<td>0.977</td>
<td>0.926</td>
</tr>
<tr>
<td>Comfort</td>
<td>0.831</td>
<td>0.490</td>
<td>0.946</td>
</tr>
<tr>
<td>Discomfort</td>
<td>0.802</td>
<td>0.000</td>
<td>0.635</td>
</tr>
</tbody>
</table>

Note: p values were given in the table; values p < 0.05 are significant.

3.3 Effect of chair, time, overall comfort and discomfort on body posture movements

Body posture movements were not significantly affected by the chair type (Table 4) in this study. The subjective ratings were unaffected by the chair type except for impression. Subjects’ frequency of movement was greatest in Chair ‘Q’ (Figure 2); this was also the most uncomfortable chair in the analysis of subjective data. Liao and Drury (2000) found that the subjects increased their frequency of overall postural shifts as body-part discomfort increased. In the present study, the results of the body posture movements confirmed the results obtained in the subjective ratings. Further we plotted the body posture movements against discomfort ratings in which positive relationship between discomfort and body posture movements (Figure 3) existed. The frequency of movement increases rapidly between discomfort levels 2 and 3. However, it was not significant. These results obtained are consistent with those obtained by Liao and Drury (2000).

Body posture movements were significantly affected by the time factor, with increase of time on task, postural shift frequency increased. Liao and Drury (2000) found that frequency of postural shifts associated with progression of time. There was no significant Chair x Time interaction effect indicating that the body postural movements caused by the passage of time was not affected by the chairs selected in this study. The frequency of body posture movements increased with the development of discomfort and fatigue. These results on the body posture movements again confirmed the results obtained in the subjective rating.
Table 4. ANOVA for the chair, Time and Chair x Time interaction as well as Comfort, Discomfort effects on posture

<table>
<thead>
<tr>
<th>Factors</th>
<th>Body posture movements (p values)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chair</td>
<td>0.054</td>
</tr>
<tr>
<td>Time</td>
<td>0.000</td>
</tr>
<tr>
<td>Chair x Time</td>
<td>0.938</td>
</tr>
<tr>
<td>Comfort</td>
<td>0.148</td>
</tr>
<tr>
<td>Discomfort</td>
<td>0.935</td>
</tr>
</tbody>
</table>

Note: p values were given in the table; values p < 0.05 are significant.

Figure 2. Body posture movement ratio against time for chair type P, Q and S

Figure 3. Relationship between body posture movement frequency and discomfort level
3.4 Effects of comfort and discomfort factors on overall comfort and discomfort perception

MANOVA was conducted to quantify the effect of comfort and discomfort factors on comfort and discomfort perception under laboratory conditions (Table 5). Comfort was not affected by the discomfort factors, although comfort level tended to decrease as the discomfort factor increased. Comfort perceptions were affected by relief while but were unaffected by impression and relaxation. When relief level increased, comfort perception level increased significantly. These results suggest that the sensation of relief is the strongest underlying comfort factor; if so, the sensation of relief is the important factor in office chair comfort and comfort evaluation.

In the present study, discomfort was affected by fatigue but not by the other discomfort factors investigated. In Thariq and Munasinghe (under review), discomfort was affected by mid-back pain and low back pain. The tasks in our study were different from those in Thariq and Munasinghe (under review) so the difference between our results and theirs suggests that the effect of discomfort factors may differ depending on the task. Helander and Zhang (1997) found that fatigue is a time effect. In the present study, time spent performing the task had a strong influence on discomfort perception (Table 5). Discomfort is affected by time on task (Liao and Drury, 2000; Helander and Zhang, 1997). In addition to the fatigue effect, discomfort levels tended to increase when discomfort factors level increased. Discomfort perception was affected by the perceptions of relaxation. Therefore, for a subject to perceive higher levels of discomfort, his or her feeling of relaxation must be low. The result may indicate that relaxation is partially emotional, as found in Thariq and Munasinghe (under review).

Table 5. MANOVA for the main effects in perceiving comfort and discomfort

<table>
<thead>
<tr>
<th>Feeling factors</th>
<th>Comfort (p values)</th>
<th>Discomfort (p values)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discomfort factors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neck pain</td>
<td>0.660</td>
<td>0.191</td>
</tr>
<tr>
<td>Upper back pain</td>
<td>0.314</td>
<td>0.521</td>
</tr>
<tr>
<td>Mid back pain</td>
<td>0.277</td>
<td>0.254</td>
</tr>
<tr>
<td>Low back pain</td>
<td>0.151</td>
<td>0.283</td>
</tr>
<tr>
<td>Upper leg pain</td>
<td>0.349</td>
<td>0.129</td>
</tr>
<tr>
<td>Lower leg pain</td>
<td>0.744</td>
<td>0.999</td>
</tr>
<tr>
<td>Upper arm pain</td>
<td>0.310</td>
<td>0.058</td>
</tr>
<tr>
<td>Lower arm pain</td>
<td>0.633</td>
<td>0.717</td>
</tr>
<tr>
<td>Wrist pain</td>
<td>0.558</td>
<td>0.097</td>
</tr>
<tr>
<td>Fatigue</td>
<td>0.964</td>
<td>0.000</td>
</tr>
<tr>
<td>Comfort factors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Impression</td>
<td>0.196</td>
<td>0.940</td>
</tr>
<tr>
<td>Relaxation</td>
<td>0.098</td>
<td>0.008</td>
</tr>
<tr>
<td>Relief</td>
<td>0.000</td>
<td>0.825</td>
</tr>
</tbody>
</table>

Note: p values were given in the table; values p < 0.05 are significant.
Table 6. Correlation values of feeling factors and factor scores with comfort and discomfort

<table>
<thead>
<tr>
<th>Comfort factors and factor scores</th>
<th>Comfort (p values)</th>
<th>Discomfort (p values)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impression</td>
<td>0.42 (0.000)</td>
<td>-0.10 (0.175)</td>
</tr>
<tr>
<td>Relax</td>
<td>0.62 (0.000)</td>
<td>-0.43 (0.000)</td>
</tr>
<tr>
<td>Relief</td>
<td>0.70 (0.000)</td>
<td>-0.40 (0.000)</td>
</tr>
<tr>
<td>Comfort factor score</td>
<td>0.67 (0.000)</td>
<td>-0.24 (0.001)</td>
</tr>
<tr>
<td>Discomfort factor score</td>
<td>-0.403 (0.000)</td>
<td>0.72 (0.000)</td>
</tr>
</tbody>
</table>

Note: p-values (in parentheses) are significant if < 0.05.

Table 7. MANOVA for the interactions between discomfort factors (average ratings of discomfort factors) and comfort factors in perceiving comfort and discomfort

<table>
<thead>
<tr>
<th>Interactions</th>
<th>Comfort (p values)</th>
<th>Discomfort (p values)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discomfort factors x impression (of chair design)</td>
<td>0.05</td>
<td>0.07</td>
</tr>
<tr>
<td>Discomfort factors x relax</td>
<td>0.52</td>
<td>0.03</td>
</tr>
<tr>
<td>Discomfort factors x relief</td>
<td>0.71</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Note: values p < 0.05 are significant.

Comfort was more strongly correlated with relief (0.70) than with impression (0.42) and relaxation (0.62) (Table 6). These results suggest that the sensation of relief had stronger influence on comfort perception than did impression and relaxation. Therefore, we suggest investigation of chair design features that may provide more relief. The results also suggest that various individual factors have varying degrees of effect on perceptions of comfort and discomfort. This finding suggests that the choice of comfort factors for chair evaluation should consider their degree of effect on overall comfort/discomfort.

3.5 Interaction of individual comfort and discomfort on comfort and discomfort perception

Bulk variables for discomfort factors and comfort factors were obtained by averaging the ratings for the constituent factors for each subject, chair and time period. These bulk variables were analyzed using MANOVA to identify the interaction effects of discomfort factors and discomfort factors with impression, relax and relief factors (Table 7).

Perceived comfort was not affected significantly by the interaction of the bulk discomfort factor with relaxation or with relief. However, the effect of the interaction of bulk discomfort factors with impression was almost significant. Perceived discomfort was not significantly affected by the interaction of bulk discomfort factors with impression and relief, but was significantly affected by the interaction of bulk discomfort factors with relaxation.

The results of the interaction of discomfort factors with impression, relaxation and relief at different levels in perceiving comfort and discomfort were obtained in the same analysis. For the analysis, the discomfort factors level was kept constant, and impression, relaxation and relief levels were changed from 1 to 7. Statistics quantifying the interactions at different levels in perceiving comfort and discomfort.
were obtained (Tables 8 – 13).

3.6 Interactions of discomfort factors with impression in comfort perception

An extreme level of comfort was perceived by the subjects only in the presence of an extreme level of impression while sitting (Table 8). Impression level 7 in association with discomfort factor levels 5 produced a mean comfort perception level 1.0. Impression level 6 in association with discomfort factor level 5 produced a mean comfort level of 3.0. The results suggest that, in comfort perception, the presence of higher levels of discomfort factors while sitting were dominant over higher levels of impression. They also suggest that higher levels of emotional factors (impression) become ineffective (secondary) when higher levels of physical factors (discomfort factors) are present. This result shows that physical comfort needs are primary. Unless physical strain factors are eliminated, the higher levels of emotional (comfort) factors will not be effective (Helander and Zhang, 1997; Helander, 2003).

