UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF PREDICTIVE MODEL FOR STOOP AND SQUAT POSTURES ON PHYSIOLOGICAL AND PSYCHOPHYSICAL RESPONSES IN MANUAL LIFTING TASKS

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NOR HAFEEZAH BINTI KAMARUDIN

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Malaysia's economic growth is led by several industrial sectors and it involves thousands of workers. Even with the increased use of automation and new technology, manual material handling (MMH) still exist in the industry due to high flexibility and low in cost. MMH contributed as major cause of work-related musculoskeletal disorders (MSD) cases in Malaysia as high as 40%. Posture and weight load identified as the leading ergonomic risk factors to MSD during the MMH task. Posture and weight load identified as the leading ergonomic risk factors to MSD during the MMH task. Frequently used postures, stoop and squat were studied since most researchers come to argument about the correct technique as squat were presumed the safest way to lift but stoop were preferred by most workers. The main objective of this study is to develop a predictive model of MAWL for stoop and squat postures in MMH task. The effects of load, frequency and height on both postures were identified together with the effect of physiological and psychophysical responses on male and female subjects. The methodology applied uses a total of 36 healthy male and female subjects between the ages of 20 to 35 years. The experimental lifting task was designed based on different load weights, heights and frequency (independent variables). The effects of the independent variables on physiological (heart rate and energy expenditure) and psychophysical (rating of perceived exertion (RPE) and maximum acceptable weight limit (MAWL)) responses were studied. The predictive models were developed based on the independent and dependent variables analysis. The results showed that the load, frequency and height were significant factors with physiological and psychophysical response of stoop and squat postures. Heart rate, energy expenditure and RPE increases as the load, frequency and height increase. Meanwhile, MAWL decreases as the frequency and height of lifting increases in both postures. Stoop denote higher MAWL than squat posture as it produces lower heart rate and energy expenditure compared to squat. The significant

factors ($p<0.05$) associated with the MAWL predictive models are subjects, height, heart rate and energy expenditure. The model significantly linear towards the stoop ($R = 0.957$) and squat ($R = 0.922$). MAWL predictive model successfully demonstrates and provides guidelines in evaluating the safe loads and without exceeding the limits of the workers in stoop and squat lifting postures during MMH task.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBANGUNAN MODEL RAMALAN UNTUK POSTUR STOOP DAN SQUAT BERDASARKAN TINDAK BALAS FISIOLOGIKAL DAN PSIKOFIZIKAL SEMASA TUGAS MENGANGKAT MANUAL

Oleh

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Pertumbuhan ekonomi Malaysia dipengaruhi oleh beberapa sektor perindustrian dan melibatkan ribuan pekerja. Walaupun dengan peningkatan penggunaan automasi dan teknologi baru, pengendalian bahan manual (MMH) masih wujud dalam industri kerana fleksibel dan kos yang rendah. MMH menjadi penyumbang utama kes gangguan muskuloskeletal (MSD) yang berkaitan dengan kerja di Malaysia iaitu setinggi 40%. Postur dan berat beban dikenalpasti sebagai faktor utama risiko ergonomik yang membawa kepada MSD semasa tugas MMH. Dalam kajian ini, postur yang kerap digunakan dalam tugas MMH, stoop dan squat dikaji. Postur stoop dan squat dikaji kerana sering menjadi pertikaian dikalangan penyelidik, postur squat dianggap postur yang selamat untuk mengangkat tetapi stoop lebih disukai oleh kebanyakan pekerja. Objektif utama kajian ini adalah untuk membangunkan model ramalan MAWL untuk postur stoop dan squat. Kesan beban, kekerapan dan ketinggian kepada postur serta menentukan kesan fisiologi dan psikofizik terhadap subjek lelaki dan perempuan. Metodologi kajian yang digunakan melibatkan seramai 36 subjek lelaki dan perempuan yang sihat, berumur diantara 20 hingga 35 tahun.Tugas mengangkat direka berdasarkan berat beban, ketinggian dan kekerapan yang berbeza (pembolehubah bebas). Kesan pembolehubah bebas terhadap fisiologi (kadar denyutan jantung dan penggunaan tenaga) dan psikofizik (rating of perceived exertion (RPE) dan maximum acceptable weight limit (MAWL)) telah dikaji. Model ramalan telah dibangunkan berdasarkan analisis pembolehubah bergantung dan bebas. Hasil kajian menunjukkan bahawa berat beban, kekerapan dan ketinggian adalah faktor yang signifikan dengan tindak balas fisiologi dan psikofizik terhadap postur stoop dan squat. Kadar denjutan jantung, penggunaan tenaga dan RPE meningkat apabila beban, kekerapan dan ketinggian mengangkat meningkat. Sementara itu, MAWL berkurangan kerana kekerapan dan ketinggian mengangkat meningkat untuk kedua-dua postur. Stoop menunjukkan MAWL yang lebih tinggi daripada squat kerana stoop menyebabkan kadar denyutan jantung dan penggunaan

