INVESTIGATION OF MANUAL MATERIAL HANDLING ON MUSCULOSKELETAL DISORDER AT COMPUTER NUMERICAL CONTROL WORKSTATION

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KUALA LUMPUR

2020

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DISSERTATION SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENGINEERING SCIENCE

FACULTY OF ENGINEERING
UNIVERSITY OF MALAYA
KUALA LUMPUR

2020

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Title of Project Paper/Research Report/Dissertation/Thesis ("this Work"):

INVESTIGATION OF MANUAL MATERIAL HANDLING ON MUSCULOSKELETAL DISORDER AT COMPUTER NUMERICAL CONTROL WORKSTATION

Field of Study: **MANUFACTURING AND PROCESSING (ERGONOMICS DESIGN)**

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ABSTRACT

Manual Material Handling (MMH) tasks have been recognized among the major source of work-related musculoskeletal disorder (WMSD) in automotive industry and they are commonly practiced at Computer Numerical Control (CNC) workstation. At this workstation, workers act as a material transfer device in the process of loading and unloading products from pallets to machines. The physical interaction of workers to machine is not self-chosen and workers are forced to follow the pace of running CNC machine. The worst situation happens when workers are required to operate more than one machine concurrently. The mismatch interaction between workers and machine exposes workers to awkward working posture which leads to high risk of WMSDs. Currently, investigation of MMH tasks at CNC workstation is still scarce. Thus, this study aims to determine the prevalence of WMSDs among MMH workers at CNC workstation and to find the relationship of loads to energy expenditure and back postural angles. The methodology in this study comprises an industrial survey and a series of experimental tasks. A total of 113 workers from automotive industry participated in the industrial survey while 14 workers and 14 novices participated in experimental tasks. The results of industrial survey reveal that 78.8% of the workers experience the symptoms of WMSDs on various regions of their body. The highest prevalence of the WMSDs is at the lower back with 85.8%. The significant factors that are associated with the WMSDs are bending the trunk slightly forward with hands above the knee level, twisting the trunk (over 45°) while bending sideways and lifting object less than 3kg. The experimental results reveal that the maximum energy expenditure is found when novice (bending: 4.32kcal/min; squatting: 4.95kcal/min) and worker (bending: 3.64kcal/min; squatting: 4.39 kcal/min) performed 3 kg load tasks. Novice has 23.73% and 16.53% higher of energy expenditure compared to worker for 1kg load tasks in bending and squatting respectively. Novice also has 15.74% and 11.31% higher energy expenditure for 3kg load

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tasks in bending and squatting respectively. Load is discovered to positively correlates with energy expenditure in both subjects and both postures. Load also have positive correlation with back postural angles in many tasks whereas has negative correlation with back postural twisting angles. The most correlated back postural angles with load occurs at Task 10 which refers to lowering task. The deviation of back postural angle increases as load increases. Novice exhibits higher back postural angles compared to worker. The result reveals that the optimum working posture is at neutral trunk posture with the lowest energy expenditure in which the deviation of trunk flexion angles fall within a range of 0° and 20° from the sagittal plane.

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ABSTRAK

Pengendalian barang secara manual (MMH) telah diakui sebagai salah satu sumber utama kepada masalah muskuloskeletal yang berkaitan dengan pekerjaan (WMSD) dalam industri pembuatan. Tugas MMH biasanya dilakukan di stesen kerja Computer Numerical Control (CNC). Di stesen kerja ini, pekerja bertindak sebagai pemindah barang dalam proses memuat dan memunggah produk dari palet ke mesin. Interaksi fizikal pekerja dengan mesin adalah bukan pilihan sendiri dan pekerja terpaksa mengikut rentak mesin CNC yang sedang berjalan. Situasi paling teruk berlaku apabila pekerja diminta untuk mengendalikan lebih dari satu mesin secara serentak. Ketidakserasian Interaksi antara pekerja dan mesin mendedahkan pekerja kepada postur kerja yang janggal yang membawa kepada risiko WMSD yang tinggi. Sehingga kini, kajian terhadap MMH di stesen kerja CNC masih tidak mencukupi. Oleh itu, kajian ini bertujuan untuk menentukan kelaziman WMSD di kalangan pekerja MMH di stesen kerja CNC, dan untuk mengetahui hubungkait antara beban dengan jumlah penggunaan tenaga dan sudut postur tulang belakang. Kaedah yang digunakan dalam kajian ini merangkumi kaji selidik di industri dan beberapa siri eksperimen. Sebanyak 113 pekerja dari industri pembuatan mengambil bahagian dalam kaji selidik sementara sebanyak 14 pekerja dan 14 orang biasa telah mengambil bahagian dalam eksperimen. Hasil kaji selidik industri menunjukkan bahawa sebanyak 78.8% pekerja mengalami gejala WMSD di bahagian anggota badan mereka. Kekerapan WMSD yang paling tinggi berlaku di bahagian bawah tulang belakang iaitu 85.8%. Faktor-faktor penting yang berkaitan dengan WMSD adalah membongkokkan badan sedikit ke hadapan dengan tangan di atas paras lutut, memusingkan badan (lebih dari 45 °) sambil melenturkan badan ke sisi dan mengangkat objek kurang dari 3kg. Hasil eksperimen menunjukkan bahawa jumlah penggunaan tenaga maksimum diperolehi ketika pelatih (membongkok: 4.32kkal / min;

mencangkung: 4.95kkal / min) dan pekerja (membongkok: 3.64kkal / min; mencangkung: 4.39 kkal / min) melakukan tugasan mengangkat beban 3 kg . Pelatih menghasilkan 23.73% dan 16.53% jumlah penggunaan tenaga lebih tinggi berbanding pekerja semasa melakukan tugas mengangkat beban 1kg dalam keadaan membongkok dan mencangkung. Pelatih juga menghasilkan 15.74% dan 11.31% jumlah penggunaan tenaga lebih tinggi untuk tugas mengangkat beban 3kg dalam postur membongkok dan mencangkung. Beban didapati berkorelasi positif dengan jumlah penggunaan tenaga bagi kedua-dua subjek bagi kedua-dua postur badan. Beban juga mempunyai korelasi yang positif dengan sudut bengkokan postur tulang belakang dalam kebanyakan tugasan manakala berkorelasi negatif dengan sudut pusingan postur tulang belakang. Sudut postur belakang yang berkorelasi tinggi dengan beban berlaku pada Tugasan 10 yang merujuk kepada tugas menurunkan beban. Sudut sisihan postur belakang meningkat apabila beban meningkat. Pelatih menunjukkan sudut postur belakang yang lebih tinggi berbanding pekerja. Hasil dapatan kajian menunjukkan bahawa postur kerja yang optimum adalah pada postur belakang dalam keadaan asal dengan jumlah penggunaan tenaga terendah di mana sudut sisihan lenturan tulang belakang berada dalam lingkungan sudut 0 ° dan 20 ° dari satah sagital.