In general, the presence of higher levels of impression (i.e., 5, 6 and 7) with discomfort factors levels from 1 to 3 was higher than with other combinations, and this presence produced above-moderate and higher levels of mean comfort. The presence of impression factor levels 5, 6 and 7 with discomfort factor level 4 produced moderate and below-moderate levels of comfort in general. Higher levels of the impression factor were less frequent with discomfort factor levels from 5 to 7 than with other discomfort factor levels. However any such association produced lower levels of mean comfort (Table 8). When the impression level increased, mean comfort increased and this happened while discomfort level was below 4. These results indicate that the transition of impression from its dominant state to a non-dominant state occurred with impression level 5 in general. At this stage, discomfort factors reached level 4 or above. Generally, the transition of discomfort factors from the dominant state to non-dominant state occurred when it was level 4 or below. The non-dominant zone for impression and discomfort factors included impression levels between 1 and 5 and discomfort factors levels between 1 and 4. Therefore, comfort and discomfort factors may co-exist at the same time at certain levels.

Table 8. Interactions of discomfort factors (average ratings of discomfort factors) with impression in comfort perception

<table>
<thead>
<tr>
<th>Impression Level</th>
<th>Discomfort factor level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>4.0</td>
</tr>
<tr>
<td>2</td>
<td>4.0</td>
</tr>
<tr>
<td>3</td>
<td>3.0</td>
</tr>
<tr>
<td>4</td>
<td>4.7</td>
</tr>
<tr>
<td>5</td>
<td>5.2</td>
</tr>
<tr>
<td>6</td>
<td>6.0</td>
</tr>
<tr>
<td>7</td>
<td>7.0</td>
</tr>
</tbody>
</table>

Note: ‘--’ means combination of factors was not observed.
3.7 Interactions of discomfort factors with relax in comfort perception

An almost extreme level of mean comfort (6.5) was perceived by the subjects in the presence of extreme levels of relaxation while sitting. Extremes levels of mean comfort were associated with extreme levels of relaxation and lower levels of discomfort factors. Generally, relaxation levels 5 and 6 in association with discomfort factor level 5 produced below-moderate levels of mean comfort (Table 9). Relaxation level 7 in association with discomfort factor level 6 produced mean comfort of 3.0. These results suggest that higher levels of discomfort factors were dominant over the higher levels of relaxation in perceiving comfort while sitting. Higher levels of emotional factor (relaxation) became secondary when moderate or higher levels of physical discomfort factors were present. The results obtained support the findings by Helander and Zhang (1997) that physical factors are dominant over emotional factors in comfort and discomfort perception. The present results indicate that physical comfort needs are primary. Unless physical comfort needs are fulfilled, emotional comfort factors will affect comfort perception.

Generally, the presence of higher levels of relaxation factor (i.e., 5, 6 and 7) was higher with the lower levels of discomfort factors (below 4). These associations also produced higher levels of mean comfort in general than did other combinations (Table 9). Higher levels of relaxation were less frequent in the presence of higher levels of discomfort factors (i.e., 5, 6 and 7) than at lower levels of discomfort. However, any association of this kind produced low levels of mean comfort. When relaxation level increased, mean comfort increased and this happened only while discomfort level was below 4. The results suggest that the transition of the sensation of relaxation from its dominant state to non-dominant state occurs at relaxation level 5 and when discomfort factor levels are level 4 or greater. The transition of discomfort factors from a dominant state to a non-dominant state may occur at discomfort levels 4 or less. According to the results presented, non-dominant zone for relaxation and discomfort factors may include relaxation levels between 1 and 5 and discomfort factors levels between 1 and 4. This may indicate that discomfort factors and relaxation can co-exist at certain levels. This is almost consistent with those obtained in Thariq and Munasinghe (under review).

Table 9. Interactions of discomfort factors (average ratings of discomfort factors) with relaxation in comfort perception

<table>
<thead>
<tr>
<th>Relaxation Level</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td>2.0</td>
<td></td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>4.0</td>
<td>4.0</td>
<td>4.3</td>
<td>3.0</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>3.0</td>
<td>3.3</td>
<td>3.6</td>
<td>3.3</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>4.7</td>
<td>4.2</td>
<td>4.1</td>
<td>3.7</td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>5.0</td>
<td>4.9</td>
<td>5.1</td>
<td>4.0</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>6.0</td>
<td>5.8</td>
<td>6.0</td>
<td>5.0</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>5.0</td>
<td>6.5</td>
<td>--</td>
<td></td>
<td></td>
<td>3.0</td>
</tr>
</tbody>
</table>

Note: ‘--’ means combination of factors was not observed.
3.8 Interactions of discomfort factors with relief in comfort perception

An extreme level of mean comfort (level 7) was produced while relief was at extreme levels and sensation of discomfort factors was at lower levels (Table 10). The association of relief levels 5 and 6 with discomfort factor level 5 produced mean comfort of 3.0 in both cases. These results show that the feeling of relief at higher levels is influenced when higher levels of discomfort factors are present. This suggests that the presence of higher levels of discomfort factors (physical strain factor) influences comfort perception. The results presented further indicate that physical comfort needs are primary. If physical comfort needs are not satisfied (i.e., if higher levels of discomfort factors are present), the contribution of a higher sensation of relief to comfort perception diminishes.

Generally, the presence of higher levels of relief (i.e., 5, 6 and 7) was higher when the discomfort levels were below level 4. These interactions also produced higher levels of mean comfort in general than did other combinations (Table 10). The presence of higher levels of relief sensations was very low in the presence of higher levels of discomfort factors. However, this type of association produced low levels of mean comfort. When relief level increased, mean comfort increased and this happened while discomfort level was below 4. The results suggest that, at similar sensations of relaxation, the transition of the sensations of relief from a dominant state to a non-dominant state may occur at level 5. At this stage discomfort factors levels reach level 4 from lower levels. The transition of discomfort factors from a dominant state to a non-dominant state may take place at level 4 or below. Therefore, the non-dominant zone between relief and discomfort factors may include relief levels from 1 to 5 and discomfort factors levels from 1 to 4. The results also suggest, as in the case of impression and relax, that discomfort factors and relief factor can co-exist at certain levels. These results are consistent with those by Thariq and Munasinghe (under review).

Table 10. Interactions of relief with discomfort factors (average ratings of discomfort factors) in comfort perception

<table>
<thead>
<tr>
<th>Relief Level</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>--</td>
<td>--</td>
<td>5.0</td>
<td>--</td>
<td>1.0</td>
<td>--</td>
</tr>
<tr>
<td>2</td>
<td>--</td>
<td>3.8</td>
<td>3.5</td>
<td>3.2</td>
<td>2.2</td>
<td>--</td>
</tr>
<tr>
<td>3</td>
<td>--</td>
<td>3.3</td>
<td>3.4</td>
<td>3.0</td>
<td>1.5</td>
<td>--</td>
</tr>
<tr>
<td>4</td>
<td>4.2</td>
<td>4.2</td>
<td>4.2</td>
<td>3.8</td>
<td>4.0</td>
<td>3.0</td>
</tr>
<tr>
<td>5</td>
<td>5.2</td>
<td>5.1</td>
<td>4.7</td>
<td>4.8</td>
<td>3.0</td>
<td>--</td>
</tr>
<tr>
<td>6</td>
<td>6.0</td>
<td>6.1</td>
<td>5.7</td>
<td>--</td>
<td>3.0</td>
<td>--</td>
</tr>
<tr>
<td>7</td>
<td>6.5</td>
<td>7.0</td>
<td>7.0</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

Note: ‘--’ means combination of factors was not observed.
3.9 Interaction of discomfort factors with impression in discomfort perception

Generally, as the level of discomfort factors increased, mean discomfort level increased while interacting with different levels of impression (Table 11). When the discomfort factors level was above 4, mean discomfort perception was also above 4 at different levels of impression (Table 11). The results suggest that when the discomfort factors level is higher, sitters tend to perceive discomfort. At this stage, the presence of higher levels of impression becomes secondary.

Discomfort factors level 4 produced in association with impression levels 5 and 6 produced mean discomfort of 4.6 and 6.0 respectively. Discomfort factors level 3 in association with impression level 1 produced mean discomfort of 4.3. Likewise, discomfort factor level 5 in association with impression levels 1, 3 and 4 produced mean discomfort of 6.0, 6.0 and 5.6 respectively. These values were higher than the corresponding discomfort factors levels; these results may indicate that some other factors contribute to cause a higher level of discomfort perception.

Discomfort factors level 5 in association with impression level 2 produced mean discomfort of 4.5. Likewise, discomfort factors level 6 in association with impression level 5 produced mean discomfort of 4.0. These results suggest that discomfort perception was affected by the sensation of impression at certain levels. However, the interaction between discomfort factors level and impression was not significant (Table 6). In previous sections we determined that a higher discomfort factor level is dominant over impression. In this interaction, mean discomfort produced was 4.5 and 4.0 which represented above-moderate and moderate levels of discomfort. These results were consistent with those of Thariq and Munasinghe (under review).

3.10 Interaction of discomfort factors with relaxation in discomfort perception

According to the results obtained, mean discomfort level generally increased with discomfort factors level, while interacting with relaxation (Table 12). When the discomfort factors level was above 4, mean discomfort perception was also above 4 while associating with different levels of relaxation (Table 12). The results suggest that when the discomfort factors level is higher, sitters always perceive discomfort. In this case, the presence of higher levels of relaxation becomes secondary.

Discomfort factors level 5 in association with relaxation levels 1, 2, and 5 all produced mean discomfort of 6.0. Likewise, discomfort factors level 4 in association with relaxation levels 2 and 5 both produced mean discomfort of 5.0. The mean discomfort values were higher than the corresponding discomfort factors levels. These results were not expected; they suggest that some other factors contributed to the higher discomfort perception.