tenaga yang lebih rendah berbanding squat. Faktor-faktor signifikan ($p<0.05$) yang dikaitkan dengan model ramalan MAWL adalah subjek, ketinggian, kadar denyutan jantung dan penggunaan tenaga. Model ini berkadar linear dengan stoop ($R = 0.957$) dan squat ($R = 0.922$). Model ramalan MAWL berjaya menunjukkan dan menyediakan garis panduan dalam menilai berat beban yang selamat dan tidak melampaui had keupayaan pekerja semasa melakukan tugas MMH dalam postur stoop dan squat.

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I certify that a Thesis Examination Committee has met on (15 January 2019) to conduct the final examination of Nor Hafeezah binti Kamarudin on her thesis entitled ("Development of Predictive Model for Stoop and Squat Postures on Physiological and Psychophysical Responses in Manual Lifting Tasks") in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
BPM	Beats per minute
DOSH	Department of Occupational Safety and Health
ECG	Electrocardiography
EE	Energy Expenditure
HR	Heart Rate
LI	Lifting Index
MANOVA	Multivariate analysis of variance
MAWL	Maximum Acceptable Weight Limit
MMH	Manual Material Handlings
MSD	Musculoskeletal Disorder
NIOSH	National Institute of Occupational Safety and Health
RPE	Rating of Perceived Exertion
RWL	Recommended Weight Limit
SEE	Standard Error of Estimate
SOCSO	Social Security Organization

CHAPTER 1

INTRODUCTION

1.1 Research Overview

Malaysia's economic growth is led by several industrial sectors and that achievement necessarily involves thousands of workers.Recently, even with the increased use of automation systems and the implementation of new technology, the manual handling of large-scale materials still exist in the industry.Manual Material Handling (MMH) usage was preferred over machineries due to high flexibility and quite low in cost. The advantage is in its flexibility to maneuver during simple and light material transfer, if compared to performing the same activity using mechanical aids (Deros et al., 2015).

MMH is defined as moving or handling loads by lifting, lowering, bending, twisting, holding, transporting, supporting and others activities in our daily life, whether in one time or regularly as part of normal work using human energy and forces. It is also characterized as the manually grasping an object of various size and load mass with both hands and move vertically without the mechanical aid.MMH occurs almost in all work environments and industries such as constructions, manufacturing, farms, healthcare, warehouses, transportation, hotels, restaurants and others (Medina and Vina, 2012; Rud, 2011).MMH normally involves in short-distance movement within the confines of a building or between buildings (Coyle et al.,1992).

MMH associated with an increased risk of work-related musculoskeletal disorder (MSD) disease and main contributor of low back pain at workplaces. Since 1980s there has been growing evidence in the scientific literature of link between MMH especially lifting task activity and lumbar spine problem, (Kothiyal et al. 1992). Low back injuries attributed as one of the leading occupational health and safety issue and most expensive, contributing almost 20% of all workplace injuries and illnesses, and contributes nearly quarter of all claims and compensation costs (Schinkel et al., 2013; Berthelette et al., 2012; Daynard et al. 2001; Guo et.al, 1999; Waters et al., 1993).Since then, extensive research is being carried out in U.S.A and other countries to reduce the number, severity and the cost of damaging by MMH injuries.

Malaysian's Social Security Organization (SOCSO) Annual Report, which comprises all the active and registered workers in Malaysia shows the number of industrial accident had increased to 35,304 cases in 2016. Manufacturing industry contributed 12,401 cases, followed by construction industry, 6072 cases (SOCSO, 2016). Meanwhile, the reported numbers of occupational diseases were reached 4270 cases. The occupational MSD increased

tremendously to 1607 cases in 2016, the trend that statistically increased each year since the cases were first recorded of 10 in year 2005 (SOCSO, 2016) as shown in Figure 1.1.