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ACKNOWLEDGEMENTS

First of all, all praises belong to Allah S.W.T for giving me strength to complete this research study.

I would like to express my sincere gratitude to my supervisor, Associate Prof. Ir. Dr. Siti Zawiah Md. Dawal for her guidance, patience and ongoing support throughout my study to make this research study success. Without her excellent guidance throughout this study, I may not succeed in this research.

I also wish to extend my warmest appreciation to Associate Prof. Dr. Junedah Sanusi, anatomist from Department of Anatomy, Faculty of Medicine, University of Malaya for her guidance and assistance on back spine anatomy. I am also indebted to the technical and administrative staff in Department of Mechanical Engineering, University of Malaya, for their support throughout the data collection process.

Cordial thanks to my colleagues in ergonomic research group, Kak Nazlin, Kak Izzah, Akmal, Kak Nadya, Kak Mirta, Kak Syida, Atiqah, Syahirah, for their friendship, valuable ideas and simultaneous encouragement throughout my study. They have truly made my studies a pleasurable experience which I shall never forget.

I deeply thanks to my dearest husband, Hamdi Ismail who is always patient throughout my struggle, comforting me when I am in difficulties, giving me continuous support when I am down, cheering me up when I am depressed, very understanding in me in all my conditions. And to my beloved son and daughter, Ahmad Muaz and Nur 'Aisyah. I love you both. I dedicate this dissertation to them with all my love. Last but not least, I would like to express my deepest gratitude to my beloved parents, Mrs Maznah Embong, my mother in law, Zainuyyah Othman, as well as my family for their endless love and prayers. Thank you all.

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LIST OF SYMBOLS AND ABBREVIATIONS

AI	:	Automated inspection
AMHS	:	Automated materials handling systems
AMT	:	Advanced Manufacturing Technology
AP	:	Automated packaging
AS	:	Automated storage
BLS	:	Bureau of Labor Statistics
CAD	:	Computer Aided Design
CAM	:	Computer-aided manufacturing
CMDQ	:	Cornell Musculoskeletal Discomfort Questionnaire
CNC	:	Computer Numerical Control
CP	:	Control Panel
ECG	:	Electrocardiography
EMG	:	Electromyography
FMS	:	Flexible manufacturing systems
GDP	:	Gross domestic product
GT	:	Group technology
LAN	:	Local area network
MMH	:	Manual Material Handling
MSD	:	Musculoskeletal Discomfort
NC	:	Numerical Control
RFQ	:	Risk Factor Questionnaire
RPE	:	Rating perceived exertion
SOCSO	:	Social Security Organization
UMREC	:	University Malaya Research Ethics Committee

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VDT	:	Video Display Terminal
WAN	:	Wide area network
WMSDs	:	Work-related Musculoskeletal Disorders

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CHAPTER 1: INTRODUCTION

1.1 Background of Research

Manufacturing industry plays a major role in generating fast economic growth. To be competitive in manufacturing global market, Malaysian manufacturing industry strives to promote higher and superior production rates to cope with market demands. It cannot be denied that technology has significant relation to the productivity. As Malaysia move towards industrial revolution 4.0, adopting powerful technologies that is gearing towards superior quality, high productivity, high reliability and great flexibility is very crucial. By adopting advanced manufacturing technologies, these improvements can be realized (Dawal et al., 2015; Mital & Pennathur, 2004).

Advanced Manufacturing Technology (AMT) offers extensive benefits to manufacturing industry in enhancing quality, inventory control, customer lead times, machine usage and efficiency, staff efficiency and morale, customer image, flexibility, and labor costs (Körner et al., 2019; Mital & Pennathur, 2004). It acts as a vital role in enhancing the quality and flexibility of small and medium enterprises (SMEs) particularly manufacturing industry. Apprehending its benefit, AMT has been introduced and implemented in manufacturing industries in all over the world since 1980s in order to gain profits and competitive advantage (Dawal et al., 2015).

In Malaysia, 94.5% of AMT has been implemented in manufacturing sector (Teng & Seetharaman, 2003). The most common technologies which have been implemented in Malaysian manufacturing industries were CAD (86%), CNC (57%) and Robotics (57%) in anchor industries while CNC (73%), NC (45%) and Robotics (45%) in vendor industries (Noori, 1997). CNC machines are mainly the application of AMT which is

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being used in many countries. As being practiced in Japan, 2/3 of CNC machine which is being used in SMEs while in Malaysia, about 60% of CNC technology is implemented in manufacturing industry (Dawal et al., 2015).

Since the implementation of CNC is exponentially increased in our manufacturing industry, the interaction of human and machine becomes more of a concern. The mismatch between human and machine will endanger human to occupational disease such as work related musculoskeletal disorders (WMSDs). The growing issue of WMSDs in automated workplace injuries become greater attention. Furthermore, despite the technological advancement used in manufacturing industries, manual material handling still remains as an essential task in handling material especially at CNC workstation. Process at CNC machine usually involves a small and light parts. Human is still required to manually handle the assembling of light parts or performing loading and unloading process (Gallagher & Heberger, 2015). Holtermann et al., (2013) reported 1-7kg is considered as light load lifted.

MMH tasks are reported as a main cause of work-related musculoskeletal disorders (WMSDs) and continue affecting the lifestyle of industrial workers (Shamsudin et al., 2017; Zurada, 2012). In Malaysia, WMSDs recorded the first ranking occupational disease which accounted 61.6% of the total disease or injury with 10.3% of disease are caused by MMH tasks (SOCSO, 2018). The number of MMH injuries recorded has increased one quarter within three years which is 38.25% from 2014 to 2017.

Working at machine environment is considered as hazardous zone (Chinniah, 2015). The engagement of workers at machine workstation such as CNC possesses high risk to health and safety of workers and workers prone to get WMSDs (Chinniah, 2015). Bureau of Labor Statistics (BLS) recorded that the engagement of material handlers to equipment

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accounted over one-fourth of all fatal work injuries in 2015 (US Bureau of Labor Statistics, 2016).

Manual material handling (MMH) includes lifting, lowering, carrying, pulling and pushing. In performing these tasks, the workers are exposed to the posture of overreaching, trunk bending, trunk twisting, and other awkward postures due to workplace design. Over the time, these postures will result to fatigue at the cardiopulmonary (energy expenditure) and musculoskeletal systems (muscle fatigue) and lead to the WMSDs. WMSDs risks have been shown to have a significant correlation on perceived fatigue and energy expenditure (Li et al, 2009).