Discomfort factors level 6 in association with relaxation level 7 produced mean discomfort of 4.0. This result suggests that discomfort perception was affected by the feeling of relaxation at a certain level. One explanation for this result is that the
sensation of relaxation is partially emotional. The previous finding in this study indicated that the sensation of relaxation was partially emotional and partially affected by biomechanical factors. However, in this and previous sections, higher discomfort factors level have been demonstrated to be dominant over higher levels of relaxation while sitting. The association of discomfort factors level 6 and relaxation level 7 was not expected. Therefore, the mean discomfort obtained was inconsistent; this inconsistent result will be explained later in this paper. The results are consistent those of Thariq and Munasinghe (under review).

### Table 11. Interactions of impression with discomfort factors (average ratings of discomfort factors) in discomfort perception

<table>
<thead>
<tr>
<th>Impression Level</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.0</td>
<td>1.0</td>
<td>4.3</td>
<td>--</td>
<td>6.0</td>
<td>--</td>
</tr>
<tr>
<td>2</td>
<td>3.0</td>
<td>2.0</td>
<td>2.9</td>
<td>4.3</td>
<td>4.5</td>
<td>--</td>
</tr>
<tr>
<td>3</td>
<td>2.0</td>
<td>3.6</td>
<td>3.1</td>
<td>4.0</td>
<td>6.0</td>
<td>--</td>
</tr>
<tr>
<td>4</td>
<td>1.2</td>
<td>2.2</td>
<td>3.4</td>
<td>4.4</td>
<td>5.6</td>
<td>--</td>
</tr>
<tr>
<td>5</td>
<td>1.6</td>
<td>2.7</td>
<td>3.1</td>
<td>4.6</td>
<td>--</td>
<td>4.0</td>
</tr>
<tr>
<td>6</td>
<td>1.5</td>
<td>2.0</td>
<td>2.8</td>
<td>6.0</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>7</td>
<td>1.0</td>
<td>3.0</td>
<td>--</td>
<td>--</td>
<td>6.0</td>
<td>--</td>
</tr>
</tbody>
</table>

Note: ‘--’ means combination of factors was not observed.

### Table 12. Interactions of relaxation with discomfort factors (average ratings of discomfort factors) in discomfort perception

<table>
<thead>
<tr>
<th>Relaxation Level</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>--</td>
<td>--</td>
<td>4.0</td>
<td>--</td>
<td>6.0</td>
<td>--</td>
</tr>
<tr>
<td>2</td>
<td>3.0</td>
<td>2.0</td>
<td>1.7</td>
<td>5.0</td>
<td>5.4</td>
<td>--</td>
</tr>
<tr>
<td>3</td>
<td>2.0</td>
<td>3.7</td>
<td>3.3</td>
<td>4.3</td>
<td>5.3</td>
<td>--</td>
</tr>
<tr>
<td>4</td>
<td>1.3</td>
<td>2.4</td>
<td>3.6</td>
<td>4.2</td>
<td>5.0</td>
<td>--</td>
</tr>
<tr>
<td>5</td>
<td>1.6</td>
<td>2.1</td>
<td>2.6</td>
<td>4.4</td>
<td>6.0</td>
<td>--</td>
</tr>
<tr>
<td>6</td>
<td>1.5</td>
<td>2.0</td>
<td>3.0</td>
<td>5.0</td>
<td>6.0</td>
<td>--</td>
</tr>
<tr>
<td>7</td>
<td>1.0</td>
<td>2.3</td>
<td>--</td>
<td>--</td>
<td>4.0</td>
<td>--</td>
</tr>
</tbody>
</table>

Note: ‘--’ means combination of factors was not observed.

### Table 13. Interactions of relief with discomfort factors (average ratings of discomfort factors) in discomfort perception

<table>
<thead>
<tr>
<th>Relief Level</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>--</td>
<td>--</td>
<td>5.0</td>
<td>--</td>
<td>6.0</td>
<td>--</td>
</tr>
<tr>
<td>2</td>
<td>--</td>
<td>3.0</td>
<td>3.3</td>
<td>4.7</td>
<td>5.2</td>
<td>--</td>
</tr>
<tr>
<td>3</td>
<td>--</td>
<td>3.0</td>
<td>3.1</td>
<td>4.1</td>
<td>5.5</td>
<td>--</td>
</tr>
<tr>
<td>4</td>
<td>1.3</td>
<td>2.3</td>
<td>3.6</td>
<td>4.4</td>
<td>5.0</td>
<td>4.0</td>
</tr>
<tr>
<td>5</td>
<td>1.7</td>
<td>2.0</td>
<td>2.7</td>
<td>4.5</td>
<td>6.0</td>
<td>--</td>
</tr>
<tr>
<td>6</td>
<td>2.0</td>
<td>2.0</td>
<td>2.7</td>
<td>--</td>
<td>6.0</td>
<td>--</td>
</tr>
<tr>
<td>7</td>
<td>1.0</td>
<td>3.3</td>
<td>2.0</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

Note: ‘--’ means combination of factors was not observed.
3.11. Interaction of discomfort factors with relief in discomfort perception

Generally, the results obtained showed that as discomfort factors level increased, mean discomfort level increased while interacting with different levels of relief (Table 13). When the discomfort factors level was above 4, mean discomfort perception was also above 4 while at different levels of relief (Table 13). The results suggest that when the discomfort factors level is high, sitters always perceive discomfort, so the presence of higher levels of relief becomes secondary.

Discomfort factors level 5 in association with relief level 1, 3, 5 and 6 all produced mean discomfort 5.5 or more. Discomfort factors level 4 in association with relief levels 2 and 5 produced mean discomfort of 4.7 and 4.5 respectively. Discomfort factors level 3 in association with relief levels 1 produced mean discomfort of 5.0. The mean discomfort levels presented were higher than the corresponding discomfort factors levels. These were unexpected results, and again suggest that some other factors contributed to the higher level of discomfort perception.

Discomfort factors level 6 in association with relief level 4 produced mean discomfort of 4.0. The results suggest that discomfort perception tends to be affected by the feeling of relief. This result was not expected. In previous sections a higher discomfort factor level was demonstrated to be dominant over a higher level of comfort factors, and that the interaction of discomfort factors with the feeling relief on discomfort perception was not significant. However, the result presented may support the previous findings in this study that the relief sensation is partially emotional. Although the higher level of relief affected discomfort perception, the mean discomfort level produced was found in the discomfort stage. These are almost consistent with those of Thariq and Munasinghe (under review).

A few inconsistent results (i.e. mean comfort) were observed in the interactions. Variability in subjective ratings may be the reasons for such inconsistent results. Variability in subjective ratings indicates that other important factors affect the subjective responses (Kyung et al., 2007). This may be a limitation to this study. However, this limitation did not affect the overall results obtained through subjective ratings.

3.12. Proposed comfort/discomfort model

Based on the findings of the interactions of discomfort factors with impression, relaxation and relief in perceiving comfort and discomfort in sitting under laboratory conditions, the following model is proposed (Figure 4). Transition from comfort to discomfort or discomfort to comfort occurs in three states: comfort ↔ neutral ↔ discomfort. In the neutral zone, neither comfort nor discomfort factors dominate the perception; therefore, reported comfort and discomfort often differ among individuals. Vink et al. (2005) referred this state as ‘no discomfort’ in which the participant is not aware of either discomfort or comfort, or that no discomfort exists. Comfort factors levels from 1 to 5 and discomfort factor levels from 1 to 4 can co-exist at the same time in the non-dominant zone. Hence, the non-dominant zone
is stretched towards the comfort zone (Figure 4). Moderate and higher levels of comfort factors become ineffective when discomfort factors are present at moderate or higher levels. The presence of adverse physical factors will break the physical harmony and direct attention to discomfort (Zhang et al., 1996). When discomfort factors are above-moderate (above level 4), discomfort factors become dominant over comfort factors (emotional comfort needs) and subjects tend to perceive discomfort. Simply minimizing discomfort factors below moderate level will not produce comfort because comfort perception is associated with higher levels of relief, relaxation and impression. When comfort factors are felt at levels above 5, subjects tend to perceive comfort and at this stage physical comfort needs have been satisfied (above-moderate levels of discomfort factors are not present).

4. Conclusion

This paper has presented a study of subjective factors that contribute to feelings of comfort or discomfort in office chairs. Sensations of comfort and discomfort can coexist when comfort levels are between 1 and 5 and discomfort levels are between 1 and 4. When comfort is perceived, discomfort factors are found at moderate or below-moderate levels. Above-moderate and higher levels of discomfort factors are dominant over above-moderate and higher levels of emotional factors. Various individual factors have varying levels of effect on comfort and discomfort perception. The feeling of relief seems to be a stronger factor than relaxation and impression in affecting comfort perception. The relative levels with which various individual underlying factors influence comfort and discomfort perception should be considered when developing a multi-dimensional checklist for chair evaluation. Chair designs should include features that increase the sensation of relief while sitting.

![Figure 4](image-url). Relationship between perception of comfort and discomfort
Acknowledgement

This study was supported by the Internal Research Budget from Sirindhorn International Institute of Technology, Thammasat University, and from the Thailand Research Fund (through the RGJ-PHD Grant No. PHD/0138/2544).

References


M.G. Mohamed Thariq

M.G. Mohamed Thariq is a Ph.D. candidate at the University of Moratuwa, Sri Lanka. He carried out part of his Ph.D. research work at State Key Laboratory of Rail Traffic Control and Safety of the Beijing Jiaotong University in China. His research interests are in product ergonomics, seating and workplace comfort, biomechanics, usability and anthropometry.

Weining Fang

Weining Fang is a Professor and Ph.D. research supervisor at the State Key Laboratory of Rail Traffic Control and Safety of the Beijing Jiaotong University in China. His research interests include vehicle operation safety theory and technology, and human engineering. He received Ph.D. degree in industrial engineering from Beijing Jiaotong University in Beijing. He is a Member of National Ergonomics Standardization Technology Committee (China).