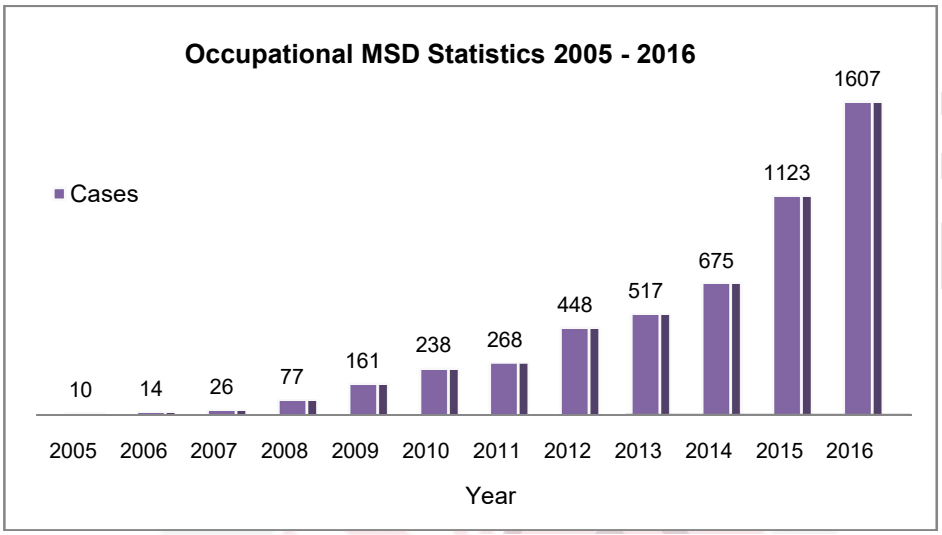

Figure 1.1: Occupational MSD cases reported to SOCSO (SOCSO, 2016)

National Institute for Occupational Safety and Health (NIOSH, 1981) recognized the growing problem of work related MSD injury which contributing to tremendous medical costs and compensation, human suffering and lost productivity in company. NIOSH had published the Work Practices Guide for Manual Lifting in 1981, model proposed by (Drury and Pfeil, 1975) and revised version of NIOSH Lifting Equation (RNLE) in 1991 by adding several task conditions (Waters et al., 1993).

Lifting Equation is an ergonomic interventions assessment tool that used to calculate the Recommended Weight Limit (RWL) and Lifting Index (LI) in evaluating and identify the hazardous lifting tasks and estimating the physical demands of the job related to manual lifting tasks. Even though the NIOSH working guidelines that were designed in the United States, were practiced and followed worldwide, but still the number of MSD cases reportedly increased due to the lack of awareness in work place including in Malaysia.

The hazard and physical ergonomic risk factors of MMH task may be due to an unfavorable ergonomic condition such as incorrect handling method, slipping and falling, awkward working postures, heavy weight lifting, forceful exertion, repetitive movements, vibration, stress, duration, prolonged periods standing or walking and improper lifting techniques while performing the MMH tasks that exceeds its safe handling capacity (DOSH, 2018; Meksawi et al., 2012; Punnett and Wegman, 2004; Kothiyal et al., 1991). Workers' abilities to perform work

duties may vary due to age difference, gender, physical condition and strength of the worker and the environment conditions that different from country to country.

Out of various kinds of MMH tasks risk factors, repetitive movements, improper and awkward lifting postures cited as the common cause of low back problems and have been considered as a major occupational hazard to workers (Kothiyal et al., 1991). In search of safer lifting techniques and optimum lifting methods, it still remains controversial (Dieen et al., 1999). There is a significant argument about the best techniques to employ the low-lying objects off the floor. Selecting the most appropriate lifting posture is an important part of safe lifting task (Vecchio, 2017). Many researchers tried to find out a solution of best posture in MMH to minimize the effects of back problems based on two types of lifting postures namely stoop posture and squat posture (Surata, 2013; Wang et al., 2012; Neumann, 2010; Bazrgari et al., 2007; Hwanget al., 2009; Straker, 2003; Kumar, 1984).Squat posture defined as the back remains as erect as possible the knees are flexed (knee bent and back straight) and stoop posture described as bend forward and down at the waist and/or mid-back while maintaining straight legs (knee straight and back bent).