Awkward postures during manual material handling are well documented to have a strong predictor of the development of WMSDs particularly at the back (da Costa & Vieira, 2010; Deros et al., 2010; Hoy et al., 2010; Punnett et al., 1991; Waters, 2004). Other than posture, tasks parameter such as weight of load also has a significant degree of effect to WMSDs (Plamondon et al., 2012). Furthermore, weight of load is recorded to have more effect on external back loading variables (moments) (Plamondon et al., 2012). This shows that weight is considered as a vital element and to be prioritized in investigating MMH tasks.

Many past studies have confirmed that the engagement of workers to modern technology such as CNC accelerates to the increasing of the acute response of perceived fatigue, muscle fatigue and energy expenditure which rapidly develop WMSDs risk (Arellano et al., 2017; Imtiaz, 2012, 2014; Maldonado-macias et al., 2009; Muthukumar et al., 2012a, 2012b). Therefore, it is very important to control the acute responses during MMH tasks at CNC workstation in order to minimize the risk of WMSDs.

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Since the operation at CNC workstation consists of the combination between MMH tasks, operating display terminal and operating the control panel, it will cause different effects of the acute responses in terms of perceived fatigue, energy expenditure and back posture. Then, it will have different degree of effect towards WMSDs. However, to date, there is still lack of research investigating the back posture during MMH task at CNC workstation. Since the MMH and CNC are always interconnected to each other, a study on this area is very crucial. The aim of this study is to investigate back postural angles in MMH tasks at CNC workstation. The findings of this study will be relevant to identify the optimum back posture during MMH task at CNC workstation which will reduce static loads and sustain the workers' performance.

1.2 Problem Statement

Manufacturing industry has the highest rate of accidents compared to other industry. It is reported by SOCSO that manufacturing industry shows the injuries compensation caused by occupational accidents and diseases (SOCSO, 2018). From the total of accidents reported, 10% of the accidents were caused by MMH (SOCSO, 2018). In Malaysia, the trend of MMH accidents had increased 38.25% from 2014 to 2017, with back as the highest accident reported (SOCSO, 2018) while in US, material moving occupation incurred 7% increment of fatal injuries in 2017 (Bureau of Labor Statistics, 2017). According to Plamondon et al., (2017) and Shojaei et al., (2016), MMH tasks have been regarded as the most stressful activities which contribute to WMSDs towards the exposed workers, and it becomes a major concern in manufacturing industries.

Working at CNC workstation requires workers to perform multiple tasks, where they are required to handle loads manually and operate control and display terminal concurrently. Tasks at CNC machine is not self-chosen. Therefore, workers are forced to

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keep performing the tasks with the running machine. Under this working condition, awkward posture such as overreaching, trunk twisting and trunk bending are commonly practiced. This mismatch between machine demand and task demand pose a greater risk of WMSDs. It is reported that fatal injuries related to workers who have engagement with machine have increased 5.04% from 2015 to 2016 (Bureau of Labor Statistics, 2017). This shows that this working environment is a risky zone to get WMSDs and lead to fatal injury. Therefore, the investigation on risk factors regarding to work posture particularly back posture among this working population is very crucial in reducing WMSDs. Furthermore, this issue was not highlighted in the previous research (Imtiaz, 2012; Muthukumar et al., 2012a; Muthukumar et al., 2012b). The safe working posture in handling parts and interaction with the machine needs to be investigated further as the aim of this study is to investigate the safe back working posture during loading and unloading tasks at CNC machine.

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1.3 Research Objectives

The objectives of this study are as follows:

1. To identify the prevalence of musculoskeletal symptoms on MMH worker at CNC workstation
2. To determine the relationship of loads and energy expenditure during loading and unloading tasks at CNC workstation
3. To determine the relationship of loads and back postural angle during loading and unloading tasks at CNC workstation

1.4 Scope and Limitation of Study

Scope and limitation of the study are:

(1) Age, gender, environment, and health condition were controlled in recruiting participants for this study.

(2) Weight of part used in this study is limited to 1 kg and 3 kg.

(3) The number of subjects involved in the experiment were 14 industrial workers and 14 novices.

1.5 Significant of Study

Poor back posture during MMH task at CNC workstation may cause back pain. A study on the back postural angles and energy expenditure in work-related tasks is crucial to determine the risky postures among manual material handler. The findings of this study are beneficial to aid the manual material handler in handling discomfort, pain and injury from continuous MMH tasks. Furthermore, the findings in this study can act as reference for engineer to design ergonomic workstation for CNC workers in improving workers' back posture in performing MMH tasks. Therefore, the bending, twisting and other awkward postures which affecting the workers' performance and working capabilities could be eliminated and this will be reduce the accumulation of stress and fatigue. The ergonomic workstation design will facilitate workers in executing MMH tasks in a more efficient and effective ways by adopting ideal back posture during working.

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1.6 Report Organization

This thesis consists five chapters and these chapters are explained as follows:

1. Chapter 1: Introduction

   This chapter contains the study background, explains the problem statements, scope of study and its limitation, purposes, and the report organization.

2. Chapter 2: Literature Review

   Literature reviews and basis of this study are written in this chapter. Initially, the discussed topic is about WMSDs issues in Malaysia. Then, it is followed by a brief explanation on CNC in terms of its implementation in Malaysian manufacturing industry. This chapter also highlighted previous research conducted on WMSDs issues at CNC workstation and its relationship with the posture. Then, this chapter highlights the back postural angle measurements which were conducted by past research.

3. Chapter 3: Methodology

   The explanation on the methods applied in this study is presented in this chapter. Methods involved are industrial survey and experimental tasks. Details of the experimental design including the criteria of the chosen participants, experimental set up, measurements tools are explained.

4. Chapter 4: Results and Discussion

   The analysis and the main discoveries are explained in this section. Thorough discussion on the findings is also provided in this chapter.

5. Chapter 5: Conclusion and Recommendations

   This chapter contains the description on the overall research and suggestions for future studies.

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CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter discusses about manual material handling tasks and work-related musculoskeletal disorders. This chapter contains several sections which covers on the background of automotive manufacturing industries in Malaysia, the implementation of CNC in manufacturing industry, the musculoskeletal disorder issues related to MMH task, factors associated to WMSDs, energy expenditure and back postural angles during MMH task. Finally, the summary of this chapter is presented at the end of this chapter.