Lijian Zhang

Lijian Zhang is a Sr. Engineering Specialist of product design in General Dynamics Corporation, specialized in Human Factors Engineering. His interests in the field of human factors include applications in product design, usability, user interface design, seating comfort and biomechanics. He received the Ph. D. degree in Industrial Engineering, State University of New York at Buffalo.

Harsha Munasinghe

Harsha Munasinghe is the Professor of Architecture, and the Head, Department of Architecture, University of Moratuwa, Sri Lanka. He is an Architect and an Urban Designer. His research interests include Interiors, Industrial Ergonomics, and Furniture Design. He received Master of Science (Architecture) from the University of Moratuwa, Master of Architecture (Urban Design) from Helsinki University of Technology, Finland, and his Ph.D. from the University of Oulu, Finland.
A study of ergonomic factors contributing to the occurrence of occupation-related musculo-skeletal problems in garment workers

Senthil Kumar.R.K*, Bobby Joseph, Padmanaban sekanan, Sulekha, Kurian Zachariah, Rajalakshmi Hariharan

St.John's National Academy of Health Sciences, Sarjapur Road, Bangalore, Karnataka State, India, 560 034

Abstract

OBJECTIVE
This study was undertaken to identify the possible ergonomic factors which may be responsible for occupation-related musculo-skeletal (ORMS) symptoms.

METHODS
A total of 1270 workers were examined during routine annual medical checks, out of which 264 workers were diagnosed to have OMRS problems. An Occupational Therapist/Physiotherapist examined 185 of these workers, and a general health questionnaire was administered to them. A walk-through observation of the work station was also conducted.

RESULTS
The major ergonomic risk factors identified in these workers were exertion of force with hands (155; 83.8%); continuous sitting (142; 76.8%); and bending and twisting at the waist (147; 79.4%). Workstation and task analysis showed static muscle loading (100%), absence of arm rest (183; 99.3%), absence of foot rest (100%) and abnormal posture and movements adopted during work (172; 93%) to be major contributing factors for the musculo-skeletal symptoms. Of these 185 workers, 156 (84.3%) reported good general health and absence of psychological distress. Most of the workers (162; 87.6%) had no abnormality during their musculo-skeletal screening examination.

CONCLUSION
Poor workstation design and lack of awareness regarding proper work practice are major factors that contribute to musculo-skeletal symptoms.

Keywords: Ergonomics, musculo-skeletal disorders, risk analysis

* Corresponding author: senthilk78@gmail.com
1. Introduction

People who work for long hours at a desk, workstation or in a factory report a significant incidence of neck, shoulder and arm pain, and tiredness. In many of them, the symptoms may be attributed to the fact that they perform repetitive tasks under ergonomic conditions that are less than ideal (Lee et al 2001). Prolonged exposure to such substandard ergonomic conditions can damage the worker’s body and lead to musculo-skeletal disorders (OSHA 2007). Moreover, in industrial work, working postures are also important, and when combined with other strain factors the effects may be worse than those of single factors (Chavalitsakulchai and Shahnaz, 1993).

The five main factors associated with the musculo-skeletal discomfort are (i) lack of appropriate worker selection and lack of adequate training to prevent occupational hazards or work-related diseases, (ii) poor ergonomic design of the workplace and tasks, including work organization, (iii) poor working postures, (iv) lack of task variation and (v) insufficient rest breaks (Chavalitsakulchai and Shahnaz, 1993). The situation in the garment industry includes all of those factors.

Work in the garment industry involves repetitive tasks and prolonged periods of sitting, standing, or walking; all of these tasks can lead to problems. This, in addition to the need to meet production goals, can result in strain on the workers, which manifest as musculo-skeletal pain, repetitive strain injury and muscle or joint stiffness.

Many simple and cost-effective ergonomic solutions could be used to prevent musculo-skeletal injuries in garment workers (Lee et al., 2001).

2. Objective

Recognising ergonomic risk factors in the workplace is an essential first step in correcting hazards and improving worker protection (Chavalitsakulchai and Shahnaz, 1993).

This observational study was therefore designed to identify the possible ergonomic risk factors which may be responsible for workers showing musculo-skeletal problems during routine annual medical checks.

3. Materials & Methods

Potential study participants were selected from two private garment factories in Bangalore, South India during routine annual medical checks. Participants were only included if they had physician-diagnosed musculo-skeletal problems. Pregnant women and any workers with a history of mental and physical disability were excluded.

A total of 1270 workers were examined during the routine annual medical checks, out of which 264 workers were diagnosed to have occupation-related
musculo-skeletal problems. The Occupational Therapist/Physiotherapist was able to examine 185 of these workers. They were administered the General Health Questionnaire-12 (GHQ-12) (Workhealth 2007) followed by an Ergonomic Hazard Identification checklist (UTSA 2006) which includes a symptoms survey form. They were then evaluated to look for any restriction in the range of motion, to estimate muscle strength and to rule out any postural problems. This was followed by a walk-through observation for workstation analysis and task analysis. Data was entered on an Excel® spreadsheet and descriptive statistics were calculated using simple statistical programs.

3. Results

3.1. Demographic Features

One hundred eighty-five workers were selected by the procedures mentioned earlier and then administered the questionnaires/schedules followed by an examination. Most of these workers were tailors, followed by checkers, ironers, helpers, feeding helpers and others.

Most of the workers were female and had 1 to 4 years of experience in the garment industry (Table 1).

3.2. Health Seeking Behaviour

Of the 185 who had musculo-skeletal pain, 133 (71.9 %) attributed it to their occupation, and 20 (10.8 %) believed that it was due to other reasons like weakness and lack of proper nutrition; the remaining 32 (17.3%) workers were not sure of the reason for their musculo-skeletal pain.

Of the workers, 107 (57.8%) had consulted a doctor for their musculo-skeletal disorders and out of these 29 (27.1%) workers said that the treatment had been effective, but 78 (72.9%) workers felt that treatment had not given any permanent symptomatic relief (Table 2).

Only 45 (24.3%) workers believed that workplace modification would be a better solution for the relief of their symptoms. Of the remaining workers, 62 (33.5%) opined that no sustained remedial measures are available for the relief of this pain, 38 (20.5%) felt that quitting the job is the only permanent solution for the problem and 40 (21.7%) felt that only medications would improve their situation.

3.3. Physical Assessment

Most of the workers (162; 87.6%) workers had no abnormality in their posture. Only 20 (9.8%) out of the 185 workers had restrictions in range of motion and 22 (11.9%) workers had decreased muscular strength (Table 3).
Statistical tests were used to compare the posture, range of motion and strength of individuals who had worked for less than 5 years to those who had worked for more than 5 years (Table 4). These tests did not show any significant differences.

TABLE 1. Demographic Features

<table>
<thead>
<tr>
<th>Occupation</th>
<th>Experience (years)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1-4</td>
<td>5-9</td>
</tr>
<tr>
<td>Tailors</td>
<td>3</td>
<td>72</td>
</tr>
<tr>
<td>Checkers</td>
<td>0</td>
<td>11</td>
</tr>
<tr>
<td>Cutters</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Ironers</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Helpers</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>Feeding Helpers</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Others</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>10</td>
<td>107</td>
</tr>
</tbody>
</table>

TABLE 2. Health seeking behaviour and previous treatment effectiveness

<table>
<thead>
<tr>
<th>Previous treatment</th>
<th>Treatment effectiveness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>107 (57.8%)</td>
</tr>
<tr>
<td>No</td>
<td>78 (42.2%)</td>
</tr>
</tbody>
</table>

| Total              | 185                     |

TABLE 3. Physical assessment

<table>
<thead>
<tr>
<th>Condition</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abnormality</td>
<td>Posture 23 (12.4%)</td>
</tr>
<tr>
<td>No abnormality</td>
<td>162 (87.6%)</td>
</tr>
<tr>
<td>Total</td>
<td>185</td>
</tr>
</tbody>
</table>

Table 4. Relationship between experience and physical assessment

<table>
<thead>
<tr>
<th>Years of experience</th>
<th>Posture Abnormality</th>
<th>Range Abnormality</th>
<th>Strength Abnormality</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>+ (+)</td>
<td>- (-)</td>
<td>+ (+)</td>
</tr>
<tr>
<td>1-4 years</td>
<td>17 (100)</td>
<td>16 (101)</td>
<td>16 (101)</td>
</tr>
<tr>
<td>&gt;5 years</td>
<td>10 (58)</td>
<td>5 (63)</td>
<td>7 (61)</td>
</tr>
<tr>
<td>χ² = 0.00, p &gt; 0.05</td>
<td>χ² = 1.71, p &gt; 0.05</td>
<td>χ² = 0.45, p &gt; 0.05</td>
<td></td>
</tr>
</tbody>
</table>
3.4. Risk Factor Analysis

The possible risk factors in the garment industry were identified using the Ergonomic Hazard Identification checklist (Occupational Safety and Health Administration 2007). The risk factors were mainly exertion of force with their hands (157; 83.8%); usage of handle tools or handle parts (157; 83.8%); continuous standing (45; 24.3%) and continuous sitting (140; 76.8%); use of electronic devices (1; 0.5%); bending and twisting at waist (147; 79.4%) and exposure to vibration (126; 68.6%).