1.2 Problem Statement

NIOSH lifting guidelines were developed based on lifting posture and anthropometric data of the population also taken into consideration (Xiao et al., 2005; Maiti and Ray, 2004; Wu, 2003; Luk et al., 2003; Lee et al., 1996).Most of the available information in literature of MMH analysis exists around the Western countries and it is believed that racial differences in physique give a significant effect to the manual lifting behavior (Cheng, 2011; Wu, 2003). NIOSH guideline may not be applicable to Malaysian, due to strength capacity and it was found that Malaysian workers have a smaller body size than the Western population (Deros et al., 2015; Mohamad et al., 2010;Taha et al., 2009).

Since for the past 40 years, squat posture were presumed as the safest way to lift and regarded as the correct technique by health professional. Work that requiring stoop postures commonly associated with high incidence of MSD, but workers often preference to stooping because it demands less energy expenditure, exert higher force and increased mobility than squatting. Many researchers come to argument about the ‘correct technique’ (Vecchio, 2017; Garg & Herrin, 2007; Straker, 2003; Limerick, 2001; Dieen et al., 1999; Burt et. al, 1999;Garg, 1993).

In Malaysia, Department of Occupational Safety and Health, Malaysia (DOSH) reported that MMH activities contribute 40% of reported musculoskeletal disorders (MSDs) cases shows one of the critical ergonomic risk factors involving in manual lifting task is caused by lifting postures (DOSH,2018). The most commonly industry that used the squat and stoop posture in MMH were

construction industries involving brickworks and concrete work activities, with uneven level of height (above shoulder height and reaching overhead), heavy weight materials and repetitive frequencies of bend down and straighten up of the body (Suzila et al.,2017). Constructions industry was among the leading industry with highest claims of accidents and injuries of MSD and greater affected body region of (low back, neck/shoulder, hip and knee) than other industries (SOCSO, 2016). DOSH have recommended the correct lifting postures in Guidelines for Manual Handling at Workplace in 2018. Squat lifting stated as a correct lifting compared to the stoop posture as shown in Figure 1.2.

Figure 1.2: Correct lifting versus incorrect lifting (Courtesy of DOSH, 2018)

The statistic of injury also shows that over-exertion in handling objects either in lifting or pushing the heavy objects cited as major factors as 7047 cases recorded in 2016 (SOCSO, 2016).Unloading either light and heavier weight of load in repetitive frequency with uncommon lifting postures can lead the workers to experience muscle pain, fatigue and metabolic energy demands on the body and exposing to physical risk factors of the MSD (Suzila et al., 2017; Leigh et al., 1997; Waters et al., 1993; Kim and Chung, 1995).

The working posture and handling heavier loads in specific lifting height were some of critical factors in working environments (DOSH, 2018). Extensive researches have been conducted to develop a guideline and determine safe limits of workers in MMH task. The maximum acceptable weight of lift (MAWL) used as a guidelines in preventing MSD in MMH task have been discovered by (Chen and Ho, 2016; Syamil and Bahri, 2016; Abadi et al., 2015; Kuijer et al., 2012: Li et al., 2007; Dedik, 2006; Cheng and Lee, 2006; Wu, 2003; Maiti and Ray, 2004). There are three significant criteria's needs to be considered in lifting task activity namely biomechanical, physiological and psychophysical criteria's. Unfortunately, the effect of lifting posture on biomechanical as studied by (Syamimi et al., 2012), physiological and psychophysical aspects is not widely studied and limited reference that focuses on the performance of biomechanical, physiological and psychophysical of Malaysian.

Thus there is a need to study the postures as a problem of MMH task and aims to propose the solutions of the posture and maximum safe limit of MAWL. Workers lifting posture will respond based on physiological and psychophysical criteria during lifting task activity. A guideline and predictive model of MAWL regarding to workers lifting capabilities should be developed in stoop and squat posture. The MAWL predictive model computed the subjects highest acceptable workload that they comfortably lifted based on their physiological and psychophysical experiences. The guidelines would help the industries in designing the ideal condition of MMH tasks that can prevent and reduce the MSD injuries in MMH task. This experimental study was conducted only at Universiti Putra Malaysia. Further studies need to be conducted in other places and industries to acquire more significant result of MAWL that can be used as a guideline throughout the country.

1.3 Aim and Objectives

This research aims to develop the predictive model based on stoop and squat posture during manual lifting task. The lifting task variables designed according to the NIOSH Lifting Equation as the baseline information in identifying the safe MAWL limit.

Objectives through this research are:

i. To identify lifting variables of load, frequency and height that affected the physiological and psychophysical response of stoop and squat posture.
ii. To investigate and analyze physiological (energy expenditure, heart rate) and psychophysical (Maximum Acceptable Weight Limit (MAWL) and Rating of Perception Exertion (RPE)) responses on male and female subjects.
iii. To develop predictive model based on variables that significantly affected relationship between male and female subjects for stoop and squat posture.