2.2 Manufacturing Industry in Malaysia

Manufacturing sector is the main contributor to Malaysia's economic growth and gross domestic product (GDP). It has been considered as the engine for the economic development since it creates goods and services and serves as a major employment generator. According to Teh et al., (2019) and Khan & Khalique (2014), Malaysian manufacturing industry which constitute small medium enterprises (SME) forms the largest in Malaysia's economy establishment which constitute 98.5% of business community in Malaysia. As reported by SME Corporation (2018), the real GDP growth has consistently outperformed the overall economy with the average annual growth rate at 6.6% compared to 5.2% for the overall growth of GDP in the period of 2011-2017. In Malaysia, SMEs represent 84% of the manufacturing sector (Dawal et al., 2015).

It is inevitable that high production rate in manufacturing is always connected to workers' performance. It becomes a key element in sustaining the productivity. Employment rate at SME has increased to 66.0% of total employment with a growth of

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3.4% compared to 2.1% in 2016 and results to 3.7% of the productivity improvement (Teh et al., 2019). Specifically in the automotive industry, the employment rate has increased by 9.82% of workers in motor vehicles and 20.31% of workers in parts and components compared to 2011 (Department of Statistics, 2017). The employment rate is expected to be increase in the upcoming years and this will affect productivity if their health is not well preserved.

2.3 Implementation of Computer Numerical Control (CNC) in Malaysia

Technology plays a vital element in manufacturing industry to increase the productivity and directly makes economy to be globally competitive. As moving towards industrial revolution 4.0, adopting modern technologies in manufacturing industry such as advanced manufacturing technology (AMT) is expanded nowadays. A few of advanced manufacturing technologies can be implemented in the production line such as computer-aided design (CAD), computer-aided manufacturing (CAM), computer numerical control (CNC), local area network (LAN), robotics (R), flexible manufacturing systems (FMS), automated materials handling systems (AMHS), automated inspection (AI), automated packaging (AP), wide area network (WAN), and automated storage (AS) technologies.

Computer Numerical Controlled (CNC) is a stand-alone technology which is mostly implemented in manufacturing industry (Shneor, 2018; Laosirihongthong et al., 2003). It is reported that CNC is the main type of implemented AMT and being used in manufacturing industry in over 18 countries (Sun, 2000). 2/3 of the CNC machine was being used in manufacturing industry in Japan (Rosnah et al., 2004). CNC also has widely used in Malaysian automotive manufacturing industry (Laosirihongthong et al., 2003). Among 16 automotive industries in Malaysia, 60% of industries have implemented CNC technology (Dawal et al., 2015).

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2.4 Computer Numerical Control and Work related Musculoskeletal Disorders

The usage of CNC in manufacturing industry improves quality, reliability and flexibility (Dawal et al., 2015; Mital & Pennathur, 2004). With the extensive of its application in our manufacturing industry, the implication of this technology towards human is of a concern. It can't be denied that the rapid and widespread application of the CNC is accompanied with a proportionate increase in occupational disease such as WMSDs (Imtiaz, 2012).

Chinniah (2015) reported that the engagement of workers at machine workstation such as CNC poses high risk to health and safety of worker and worker is prone to get WMSDs. Many studies have addressed this issue previously. Table 2.1 summarizes the previous studies and their findings.

Table 2.1: Studies on WMSDs issue at CNC machine

Author (year)	Objectives	Methodology	Findings
Imtiaz, (2014)	Effect of gender in the HCMI environment (panel's height, panel's angle and working distance)	Experimental	females (age: 19–23) have minimum MSDs in 90 cm of CNC machine panel height, panel angles 60 and 90 degrees, followed by 110 cm and 130 cm of panel heights.
Krishnamoorthy et al., (2014)	Investigation on frequency, intensity of discomfort and interference on the level of discomfort at VDT	Questionnaire survey by Cornell Musculoskeletal Discomfort Questionnaire (CMDQ)	The most reported body region had pain is lower back, neck, upper back, shoulder and leg.

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Table 2.1: Continued

Author (year)	Objectives	Methodology	Findings
Muthukumar et al., (2012)	Investigation on postural discomfort and its relationship to display and control panels' height	Questionnaire survey by Corlett and Bishop's body part discomfort	The highest body part experiencing discomfort is lower back, neck, upper-back, shoulder and arm. Neck discomfort is due to the machine display. Shoulder and arm discomfort were caused by panel controller.
Imtiaz (2012)	Investigation on angle abduction of display and control unit among CNC operators	Job analysis, observation and interview	Angle of abduction and viewing has significant effect on CNC machine operators.
Imtiaz & Asghar (2010)	Investigation on the effect of the angle of abduction in a CNC-EDM interaction environment	Experimental	Angle of abduction significantly affects the operator's performance in a CNC-EDM inter-action environment. 45° abduction angle gives the optimal performance as far as a human–machine interaction environment
Maldonado-Macias et al., (2009)	Apply anthropometric and ergonomics principles in CNC workstation.	Body map, Video Recording, Rapid Entire Body Assessment (REBA)	Trunk is the most affected body part, followed by legs.
Vieira & Kumar (2007)	Investigation on the perceived occupational risk factors and cause of WLBD among CNC workers and welders	Questionnaire survey (Borg's scale and visual analogue scale).	Highest discomfort occurred at lower back Repetitions and duration contributed more to the total effort than postures, movements, and force for CNC workers.

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Table 2.1: Continued

Author (year)	Objectives	Methodology	Findings
Arellano et al., (2017)	To identify the workload, fatigue, and WMSDs and to explore the relationship between workload and fatigue among CNC lathe operators	Survey (NASA-TLX), Swedish Occupational Fatigue Inventory (SOFI) and the Occupational Fatigue Exhaustion Recovery (OFER) scales.	Positive correlations were found among workload items, dimensions/states of fatigue, and musculoskeletal discomfort.

Based on previous studies, it is proved that working at CNC workstation exposes workers to a high risk of having WMSDs. Working at CNC which includes operating video display terminal (VDT) and control panel severely affecting upper limb region particularly at trunk, shoulder and neck. From these studies, survey was used as a useful and essential method in determining the prevalence of musculoskeletal discomfort among workers population at CNC workstation.

Tasks at CNC are not limited to operating VDT and control panel only, but there are also other tasks such as manual material handling (MMH). These includes loading, unloading, transferring, holding, carrying, lifting and lowering. In details, workers at CNC work as material transfer to perform the activity of loading part to machine, unloading part from machine, inspecting and sorting and at the same time, they are required to operate the control panel. For example, workers are struggling to complete MMH tasks and at the same time operating control terminal based on the cycle setting at the CNC machine. The situation is getting worse when they are operating the running machine more than one machine concurrently. If this condition continues in the prolonged time, the workers are highly exposed to the high risk of having WMSDs.