3.5. Work Station Analysis

Work station analysis showed that static muscle loading contributed to the musculo-skeletal pain in all 185 (100%) workers. Of these, 169 (91.3%) were not able to vary posture during their work time. Out of 138 workers who worked in a sitting position, 137 (99.3 %) were not provided with an arm rest on their chair, and 50 (36.2%) had chairs that were not adjustable. None of the 185 (100%) workers were provided with a foot rest while they were at work. Floor mats were not provided for any of the 24 (100%) workers who had to stand for long durations.

3.6. Task Analysis

Task analysis revealed that 157 (84.9 %) workers had to bend or twist their back during work; 139 (75.1%) workers had to sit in a hunched posture continuously for long periods; and 172 (93 %) workers had to work with raised elbows. All of the workers had to sit or stand continuously for long durations, which increased the static muscle load on their back muscles. None of the workers in the company were trained in proper work practices including adjustment of work chairs and early recognition of signs and symptoms of their potential problems. None of the workers had any job rotation, self pacing, sufficient rests or adjustment of job skill level, which are all standard procedures to prevent ergonomic problems.

3.7. Mental Health Status

The GHQ-12 test showed that 11 (5.9%) of the workers were under severe psychological distress (Score ≥ 20); 18 (9.7%) had evidence of some distress (Score 15 to 20), and the rest (156; 84.3%) were normal.

4. Discussion

Few studies in the garment industry have evaluated the parameters that are described in this study. Health-seeking behaviour, physical assessment, risk factor
analysis, work station analysis, task analysis and mental health status analysis of garment industry workers have not been reported in the literature. However, a number of studies allude to the ergonomic problems faced by garment workers in other countries.

In a study in an Oakland, California garment industry in 2002, approximately 94% of patients reported one or more problems with their work stations including inadequate seating (90%), awkward bending and twisting (67%), and less than adequate rest breaks (40%) (Lashuay et al 2006). Our study also supports the findings reported in this paper where similar problems were observed, such as prolonged sitting (91.35 %), chairs without armrests (74 %) and the absence of foot rests (100%).

In a study of sewing machine operators in Denmark, a high prevalence of musculo-skeletal symptoms of the neck and shoulders was observed among tailors (Schibye et al 1995) which is similar to our study findings which shows that 67% of musculoskeletal problems were reported among the tailors. In a study conducted in Bangalore City on 3858 Indian garment workers, 670 (63%) complained of musculoskeletal problems predominantly and 28 % of the workers attributed their illness to their occupation. In our study, nearly 72 % of the workers said that their musculo-skeletal pain was due to their job (Joseph and Kiran, 2008).

Lee et al. (2001) states that the risk factors for the musculo-skeletal pain are force, repetition, awkward postures, static postures and vibration which were similar to our findings.

In a Finnish study of machine operators, working in a twisted or bent posture was a significant risk indicator for neck and shoulder symptoms (Tola et al., 1998). Our study also revealed that repeated bending and twisting was implicated in 84.86% of the workers.

In an ergonomic survey conducted in Sweden for evaluating musculo-skeletal disorders of 1,000 female workers in five different industries, including the garment manufacturing industry, ergonomic problems were mainly attributed to poor working practices and work place programs without sufficient knowledge of ergonomic principles (Chavalitsakulchai and Shahnavaz, 1993) Our study also revealed that the workers were improperly trained in work practices and were unaware the signs and symptoms of their musculo-skeletal pain.

Chavalitsakulchai and Shahnavaz (1993) also showed that the main factors associated with musculo-skeletal discomfort were lack of appropriate training, poor ergonomic design of the work place, poor working postures, lack of task variation and insufficient rest breaks. Our study indicated that all the workers had no job rotation, insufficient pauses and no self–pacing, and that most of the workers sat in a hunched posture for long periods. Prolonged sitting and standing and lack of arm rest and foot rest in the work site were also common.

5. CONCLUSION

Most of the workers in our study had abnormality in their posture, range of motion and strength. The possible risk factors that were identified were exerting
force with hands, vibration, static muscle loading, awkward postures and bending and twisting at the waist. The common risk factors that were seen in the work station were inability to vary the posture, with no provision of arm or foot rest, and lack of floor mats for workers who had to stand for long periods. Although adjustable chairs were provided for some of the workers, the workers demonstrated a general lack of awareness regarding the correct positioning of the back rest. The remaining workers had to be content with non-adjustable chairs.

The workers were not trained in proper work practices, and most maintained abnormal postures while working. Moreover, many workers showed lack of awareness regarding the recognition of the signs and symptoms of their musculo-skeletal pain. Most of the workers were psychologically well and few workers had severe distress.

Based on the observation and supporting statistical data the following recommendations can be made to prevent secondary complications:

1. Arm and foot rests should be provided for all the workers who sit for long periods. Floor mats should be provided for the workers who have to stand for long periods.
2. A simple stretching and exercise programme should be conducted to overcome the pain and problems that may be likely to occur.
3. A “back school” program may be instituted – these are educational programs for prevention and rehabilitation of mechanical back pain. The goals of a back school program are reduction of existing back pain and prevention of recurring back pain. This school should be conducted to create awareness and to help the workers recognise the signs and symptoms of musculo-skeletal problems. Such a program has been shown to reduce existing back pain and prevent recurrence of back pain (Maier-Riechle and Harter, 2001).
4. Educational programs should be conducted for the supervisors and managers regarding proper work practice and appropriate bio-mechanical techniques while working to increase the workers’ efficiency and the productivity of the company while maintaining workers’ quality of life.

References


Senthil Kumar.R.K

Senthil kumar is an Occupational therapist and currently the in charge of the occupational therapy in the department of PMR. His major research interest includes in the areas of physical and cognitive ergonomics, apart from that working in various adult and paediatric rehabilitation related research activities. He received the Bachelor’s degree in occupational therapy from The Tamil Nadu Dr.M.G.R. Medical University, Chennai. and the master’s degree in psychology from Madras University.
A study of ergonomic factors contributing to the occurrence of occupation-related musculo-skeletal problems in garment workers

Bobby Joseph
Bobby Joseph is a professor of Community Health at St. John’s Medical College, Bangalore, India. His academic interests are in Occupational Health and he has many years of experience working with the tea and coffee plantations and with the garment manufacturing industry in southern India. He received his MD in Community Medicine from Bangalore University and is a Diplomate of the National Board in Social and Preventive Medicine.

Padmanaban sekaran
Mr. Padmanaban sekaran is a physiotherapist graduated from The TamilNadu Dr. M.G.R. Medical University, Chennai. He currently works as a senior physiotherapist in the St. John’s Medical College & Hospital, Bangalore. He is an avid researcher and brilliant clinician in the field of musculoskeletal physiotherapy and has been an invited speaker in many national and international conferences.

Sulekha
Dr. Sulekha is an Associate professor in the department of community health at St. John’s Medical College. She received her MD in Community Medicine from Rajeev Gandhi Institute of Health Sciences.

Kurian Zachariah
Dr. Kurian Zachariah is professor and head of the physical medicine and rehabilitation department.

Rajalakshmi Hariharan
Dr. Rajalakshmi Hariharan is an Associate professor of physical medicine and rehabilitation.
Redesign of a hand pallet truck by integrating ergonomics analysis and quality function deployment

Isa Halim\(^1\)\(^*\), Abdul Rahman\(^2\), Wan Fadhli\(^1\)

\(^1\) Faculty of manufacturing Engineering, Universiti Teknikal Malaysia Melaka, Melaka, Malaysia
\(^2\) Faculty of manufacturing Engineering, Universiti Teknologi MARA, Shah Alam, Malaysia

Abstract

Today, materials handling devices (MHDs) that provide effective handling of goods have become important tools in industrial workplaces. Hence proper design of MHDs can increase productivity, minimize the risk of injury and improve the comfort of industrial workers. Sprains and strain are common injuries experienced by workers due to misuse or improper design of MHDs. In recognition the importance of the MHD design, this study conducted to redesign the existing MHD for pushing and pulling activities in manufacturing industry, using a hand pallet truck (HPT) as case study. Ergonomics analysis and Quality Function Deployment (QFD) were integrated to redesign the HPT so that it can fulfill workers’ requirements while reducing stresses on workers during pushing or pulling activities. Based on the findings, we conclude that the integration of ergonomics analysis and QFD is an effective and scientific solution in designing an ergonomic HPT.

Keywords: Materials Handling Devices (MHDs), Pushing-Pulling Activities, Ergonomic Design

1. Introduction

The quest for worker-friendly environment has culminated in the application of materials handling devices (MHDs) to transfer materials and products to the production lines in the manufacturing industry and in other industrial sectors. One common MHD is the hand pallet truck (HPT). Usually, an HPT is used to transfer materials that are stacked on a pallet from one location to other destinations. Mass production in industry has placed a burden of manual materials handling on

\(^*\) Corresponding author: isa@utem.edu.my, Tel: +606-5552000, Fax: +606-3316247
workers (Jung, et al., 2005). For instance, when production rates are increased, faster and more efficient HPTs are required. To support the increase of production rates, the load on pallet should as great as possible. This working condition requires extra efforts and increased loads on the workers, and could potentially contribute to occupational injuries. To maximize the production rate and ensure workers’ safety, the employer provides MHDs. The use of such devices has been shown to be efficient because a worker needs to expend only about 12 cal/min extra energy per kilogram of load (Haisman et al., 1972, Datta, et al., 1978, 1983). However those devices have caused suffering and injuries to industrial workers, because misuse or improper design can increase the risk of musculoskeletal injuries (Jung, et al., 2005). A study has identified strains, sprains and bruises as major injuries associated with pushing and pulling MHDs (Health and Safety Executive, 2002). Therefore, design of MHDs that can accelerate productivity and provide safety and comfort to workers is crucial in an industrial environment. To establish efficient and safe MHDs, innovative and creative designs should be developed so that job demands and workers’ requirements can be achieved simultaneously.