1.4 Scope of Works

This study conducted based on stoop and squat lifting posture in developing the predictive model based on physiological and psychophysical response in manual lifting task. As currently practice, the lifting model that was developed by NIOSH lifting equation was based on United States anthropometry. In this study, the physiological and psychophysical responses were analyzed to investigate its behaviors based on stoop and squat posture for male and female subjects. The physiological and psychophysical response collected non-invasively through questionnaires, lifting sessions and selected equipment such as Actiheart in Engineering Laboratory, Universiti Putra Malaysia (UPM). Subject's age, gender and health condition were selected and observed under controlled lifting tasks period and sessions as approved by Jawatankuasa Etika UPM.

1.5 Contributions

The contribution of this study is the ability to identify variables of the lifting model based on the Malaysian physiological and psychophysical criteria's. Most of the proven lifting model developments design pertinent to Western countries. It is also important to study the performance and effective postures during the MMH tasks, since the studies that correlate the lifting posture on weight load, height and frequency have never been reported in the literatures in Malaysia condition.

The major contribution of this study proposed the new predictive model to determine the highest acceptable workload that comfortably lift without exceeding the safety limit on both stoop and squat posture. Predictive model which were developed based on lifting low-lying objects were formed by lifting variables of gender, height, and frequency together with physiological responses (heart rate and energy expenditure).

The developed MAWL predictive model may be very useful to the subjects and practical for industrial purpose. Further study need to be done in the industry to obtain more significant result of MAWL that can be use all over the country. Predictive model helps in designing the appropriate ergonomic workstations and assessment of MMH tasks in the workplace and also reduce the MMH hazard and fatigue among the workers while performing lifting tasks. Besides, it can predict the maximum load in normally used lifting posture either in stoop or squat posture. In addition, MAWL predictive model benefits as a guideline in assists and creates continuous safety awareness of the people in choosing and performs the correct lifting and posture. The model hopefully meets the human factors design criteria based on Malaysian anthropometric and provides useful contribution in MMH tasks in ensure to increase productivity, physical health, safety and satisfaction together with reducing the risks of MSD in workplace and society.

1.6 Thesis Outline

This thesis consists of five major chapters which are Introduction, Literature Review, Methodology, Result and Discussion and Conclusion and Recommendation of Future Work. The contents of each chapter are outlined as follows:

Chapter 1 gives brief information about the research overview, problems statement, aims and objectives, scope and contributions of the lifting task.

Chapter 2 focuses on the literature review and the methodologies of the previous studies including the dependent and independent variables, procedures of lifting tasks and statistical analysis and predictive model development of previous studies.

Chapter 3 discusses about the research methodology and analysis of the study. This will explain how the study is organized, equipment used and the flow of all the study analysis part. This chapter also describes about the lifting task design and the implementation of physiological and psychophysical analysis.

Chapter 4 presented and discussed the findings, analysis result, predictive model development and validation and details discussion of the lifting task findings.

Chapter 5 shows the conclusions and recommendation for future work of the research. It also explains the objectives achieved through the finding of the lifting task.

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LIST OF PUBLICATIONS

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Ahmad, S.A., Kamarudin, N.H., Yusuff, R.M., Hassan, M.K. and Dawal, S.Z.M. Analysis of Stoop and Squat Lifting Postures on Physiological Response in Manual Lifting Task. Journal of Applied Ergonomics (*Submitted Pre-review*)

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Yusuff R.M., Kamarudin N.H., Ariffin A.M.K., Ahmad S.A. and Soom M.A.M. (2016) Physiological Analysis of Stoop Lifting Based on Heart Rate for the Malaysian Population. *In: Goonetilleke R., Karwowski W. (eds) Advances in Physical Ergonomics and Human Factors. Advances in Intelligent Systems and Computing,* Vol 489. Springer, Cham, pp 829-838, doi: 10.1007/978-3-319-41694-6_79, ISSN 2194-5357.

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Nor Hafeezah Kamarudin, Siti Anom Ahmad, Mohd Khair Hassan, Rosnah Mohd Yusuff, Siti Zawiah Md. Dawal. A Review of the NIOSH Lifting Equation and Ergonomic Analysis, *2nd International Conference on Ergonomics*, September 2-4, 2013, Kuala Lumpur, Malaysia.

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