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Both of these activities which are MMH and operating control panel give different degree of effect toward musculoskeletal discomfort. Combination of these activities expose workers to the high risk of the musculoskeletal discomfort compared to an activity itself since it adds more strain and stress to the muscles. Therefore, it is important to note that study on a whole activity at CNC workstation is very crucial since it has not been addressed in the past research.

2.5 Manual Material Handling and Work related Musculoskeletal Disorders

Despite the increase of technology advancement implemented in manufacturing industry, MMH continues to be a vital role in completing a task (Dempsey, 1998; Rajesh, 2016). Manual material handling (MMH) is the common practice tasks at automotive manufacturing industry. According to Deros et al., (2015) and Li et al., (2009), MMH tasks refer to the transporting or supporting a load from one place to another through lifting, lowering, pushing or carrying in a work setting. Most of the handled objects are in different sizes, weight and shape, and thus impose the workers to adopt poor body postures such as trunk twisting, trunk bending and awkward posture. The extreme physical demands on workers under these working conditions in a prolonged time have proven to be the main cause of work-related musculoskeletal disorder (WMSD) (Ferguson et al., 2012).

MMH is a trigger of work related musculoskeletal disorder which affecting many working populations in many countries (Shojaei et al., 2016; Waters, 2004). In US, manual material handler or material movers incurred the highest number of MSD cases with 27% from the total of injuries reported in 2014 (Bureau of Labor Statistics, 2015) and accounted for more than one-quarter of all work-related fatalities in 2016 (Bureau of Labor Statistics, 2017). Similar trend of MMH injuries is also recorded in Malaysia which

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is increasing over the year. From 2014 until 2017, the number of MMH injuries have increased about 38.27%. Details of the injuries for each year is shown in the Figure 2.1.

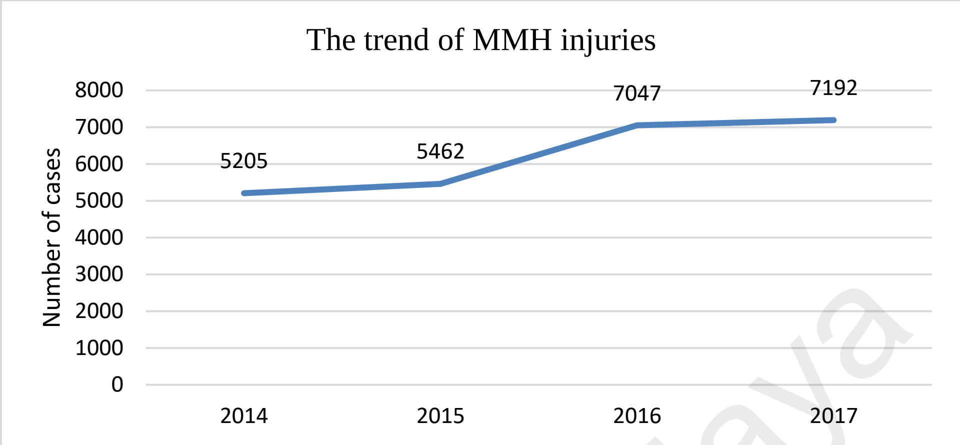

Figure 2.1:The trend of MMH injuries in Malaysia (SOCSO, 2018)

Several epidemiological studies have proven that MMH has a strong predictor to the development of low back disorder (Shojaei et al., 2016; Deros et al., 2015; Hoy et al., 2010; Hoozemans et al., 2008). Besides, back, knee and hip musculoskeletal disorders mainly happened due to MMH task (da Costa & Vieira, 2010). All of these musculoskeletal disorders of body regions were occurred due to MMH activity and resulting to the muscle fatigue. Based on the level of severity, severe pain may affect workers and stop workers from continuing their work.

Muthukumar et al., (2012a) stated that the occurrence of musculoskeletal disorders at shoulder and neck was due to the awkward postures adopted by workers in performing MMH task at CNC workstation. Awkward postures such as bending, twisting, vibration exposure and forceful movements are the major risk factors for lower back, neck and knee work related musculoskeletal disorders (Punnett et al., 1991; Vieira & Kumar, 2007). Low back injury occurs when the interaction between tissue strains and dynamic spinal loads exceeds the spine tolerance (Marras, 2000). When this happened, worker will be

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exposed to the high risk of low back musculoskeletal disorder. Previous studies also have demonstrated evidence that low back musculoskeletal disorders and workload are related to each other (Kuijer et al., 2014; Van Der Molen et al., 2008; Hansson et al., 2006).

2.6 Energy Expenditure and Manual Material Handling

Energy expenditure is always interrelated to the amount of physical activity (Lustrek et al., 2012). The total of energy consumption during physical activities such as MMH can be measured through energy expenditure. Through this physiological measurement, the physical burdens and capabilities of worker performing MMH tasks can be evaluated (Li et al., 2009). Hence, this can ensure that the assigned MMH task will not induce fatigue and will reduce the risk of WMSDs.

Energy expenditure during MMH tasks is associated with oxygen uptake and heart rate. In performing MMH tasks, the muscle exertion require oxygen to move. As the physical activities increased, the metabolic demand of the muscles also increased. In other word, muscles need more oxygen to continue the task. This will give a signal to the cardiopulmonary system which is heart to pump oxygen and supply enough oxygen to the working muscles. This shows that oxygen consumption is linearly increases with heart rate (Chaves et al., 2015).

The energy expenditure is often expressed in terms of kilocalories per minute (kcal/min). There is various equipment which can be used to measure energy expenditure and the most commonly used is Actiheart monitoring device. Actiheart is the first commercially available device which combines a heart rate monitor and accelerometer into a single unit (Crouter et al., 2008) and the reliability of this monitoring device has been validated in past studies (Barreira et al., 2009; Crouter et al., 2008).

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Numerous physiological researches have been carried out to determine the energy expenditure in relation to MMH tasks and the main findings of the research are presented in Table 2.2.