The aim of satisfying workers’ needs in materials handling activities can be achieved by integrating ergonomics analysis and Quality and Function Deployment (QFD) (Akao, 1990) during the design stage of MHDs so that the MHD can safely accommodate the requirements and satisfaction of workers. Basically, QFD is used to ensure that the needs of customers (workers) are satisfied and translated throughout the process of design and development of a product (Harding, 1999).

The objective of study is to determine the workers’ requirements that should be incorporated to redesign MHDs for pushing and pulling jobs. The information was used to redesign the existing HPT to satisfy workers’ requirements and to minimize physical stress on workers. An established ergonomics tool was used to evaluate the effectiveness of the redesigned HPT. The value of the established design was demonstrated using an application example.

2. Challenges in ergonomics design

The requirements of consumers and aesthetics values are always considered by manufacturers when designing their products. Even though all user requirements and ergonomics criteria have been identified and considered in the design of a product, these efforts do not guarantee that the product will satisfy the end user. This problem arises when communication during design and fabrication of the product is difficult or even absent between technical experts (e.g., engineers, designer) and those representing different disciplines such as ergonomics and marketing. As a consequence, the product will fail to customers or in the worst-case it may be harmful to the users.

The gap between the designed product and users’ requirements has been caused by the tradition of considering the design independently of requirements. However, users’ requirements must be considered in product design development because failing to do so may mean that the product is not saleable. A product may have impressive features, but it will be no value if end users cannot use the features.
QFD has been promoted as a methodological tool to support ergonomics considerations because its objectives are to protect customers’ needs throughout the design process, to promote communication between design contributors (e.g., engineers, ergonomists, users) and to address possible contradictions among the various design parameters (Marsot, 2005).

QFD is a tool that focuses on satisfying the customer; it was designed to convert customer expectations and requirements into technical characteristics that can be met during product planning, part development, process planning, and production planning (Besterfield, 2004). The fundamental goals of QFD are to increase customer satisfaction and to reduce the time required for product development. Hence integrating ergonomics assessment analysis tools with QFD would be an integrated solution to design.

The philosophy of QFD is to transform users’ needs into technical aspects during product development and production. The method has numerous advantages (Hsiao 2002): it reduces the time required to develop a new product; it can reduce the number of design changes; it avoids the uncertainty of design problems; and it fulfill the needs of customers.

Basically, the procedures of applying QFD method are classified into: identification of users and customers, determination of the needs of users and customers, determination of the relative importance of these needs, benchmarking against other competitors, translation of users/customers needs into quantitative forms, and setting the engineering targets for the design (Figure 1).

Figure 1. Simple flow diagram of QFD Process (Omar, 1997)
3. The integrated ergonomics analysis and QFD method

Ergonomics is a scientific discipline concerned with the understanding of interactions among humans and work systems. It optimizes human well-being and overall work system performance by applying theories, principles, data and methods to product design (International Ergonomics Association, 2000). Ergonomics is widely applied in many industrial applications. One common application of ergonomics in industry is to minimize the risk of occupational injuries during manual material-handling activities. Many studies have identified manual materials activities as a primary contributor to lower back pain among industrial workers (Kuiper, et al., 1999; NIOSH, 1997; Burdorf and Sorock, 1997). Ergonomic design of MHDs is seen as one approach to minimize occupational injuries. Occupational health and safety, comfort, productivity, quality, as well as work efficiency can be improved by improving the ergonomics criteria and usability of MHDs. Many studies have applied ergonomics analysis to improve the usability of MHDs by reducing biomechanical stresses during performing manual material-handling activities (Resnick and Chaffin, 1995; Okunribido and Haslegrave, 2003; Glitsch, et al., 2007).

In recognition the importance of developing usable products of high quality, human needs and requirements are primary concerns that must be considered during the design and production stages. By applying the QFD method, various human needs and technical aspects can be integrated systematically to establish product design and specifications, so that the products fulfill market demands.

Ergonomics can be integrated with QFD because humans’ needs are usually determined by considering human abilities and limitations. The association between the quality of a product and its accommodation of human abilities and limitations could be explored easily with the help of knowledge in ergonomics (Bergquist and Abeysekera, 1996). In addition, QFD method has been recognized as the most suitable approach to ensure attention to comfort requirements in the design process of a product, because it is the only means that explicitly addresses the translation of humans needs such as comfort into technical specifications (Kuijt-Evers, et al., 2009). Previously, QFD has been applied by to investigate the specifications of studied product that can satisfy humans needs; products include a boning knife (Marsot, 2005), pruning shears (Haapalainen et al. (1999/2000), and safety shoes (Bergquist and Abeysekera, 1996). In all cases QFD increased user satisfaction while meeting safety needs.

4. Methods

The process of redesigning the MHDs began by identifying the type of HPT and its applications. A questionnaire was developed and distributed among industrial workers to acquire their requirements regarding the design of an HPT. The questionnaire is divided into four sections: 1) personal details of worker, 2) ergonomics analysis, 3) information on the existing HPT, and 4) features for
improvement. In the personal details section, workers’ demographic information, such as age and gender were obtained. This information is necessary because even though most HPT users are young males, the design of the HPT should be acceptable for most users (Mack et al., 1995). In ergonomics analysis section, information was obtained about the frequency of HPT use, and the types of difficulties and injuries experienced by the workers when handling the HPT. The third section captures workers’ comments regarding the existing HPT. Scores 1 to 5 (1: unnecessary; 2: less needed; 3: needed; 4: desirable; and 5: critically desirable) are used to identify the workers’ requirements regarding to the features of HPT such as structure, wheels, handle, security system and forks. The final section of questionnaire recorded the workers’ requirements for the new design of an HPT. The information was analyzed using the QFD method.

Workers’ requirements were utilized to redesign the existing HPT with the objective of fulfilling workers’ satisfaction. As illustrated by Figure 1, it is described steps involved in capturing and analyzing workers’ requirements. The first three steps involve populating and capturing workers’ requirements, developing the workers’ portion of the matrix, and developing the technical portions of the matrix. In the final step this matrix is analyzed and design attributes are prioritized. Meanwhile, Computer Aided Design (CAD) that is available in CATIA Software was used to redesign the HPT.

5. Case Study

A direct workplace survey using questionnaires was conducted among 30 production workers who were familiar with using an HPT. The average age of workers was 25.3 years; all were male. Of these workers, 60% used the HPT 1 to 20 times per day, 37% used it 21 to 40 times and only 0.3% of worker used it 61 to 80 times per day. Of these workers, 86.6% of them have experienced difficulties while handling the existing HPT: 32% when transferring heavy objects, 19% during handling, 18% while pushing and pulling the HPT and 15% while lifting the objects.

Difficulties reported include size of load, instability when transferring loads, and unsatisfactory maneuverability. Only 53.3 % of workers agreed that the existing HPT is suitable for the current job; the rest said that they needed assistance from colleagues to move the HPT while transferring loads.

Injuries experienced by the workers when handling the existing HPT were also investigated. Of the workers, 86.7% had been injured when operating the existing HPT, 60% had experienced discomfort and injuries in their shoulders, 30% had suffered arm injuries, 40% had suffered wrist injuries and 30% had experienced injuries and pain in their lower back, 16.7% had felt discomfort in their upper back, 6.7% had suffered leg injuries and 2% had suffered neck and ankle injuries.

The workers were also interviewed regarding their requirements on the main features of the existing HPT. Their inputs (Table 1) are important in development of a new HPT. Workers’ inputs relating to design improvement of HPT were divided into five categories of score: 1 (unnecessary); 2 (less needed); 3 (needed); 4 (desirable) and 5 (critically desirable). Findings indicate that “easy to maneuver”,
“stability of load”, and “able to carry various sizes of object” as the critically desirable requirements. Workers’ requirements for the new HPT design were compiled in the customers’ requirements section of the QFD House of Quality (HoQ) (Figure 2).

Table 1. Workers’ requirements to improve the existing HPT

<table>
<thead>
<tr>
<th>Features</th>
<th>Workers’ requirements</th>
<th>Score</th>
<th>Relative importance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td><strong>Structure</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Light</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Stable while maneuvering</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td><strong>Wheels</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Having front wheels</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Having rear wheels</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Easy to maneuver</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td><strong>Handle</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Comfort handle height</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Comfort handle size</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Comfort handle position</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td><strong>Security system</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Security of carried object</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Stability of load</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td><strong>Fork</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Able to carry various sizes of object</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Suitable size of fork</td>
<td>2</td>
<td>6</td>
</tr>
</tbody>
</table>

Rating Score: 1- Unnecessary, 2- Less needed, 3-Needed, 4-Desirable, 5-Critically Desirable
Redesign of a hand pallet truck by integrating ergonomics analysis and quality function deployment

Figure 2. House of Quality (HoQ) for HPT improvement

Development of the HoQ starts by capturing the workers’ requirements. Once all the workers’ requirements have been obtained, the relative importance of each worker is calculated by weighting each score by the number of worker who assigned it. The summed score for each row is then divided by the total number of workers involved in the survey. For example, to calculate the relative importance for the workers’ requirements “light”: \((1 \times 6) + (2 \times 5) + (3 \times 6) + (4 \times 5) + (5 \times 8) = 94\). Hence, the relative importance = \(94 / 30\) (number of workers) = 3.13 (Table 1).