Table 2.2: Previous researches on energy expenditure

Researcher(s)	Objective(s)	Methodology	No. of Subjects	Main Findings
Li et al., (2009)	To investigate the physiological and perceptual responses among male Chinese worker performing multiple manual material handling tasks	**Tasks:** Lifting and lowering height combinations included: F–F, F–K, K–F, and K–K at frequency once, twice per minute. **Load:** 23kg **Equipment:** Oxygen uptake, heart rate and ratings of perceived exertion (RPE)	8 male construction workers	The oxygen uptake, heart rate and RPE were higher at frequency twice per minute than once per minute. The oxygen uptake, heart rate and RPE were higher in lifting (F-K) than lowering (K-F) The difference between actual (4.3±1.3 kcal/ min) and predicted energy expenditure (4.2±1.1 kcal/min) is not statistically significant.
(Lim et al., 2011)	To evaluate the effects of shoulder and back flexion angles on upper-limb muscle activity, perceived discomfort as well as heart rate	Workers perform different shoulder and back flexion angles **Equipment:** Discomfort ratings, heart rates and EMG	20 workers	There is an increase in muscle activity, heart rate and perceived discomfort with the increase in back and shoulder angles.
Plamondon et al., (2014)	To evaluate the effect of box height and distance on back loading during MMH task	**Task:** Workers perform MMH tasks with self-paced and imposed-pace task (9 lifts/min). **Weight:** 25kg and 15 kg **Equipment:** Heart rate, Borg's Scale, EMG and 3D link segment model.	15 experts and 15 novices	Imposed-paced MMH task is higher in HR and overall physical fatigue and back muscle fatigue than self-paced task.

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Table 2.2: continued

Researcher(s)	Objective(s)	Methodology	No. of Subjects	Main Findings
Anton et al., (2005)	Compare the effect of LWBs to SWBs on specific muscle activity and energy expenditure	**Task:** Participants constructed two concrete block walls in a counterbalanced order, with high 1.42 m and 2.4m wide. **Weight:** 11.8 kg (Light weight block-LWB) and 16.3 kg (Standard weight block-SWB) **Equipment:** EMG and Heart rate	21 male workers	EMG amplitudes were slightly lower when masons were laying LWBs compared to SWBs. Upper back and forearm extensor, EMG amplitudes were greater for the higher wall courses for both block weights. There were no significant differences in heart rate between the two blocks. LWBs=103 beat/min, SWBs=105beat/min
Van Der Molen et al., (2008)	Investigate the effects of blocks' weight on work demands and physical workload during a full working day.	**Task:** Construction work (Line block, positioning, mortar application, block laying, finishing. **Weight:** 11 kg, 14 kg or 16 kg. **Equipment:** Heart Rate Portable Analyzer	**Subject:** 13 masons	Block weight had no effect on energetic workload and cumulative spinal load over a full work day (repetition is low (<2 lift/min)).

Different work exposure and workplace setting result to difference of energy expenditure. Poor workplace design in working environment will influence the level of energy expenditure and will affect the work performance of worker. Sengupta & Das, (2004) showed that workers who performed task in extreme workspace reach envelope recorded the higher oxygen uptake and heart rate as compared to normal. The effect of an awkward posture towards energy expenditure also has been investigated by Lim et al., (2011). The effect of energy expenditure toward different shoulder and back flexion angles were examined by measuring the oxygen consumption and heart rate. The results revealed that energy expenditure increased as the shoulder and back flexion angles increased. The energy expenditure also was discovered to be increased when the tasks were carried out beyond the workers' limitations.

Anton et al., (2005) investigated the effect of load to energy expenditure among construction workers. Two weights of loads had been investigated which were 11.8 kg (considered as a light load) and 16.3kg (considered as a standard load). The result showed that light load recorded lower heart rate compared to standard load which means the decreasing of load results to decreasing of energy expenditure.

Van Der Molen et al., (2008) investigated the effect of block weight on work demands and physical workload during masonry work. The main objective of this study was to establish the effects of different block weights (11, 14 and 16 kg) on work demands and physical workload during a full workday. They found that block weight did not have any impact on the work demand and the energetic workload. The finding was contradicted with Looze et al., (1994) who found that block weight had a positive effect on energetic workload. The differences might be due to the difference of level in the investigation either for activity level or task level. Task level was regarded as a less stressful activity such as standing or walking without load and then followed by more stressful activity of lifting blocks. This would lead to the calculation of average heart rate at task level lower than activity level.

Maiti & Ray, (2004) investigated 48 different modes of lifting among building construction activities by considering vertical lifting distance (knee, waist, shoulder and

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maximum reach height), lifting frequency (1, 4, 7 and 14 lifts/min) and load weight (5, 10 and 15 kg) to develop an equation in estimating a maximum load limit for lifting based on physiological criteria. The result showed by using the equation suggested the maximum load limit calculated was 15.4kg.

Yusuff et al., (2016) studied the energy expenditure in different lifting techniques among Malaysian population by measuring their heart rate. The result revealed that energy expenditure is linearly related to the height of lifting, weight of load lifted, frequency of lifting and angle of twisting with the squatting posture which require more energy compared to stooping. The result also proved that the energy expenditure increased when the performed task exceeded the lifting capabilities of the respondents. Thus, these findings can be used as a guideline to design lifting tasks in squatting and stooping for the Malaysian population.

Different lifting techniques give different level of energy expenditure. Stooping was proven to consume less energy compared to squatting (Li et al., 2009; Welbergen et al., 1991) and considered as a more effective lifting technique in manual material handling since it reduced the change in potential energy of the material mover and less tiring. Straker (2003) has proved that stooping reduces 20–30% of energy expenditure compared to squatting.

Li et al., (2009) had studied the energy expenditure among the construction workers in China by measuring their oxygen uptake and heart rate under 1 lift/minute and 2 lifts/minute using 23kg of load. The result reveals that energy expenditure increased when the frequency of tasks increased. The result also found that lifting heavy loads at slower pace is physically less taxing to the worker compared to lifting light loads at faster pace. Lifting light load in a faster frequency or pace may increase energy expenditure and spinal compression (De Looze et al., 1996).

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The results of past researches show that energy expenditure was influenced by the weight of load, working posture, frequency of load and height of lifting. Previous studies provide the information of workers' capability under various of work exposure throughout energy expenditure. Therefore, in designing task, this physiological measurement is vital in reducing stress on physical capabilities of workers to reduce the risk of WMSD.

2.7 Back Posture and Manual Material Handling

Working posture can be defined as the orientation of body parts in space and in relation to each other while an operator performs a task (Elbert et al., 2018). An awkward working posture such as awkward in back posture while performing a task can be caused by the interaction of several factors including poor workstation layout and incorrect working methods such as twisting the spine during a manual lifting and transfer operations.

Research regarding the back posture has been done by many past researchers. The location of spinal segments and gravity point are referring to the back posture. Different types of standing position can be differentiated through back posture. Keyserling (1986) studied the variety of standing posture among automobile assembler and classified the standing posture in several categories, as shown in Figure 2.2.

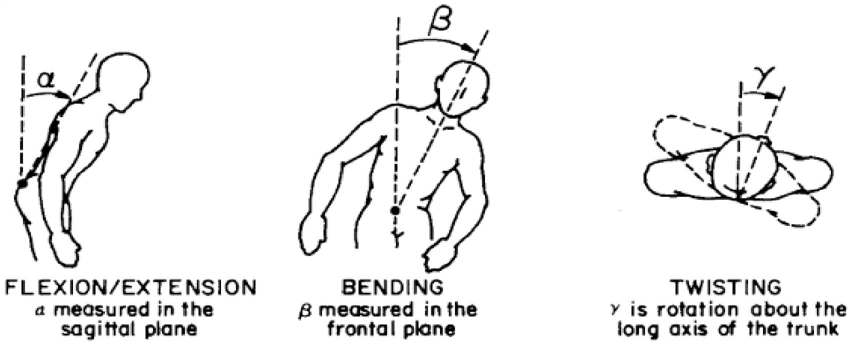

Figure 2.2: Standard classification for the trunk (Keyserling, 1986)

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Trunk is considered in the neutral condition when the trunk is within 20° of vertical with less than 20° of twisting. The deviation of the trunk from its neutral position will occur if it is extended (bent backward), flexed (bent forward), bent sideways, or twisted more than 20° from the vertical and forward-facing condition and hyperflexion (forward bending of more than 45°). The trunk is regarded to deviate from the neutral upright posture of a standing worker and the risk of injury will be increased if the trunk is extended, flexed, bent, or twisted more than 20° (Keyserling et al., 1988). The explanation of trunk angle categories is summarized in Table 2.3. These trunk angle classifications are being used Plamondon et al., (2010).

Table 2.3: Trunk angle categories

Angle range	Posture
$\theta < -20°$	Trunk in extension
$20° \leq \theta \leq 45°$	Trunk in mild flexion
$0° < \theta < 20°$	Trunk in neutral posture
$\theta > 45°$	Trunk in severe flexion
$\theta > 20°$	Trunk twisted/ bend laterally

There are numerous studies of back posture associated to manual material handling. Several factors influencing the back postural angles have been highlighted including load (Plamondon et al., 2012), posture (Ulrey & Fathallah, 2013), frequency (Li et al., 2009), expertise (Riley et al., 2015; Lee et al., 2014; Plamondon et al., 2014; Plamondon et al., 2010) and sex (Plamondon et al., 2017; Plamondon et al., 2014). Table 2.4 below presents the past research on back posture in manual material handling.

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Table 2.4: Past research on back posture

Researcher(s)	Objective(s)	Methodology	Main Findings
Plamondon et al. (2012)	To determine the effect size of working experience, lifting height and weight lifted in manual material handling	*Subject:* 15 workers and 15 novices *Equipment:* Dynamic 3-D linked segment model *Task:* Transferring a series of boxes from a conveyor to a hand trolley.	Lifting height and weight lifted had more effect size than expertise on external back loading variables (moments) Working experience factor showed a significant effect of posture variables on the lumbar spine and knees.
Ulrey & Fathallah, (2013)	To determine the effect of a weight transfer device on muscle activities and joint flexions in the stoop posture.	*Subject:* 11 male and 7 females *Equipment:* EMG, inclinometers and electrogoniometers *Task:* Perform manual material handling in a stoop posture for 0.0, 4.54, and 9.07 kg	Lumbar flexion was significantly reduced when wearing transfer device. Increased load resulted to increased muscle activation in some sections of the torso. Males had 44% more lower lumbar flexion than females while females had 25% more hip flexion than males
Plamondon et al., (2010)	To verify the safer and more efficient method by expert handlers than by novice handlers	*Subject:* 15 workers and 15 novices *Equipment:* Dynamic 3-D linked segment model Two photogrammetric measuring systems *Task:* Transfer four boxes (24 15-kg boxes) from a conveyor to a hand trolley at self-determined pace and an imposed pace of 9 lifts/min	Lifting phase: Upper Trunk= (Experts = 62° vs. novices = 76°) Lumbar flexion = (experts 54° vs. novices =66°; Lowering phase: Upper Trunk= (Experts = 39° vs. novices = 51°) Lumbar flexion = (experts 31° vs. novices =45°; Expert bent their knees more (experts: 72°; novices: 53°)

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Table 2.4: Continued

Researcher(s)	Objective(s)	Methodology	Main Findings
Lee et al., (2014)	To assess the torso kinematics and during repetitive lifts/lowers under different task configurations (symmetric vs. asymmetric and lift vs. lower).	*Subject:* 6 workers and 6 novices *Equipment:* Dynamic 3-D linked segment model Two photogrammetric measuring systems *Task:* Lifting 7.3 kg and 7.1 kg 0°sagittally symmetric vs. 60° asymmetric with 10 lift/min (lift/lower)	Lumbar angles were higher among experienced workers than novices. Experienced workers used 7° more torso flexion. Twisting angles were larger among experienced workers during symmetric conditions
Plamondon et al., (2014)	Verify whether multiple box transfers leading to fatigue would also lead to differences between expert and novice in joint motions and back loading variables (L5/S1 moments). To evaluate the effect of box height and distance on back loading during the repetitive depalletizing-palletizing task.	*Subject:* 15 workers and 15 novices *Equipment:* Heart rate, EMG and 3D link segment model. *Task:* Transfer four boxes (24 15-kg boxes) from a conveyor to a hand trolley at self-determined pace and an imposed pace of 9 lifts/min	Lifting phase: Trunk= (Experts = 36° vs. novices = 46°) Lumbar flexion = (experts 29° vs. novices =39°; Lowering phase: Trunk= (Experts = 32° vs. novices = 39°) Lumbar flexion = (experts 24° vs. novices =33°; Experts bent their lumbar spine less (10° less) and were closer (4 cm) to the box than novice workers. Knee flexions were similar in both groups except when the box was lifted from ground level (expert =71°, novice = 48°).
Hagen & Harms-Ringdahl, (1995)	To examine the influence of weight/ frequency combinations on thigh and lower-trunk movements during sagittal symmetric repetitive lifting employing squat and stoop techniques.	*Subject:* 10 experienced male forest *Equipment:* Electrolytic liquid level sensors *Task:* Perform sagittal symmetric lowering and lifting box at different weight/frequency combination (1/20, 8.5/10, 8.5/20, 17/10 and 17/20)	Weight or frequency did not influence the motion range in stoop lifting. In squat lifting, the thigh motion range was significantly smaller at lifting frequency of 20 lifts/min than at a frequency of 10.