A relationship matrix is determined by mapping the strength of the relationship between workers’ inputs and the design features using the scores of 9, 3, 1 or 0 depending whether they were strong, medium, weak or none. The correlations among the design features were calculated to determine how well the design features are connected (e.g., strongly positive strong, strong, negative or strongly negative). Competitive analysis was not conducted because the study focused only on what needs to be improved. This information is obtained through technical relative importance, i.e., the sum of the product of each workers’ relative importance and each strength relationship. As an example, to obtain the technical relative importance for technical specification “size of load supporter” (Figure 2): \((3.70 \times 9) + (3.67 \times 9) + (3.13 \times 3) + (3.83 \times 3) + (3.60 \times 9) = 119.61 \approx 120\). High technical relative importance and percentage importance represent criteria that merit serious consideration. Hence, technical specifications such as “width of fork”, “size of load supporter”, “overall width”, and “wheel size (wide)” should be given highest priority because they obtained high technical relative importance and percentage importance. Therefore, a wider and adjustable fork, with load supporter, and appropriate design of wheels should be the main features of the redesigned HPT. A further requirement is that, minimizing structure weight is meaningful to ensure that the workers exert the least possible amount of force when moving the HPT.

In the redesigned HPT (Figure 3; Table 2), the fork is designed to be adjustable and longer to stabilize the HPT as well as to ease lifting and carrying the load. Installation of a pair of wheels one each at the left-rear and right-rear of the HPT is effective to reduce the required force and increase stability. A load supporter was also included in the new HPT design to minimize the tendency of the cage and load to slip off the HPT during load transfer.

Figure 3. Redesigned HPT is equipped with load supporter and rear wheels (left), wider and...
adjustable fork also were introduced (right).

6. Ergonomics simulation models

In manufacturing workplaces, production workers use the HPT for pushing and pulling activities. These activities should be analyzed to ensure that the HPT and carried materials do not lead to injury to the workers. Before pushing-pulling activities were analyzed, the existing HPT was modeled using CAD that is available in CATIA Software (Figure 4). A manikin was used to represent the actual worker; it was created based on the 50th percentile of anthropometry dimensions of 56 workers (Table 3).

Inferential statistical analysis such as comparison tests, correlations, and regression analysis are not included in the paper because the study focused primarily on determining the requirements of workers when using an HPT and incorporating those requirements in the new HPT design. However, the effectiveness of the redesigned HPT was confirmed by comparing a set of results obtained using the manikin when simulating the existing HPT and the redesigned HPT.

Table 2. New design specifications for the redesigned HPT

<table>
<thead>
<tr>
<th>Parts</th>
<th>Dimension</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forks</td>
<td>1325 mm (L), 160 mm (W), 240 mm (spread)</td>
</tr>
<tr>
<td>Additional Wheel</td>
<td>(101.6 dia. x 51.8) mm</td>
</tr>
<tr>
<td>Load supporter</td>
<td>950 mm (H) x 560 mm (L) x 30 mm (W)</td>
</tr>
</tbody>
</table>

Table 3. Anthropometry data of workers

<table>
<thead>
<tr>
<th>Body parts</th>
<th>Mean</th>
<th>SD</th>
<th>5th Percentile</th>
<th>50th Percentile</th>
<th>95th Percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stature</td>
<td>170.68</td>
<td>2.9301</td>
<td>165.86</td>
<td>170.68</td>
<td>175.50</td>
</tr>
<tr>
<td>Axilla height</td>
<td>127.5</td>
<td>1.0787</td>
<td>125.73</td>
<td>127.50</td>
<td>129.27</td>
</tr>
<tr>
<td>Bimalleolar breadth</td>
<td>8.34</td>
<td>0.5486</td>
<td>7.44</td>
<td>8.34</td>
<td>9.24</td>
</tr>
<tr>
<td>Crotch height (standing)</td>
<td>78.48</td>
<td>1.6948</td>
<td>75.69</td>
<td>78.48</td>
<td>81.27</td>
</tr>
<tr>
<td>Hip breadth (standing)</td>
<td>32.46</td>
<td>2.0799</td>
<td>29.04</td>
<td>32.46</td>
<td>35.89</td>
</tr>
<tr>
<td>Waist height (omphalion)</td>
<td>100.61</td>
<td>5.2766</td>
<td>91.93</td>
<td>100.61</td>
<td>109.29</td>
</tr>
<tr>
<td>Waist breadth</td>
<td>30.23</td>
<td>2.1148</td>
<td>26.75</td>
<td>30.23</td>
<td>33.71</td>
</tr>
<tr>
<td>Chest height (standing)</td>
<td>123.98</td>
<td>1.9678</td>
<td>120.75</td>
<td>123.98</td>
<td>127.22</td>
</tr>
<tr>
<td>Chest breadth</td>
<td>32.43</td>
<td>1.9527</td>
<td>29.22</td>
<td>32.43</td>
<td>35.64</td>
</tr>
<tr>
<td>Sleeve outseam</td>
<td>55.63</td>
<td>3.9523</td>
<td>49.12</td>
<td>55.63</td>
<td>62.13</td>
</tr>
<tr>
<td>Radiale-styliion length</td>
<td>26.21</td>
<td>2.1802</td>
<td>22.63</td>
<td>26.21</td>
<td>29.80</td>
</tr>
<tr>
<td>Acromion-radiale length</td>
<td>28.96</td>
<td>2.0268</td>
<td>25.63</td>
<td>28.96</td>
<td>32.30</td>
</tr>
</tbody>
</table>

7. Analysis of pushing-pulling activities

For both designs, the HPT and its cage along with a manikin were modeled under actual working conditions to simulate pushing-pulling activities. This
Redesign of a hand pallet truck by integrating
Ergonomics analysis and quality function deployment

Simulation is useful to determine the effects of the existing HPT design when workers perform pushing and pulling activities. In CAD, the existing HPT design was transferred into an ergonomics analysis environment, and the manikin was positioned where actual workers perform the pushing and pulling activities.

An ergonomics analysis tool, Push and Pull Analysis (Snook and Ciriello, 1991) was utilized to estimate the forces required to push and pull the existing HPT. Input data such as pushing-pulling frequency and travel distance of HPT were considered. Observation indicated that, pushing time is 18.75 s per push, that travel distance is 15 m, and that the distance from the hand to the floor is 1 m.

For both HPTs, the analysis determined that maximal forces were different when pushing and pulling (Table 4). When pushing the existing HPT, the maximum acceptable initial force is 311.094 N, and the maximum acceptable sustained force is 167.20 N; when pulling the HPT, the maximum acceptable initial force is 291.308 N, and the maximum acceptable sustained force is 159.042 N (Figure 5).

Table 4. Comparison results of Pushing-Pulling Analysis between existing HPT and redesigned HPT

<table>
<thead>
<tr>
<th>Forces</th>
<th>Existing HPT</th>
<th>Redesigned HPT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Push</td>
<td>Pull</td>
</tr>
<tr>
<td>Maximum acceptable initial force</td>
<td>311.094 N</td>
<td>291.308 N</td>
</tr>
<tr>
<td>Maximum acceptable sustained force</td>
<td>167.204 N</td>
<td>159.042 N</td>
</tr>
</tbody>
</table>

Figure 4. Model of Hand Pallet Truck (HPT)
When pushing the redesigned HPT, the maximum acceptable initial force is 319.874 N, and the maximum acceptable sustained force is 167.064 N; when pulling, the maximum acceptable initial force is 273.212 N, and the maximum acceptable sustained force is 153.302 N (Figure 6).

8. Discussion

This section discusses the findings of study. Based on the questionnaire survey, workers identified “easy to maneuver”, “stability of load”, and “able to carry various sizes of object” as the most important requirements for an HPT.

Priorities were developed in the HoQ to determine which technical specifications must be considered in HPT design. Based on the technical relative importance and percentage importance, a designer should focus on the following specifications to redesign the HPT: “width of fork”, “size of load supporter”, “overall width”, and “wheel size (wide)”. These technical specifications were incorporated in the new design of HPT to accommodate workers’ requirements such as “able to carry various sizes of object”, “easy to maneuver” and “stability of load”.

The existing HPT has been redesigned by considering all workers’ requirements as identified using QFD method. Both existing HPT and redesigned HPT were analyzed to determine their maximum acceptable initial force and maximum acceptable sustained force during pushing and pulling activities. Through this analysis, the workers can determine the limit of forces that they should exert to avoid having a significant chance of being injured or developing occupational injuries.

The results of analysis showed that the existing and redesigned HPT have different force limits for pushing and pulling activities (Section 7). To avoid the risk of injury, workers should respect those limits when performing pushing and pulling activities using either existing design or redesigned HPT. The force limits were not changes significantly by the redesign (Table 4), but this finding is essential to minimize the stresses on the workers when handling the HPT and reduce the risk of occupational injuries.
9. CONCLUSION AND FUTURE WORK

This study has successfully determined the workers’ requirements relating to the design of an HPT. To redesign the HPT, these requirements were considered using QFD. The existing HPT and redesigned HPT were analyzed using an ergonomics analysis tool, to determine maximum forces which should be exerted when workers push or pull the HPT. No significant difference was observed between the force limits of the HPT designs, however, to avoid the risk of injury, workers should respect the identified limits when pushing or pulling the HPT. Based on the study’s findings, “easy to maneuver”, “stability of load”, and “able to carry various sizes of object” were the most essential features in the design of HPT. Furthermore, the integration of ergonomics analysis and QFD was proved to be a suitable and scientific method for designing an HPT.

Future study should investigate the appropriate materials to be used in designing and fabricating the HPT so that its weight can be reduced while increasing its strength and durability.

Acknowledgement

The authors would like to acknowledge the Centre of Research Management and Innovation (CRIM) of Universiti Teknikal Malaysia Melaka (UTeM) for funding this research under UTeM Short Term Research Grant, the Faculty of Manufacturing Engineering (FKP) of UTeM for providing facilities and assistance in performing this study. Finally, the authors would like to thank WINCO Precision Engineering (Melaka) Sdn. Bhd. for the permission and ample opportunity to facilitate fruitful case study.

Reference

http://www.iea.cc/browse.php?contID=what_is_ergonomics
Redesign of a hand pallet truck by integrating
Ergonomics analysis and quality function deployment

supported design”. PhD thesis. Loughborough University.
26, pp. 173-178.
Snook and Ciriello (1991), “The design of manual handling tasks: revised tables of
maximum acceptable weights and forces”. Ergonomics, Vol. 34, pp. 1197-1213.

Isa Halim
Isa Halim is a lecturer at Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka (UTeM),
Melaka, Malaysia. He received the MSc in Mechanical Engineering from Universiti Teknologi MARA (UiTM),
Malaysia. His research disciplines include Industrial Ergonomics and Occupational Health & Safety. Currently he is
a PhD student under research grant entitled “Muscle Fatigue Solutions for Prolonged Standing at Workplace using
Electromyography (EMG) and Customer Reliability

Abdul Rahman
Zubaidah Ismail is an associate professor at the Department of Civil Engineering, University of Malaya, Kuala Lumpur,
Malaysia. Her research interests include the field of ergonomics, structural dynamics, and contaminant transport.
She received her M.A. degree in applied mathematics from Temple University, USA and the PhD degree in civil
engineering from University of Malaya.

Wan Fadhli
Wan Fadhli is an engineer at Kiswire Sdn Bhd, Johor, Malaysia. This Korean company produces large scale of wire products.
He manages product quality improvement and product specifications. He has a Bachelor Degree in Manufacturing
Engineering (Manufacturing Management) with Honours from Universiti Teknikal Malaysia Melaka (UTeM), Melaka,
Malaysia.
Asian Journal of Ergonomics aims to:

- provide a forum for new development in theory, application, and result of empirical research on ergonomics in the Pan-Pacific region
- promote the awareness of ergonomics in the Pan-Pacific by publishing quality articles from all over the world
- cater to the demand for regional and international collaboration on ergonomics and ergonomics-related issues

Asian Journal of Ergonomics is the official journal of the Pan-Pacific Council on Occupational Ergonomics. The journal is devoted to the development of ergonomics and globalization of ergonomics and will be published in June and December.

Submissions are invited in all areas of ergonomics including, but not limited to the following:

- Anthropometry
- Cognitive Engineering
- Comparative Studies in Ergonomics
- Cumulative Trauma Disorders
- Ergonomics Case Studies
- Ergonomics Standards
- Human Computer Interaction
- Occupational Biomechanics
- Occupational Safety
- Participatory Ergonomics
- Product Design
- Stress and Fatigue at Work
- Task Analysis
- Work Environment
- Workplace Analysis and Design
- Work-related Musculoskeletal Disorders
Author's Responsibilities and Copyright:

The submitted manuscript should not have been previously published and should not be under consideration for publication elsewhere. Asian Journal of Ergonomics assumes that all submitted manuscripts are the property (copyright) of the submitting author(s) and that copyright will be transferred to PPCOE when the manuscript is accepted. The author(s) should secure permission for the reproduction of any figure, table, or extensive (more than fifty word) extract from the text, from a source which is copyrighted or owned by a party other than PPCOE or the author(s). This rule is enforced both to direct reproduction or ‘derivative reproduction’, when a new figure or table is substantially derived from a copyrighted source. Any cost that is incurred by the author's violation of the rule is charged to the responsible author.

The corresponding author is charged 100 US dollars for his/her accepted manuscript. The corresponding author receives 50 off-prints and a copy of the journal issue in which his/her article appears.

Instruction for Authors

Interested authors should submit four copies of their paper in English to the editor-in-chief. All submitted manuscripts will be peer reviewed based on their originality, thoroughness, and usefulness. Electronic submission via e-mail is strongly encouraged for rapid communication and review process. For more information and details please contact the editor-in-chief.

Sung H. Han
Department of Industrial and Management Engineering
Pohang University of Science and Technology
San 31 Hyoja, Pohang, 790-784 South Korea
Phone: 82-54-279-2203 / Fax: 82-54-279-2870
E-mail: shan@postech.ac.kr

The web site for the journal is: http://iems.net/aje
Instruction for Authors

Pre-Review Manuscript Preparation

The journal language is English and all contributions should be submitted in English.

Submit three copies plus original manuscript to the Editor-in-Chief. See the electronic submission instructions for an e-mail submission.

Manuscripts should be typewritten on one side of A4 (210 mm×297mm) paper, double-spaced, with 25.4mm margins left and right, top and bottom. Follow the standard composition given below and begin each component on a new page, with the page number typed in the upper, right hand corner of each page. Paginate the entire manuscript.

Title Page

Page 1 should include:
1. the title of the article: Bold 14 point
2. the author's full name [first name, middle initial(s), surname]: Capital 12 point
3. affiliations [department (if any), institution, city, state or country where the research is done]: Italic 12 point
4. acknowledgment of grant support and individuals who have directly helped in the study: 10 point

Abstract and Key words

Page 2 should include the title of the article followed by an abstract not exceeding 250 words. The abstract should state the purpose of the study, basic procedures, important findings, and conclusions. On a separate line below the abstract, include 5 key words relating to the main topics of the paper for indexing.

Main Text: The paper should be reasonably subdivided into sections and, if necessary, into subsections. Writing should be concise and in one column format. Illustrations should be prepared on separate sheets and submitted with the manuscript.

References

All sources cited in the text should be included in the reference list. All references to publications made in the text should be presented in a list of references following after the text of the manuscript. In the text, refer to author's name (without initial) and year of publication. Example. "Since Peterson (1967) showed that......." "This is in agreement with results obtained later (Kramer, 1969)". If reference is made in the text to publications written by more than two authors the name of the first author should be used, followed by 'et al.' However, 'et al.' should never be used in the reference list. The list of references should be arranged alphabetically on authors' last names, and chronologically per author. If an author's name in the list is also mentioned with co-authors the following order should be used: Publications of the single author, arranged according to publication.
dates—publications of the same author with one co-author—publications of the author with more than one co-author.

Use the following system for arranging your references. Do not abbreviate the titles of periodicals mentioned in the list of references.

For periodicals

For books

For edited books and edited proceedings of conferences, symposia, etc.

Formulae
Formulae should be typewritten. Leave suitable space around the formulae. Subscripts and superscripts should be displayed clearly. Give the meaning of all symbols immediately after the equation. Equations should be numbered serially in the right-hand side using parentheses.

Units
The use of S.I. units is encouraged.

Footnotes
Footnotes should not be used except for tables.

Tables
A table should not exceed the printed area of the page. Large tables should be avoided. If many data are to be presented, attempt to divide into two or more tables. Drawn tables should not be used. Tables should be numbered according to their sequence in the text. The text should include references to all tables. Tables should be typewritten on separate pages, added to the manuscript. Each table should have a self-explanatory title. Column headings should be sufficiently explanatory. Units of measurements should be added between parentheses. Vertical lines should not be used to separate columns. Leave some extra space between the columns instead. Explanations essential to the understanding of the table should be given in footnotes at the bottom of the table.

Illustrations
All illustrations should be given separately. Illustrations should be numbered according to their sequence in the text. References should be made in the text to each figure. Each illustration should be identified on the reverse side (or-in the case of line drawings-on the lower front side) by its number and the name of the author. Illustrations should be designed with the format of the page of this journal in mind.
Illustrations should be of such a size as to allow a reduction up to 50%. Lettering should be in Indian ink or by printed labels. Make sure that the size of the lettering is big enough to allow a reduction of 50% without becoming illegible. The lettering should be in English. No letter, number or symbol should be less than 5 mm high.

Each illustration should be accompanied by a caption. Put the captions on a separate list, added to the manuscript. Explanations should be given in the typewritten legend. Drawn text in the figures should be kept to a minimum. Photographs are only acceptable if they have good contrast and intensity. Sharp and glossy copies are required. Reproductions of photographs already printed cannot be accepted. Color illustrations cannot be included, unless paid for by the author.

Authors may be charged for changes or additions made in proof stage.

Where to Mail Pre-Review Manuscript

All manuscripts will be anonymously reviewed to evaluate the suitability and originality of the contents for publication. Please submit your manuscript by mail or e-mail to the Editor-in-Chief:

Dr. Sung H. Han
Editor-in-Chief, Asian Journal of Ergonomics
Department of Industrial and Management Engineering,
San 31 Hyoja, Pohang, 790-784 Korea
Phone: 82-54-279-2203, Fax: 82-54-279-2870
E-mail: shan@postech.ac.kr

Electronic Submission Instructions

Please return your final, revised manuscript on disk as well as hard copy. The hard copy must match the disk. The Journal encourages authors to submit their initial papers via e-mail, and to deliver the final, revised version of their accepted manuscripts (text, tables, and illustrations) via e-mail as well as on disk. Microsoft Word 6.0 or above is the preferred software. Other formats are acceptable only if conversion to MS Word is guaranteed. Refrain from complex formatting specifications. Do not use desktop publishing software such as Page Maker. Please do not deliver files that contain hidden text: for example, do not use your word processor's automated features to create footnotes or reference lists. Submit all the text and figures of each manuscript as a single file, if possible. Please provide separate files for the illustrations used in the manuscript. All color reproduction should be convertible to the graphic files for an IBM PC. If necessary, technical details of the image reproduction should be attached to all digital image submissions. All illustration files will be converted to JPG, GIF or Bit map formats. Consider the resolution and size of the files so that the maximum 50% reduction printing can be acceptable. Label all disks with your name, the file name, and the word processing program and version used.