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Table 2.4: Continued

Researcher(s)	Objective(s)	Methodology	Main Findings
Nogueira et al., 2018)	To evaluate the level of handling task exposure to the upper body in the real setting.	*Subject:* 13 male workers *Equipment:* Electromyography and inclinometer *Task:* Performed three tasks of material handling level - Handling - No handling - Non vigorous task	Manual box handling presented higher biomechanical demands to the upper body particularly on upper back forward flexion postures. Decreasing loads in handling tasks can be relevant to decrease peak loads and avoid ULWMSds
Shojaei et al., (2016)	To investigate age-related differences on lower-back biomechanics in sagittally-symmetric simulated manual material handling tasks.	*Subject:* 60 participants with five equal-sized and gender-balanced age groups spanning 20-70 years *Equipment:* wireless Inertial Measurement Units *Task:* Lowering a 4.5 kg load from an upright standing posture to both knee height and a fixed height and then lifting the load back to the initial upright posture.	Older participants had larger pelvic rotation and smaller lumbar flexion. The elderly had high risk for developing lower back pain.
Harari et al., 2020)	To investigate the biomechanical loads and kinematics of workers during multiple-task manual material handling (MMH) jobs	*Subject:* 20 subjects *Equipment:* Motion-capture *Task:* Performing 8 hours of continuous sequence in removing, carrying and depositing boxes with different weight (2, 5, 8, or, in the case of males, 12 kg)	The origin/destination height was the most influencing predictor of the spinal and shoulder moments and the peak trunk, shoulder and knee angles. The relationship between the origin/destination heights and the above parameters was nonlinear. The mass of the box, and the subject's height and mass also influenced the spinal and shoulder moments.

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The past research has proven that the deviation of back postural angles is proportionally increased with load. Ulrey & Fathallah, (2013) investigated the deviation of back postural angles toward load. The measurement was taken for trunk flexion (T3 to T12), lumbar flexion (T12 to S1), upper lumbar flexion (T12 to L3), lower lumbar flexion (L3–S1), hip flexion, knee flexion/extension and ankle dorsi-flexion/plantar-flexion. Three different weight of loads were investigated consisting of 0kg, 4.54kg and 9.04kg. The increasing of load increases the deviation angle at the trunk. The result also found that males had 44% more lower lumbar flexion than females while females had 25% more hip flexion than males.

Plamondon et al., (2010) suggested that load is an important characteristic that needs to be prioritized to minimize the back loading. Three important characteristics have been highlighted which are height (from the ground and 32 cm), expertise (novice and expert) and load (15 kg and 25kg). Results revealed that back loading was increased when the weight of load lifted increased. The trunk was found to be more vertical and more to the neutral axis while knee was found to have more flexion as weight of load lifted increased. The trunk inclination angle was found to be less for experts compared to novice.

From the previous study, it can be concluded that the deviation of back postural angles increased when there were increment of weight of load lifted. Nevertheless, the effect of light load toward back posture particularly on the trunk deviation angle is still lacking in terms of research and this issue remains unclear especially when worker performs MMH task. Therefore, better comprehension on the effect of light load toward back posture in performing MMH tasks is important.

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2.7.1 Back posture measurement

Back posture can be measured in various methods by using different equipment. The various of back posture measurements have been determined and analyzed for the comparison purposes. The description of the equipment, methodology and findings in past research are summarized in Table 2.5.

Table 2.5: Methods used in Back Posture Measurement

Author	Methodology	Equipment	Main Findings
Hansson et al. (2006)	Devices were attached at T3, T12, L3 and S1	Inclinometer	Thoracic angle during flexion: 14°
Lee & Nussbaum (2013)	Devices were placed on C7 and T10	Dynamic 3-D linked segment model Two photogrammetric measuring systems	Lumbar angle for symmetric: Lifting (expert=38.6°, novice=31.3°), deposit (40.5°,32.9°) Lumbar angle for asymmetric: Lifting (expert=38.5°, novice=32.3°), deposit (40.6°,34.0°)
Plamondon et al. (2010)	Device were attached at the back at C7 (1); T12 (1) and S1 (1)	3D link segment model	Lumbar flexion angle (expert:54°, novice 66°) Upper trunk flexion angle (expert=62°, novice=76°)
Plamondon et al. (2014)	Device were attached at the back at C7 (1); T12 (1) and S1 (1); both arms (2)	3D link segment model	Lifting lumbar flexion angle=expert 29°, novice 39° Trunk inclination =expert 36°, novice 46° Lumbar flexion angle=expert 24°, novice 33° Trunk inclination =expert 32°, novice 39°

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Table 2.5: Continued

Author	Methodology	Equipment	Main Findings
Riley et al. (2015)	Sensors were placed on the T10 and S1	Electromagnetic sensors	Novice group maintained a much more kyphotic lumbar angle for both the flexion (74% of the lumbar angle ROM) and extension phases (86% of the lumbar angle ROM) of the lifting cycle
Zare et al., (2017)	Sensors were placed on right and left arms, L3, C7 and T1	Inclinometer and self-reported questionnaire	Self-reported questionnaire and direct measurement showed more accurate measurement for assessing posture.

Based on Table 2.5, many methods have been used in the past research to measure back posture including observing, evaluations through inclinometers and dynamic 3-D linked segment model. Nevertheless, various methodology implemented for back posture measurement result to diversity in the findings. Skin surface tracking is an effective equipment in quantifying back posture measurement since it has been validated against radiography (Hansson et al., 2006). Inclinometer is among accurate equipment since it can provide depth and precise data on three trunk postural exposure metrics such as flexion/extension, lateral flexion and speed of trunk movement (Teschke et al., 2009) and it is still being used in manual material handling research recently (Nogueira et al., 2018; Zare et al., 2017). Inclinometer enables repeated posture recordings and it is the most cost-effective for spinal loading estimation compared to other measurement such as EMG (Trask et al., 2006). Combination of inclinometer and observation is suggested to be the ideal alternatives to provide depth and breadth of data on postures and other physical exposures for epidemiological research (Teschke et al., 2009).

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2.8 Summary of Literature Review

A comprehensive review on the significant literature pertaining to implementation of computer numerical control (CNC), work related musculoskeletal disorder related to manual material handling (MMH), energy expenditure and back posture evaluation has been explained in this chapter. There are numerous studies in investigating the issues related to MMH tasks. Past researches have proven that there is a strong correlation between MMH task and WMSDs. This shows that workers who work under extreme physical demand results in a higher energy expenditure and back posture deviation angle. This condition will expose workers to high risk of WMSDs. Evaluation of energy expenditure and back posture is a vital to design the MMH tasks in order to prevent workers from carrying out tasks beyond their capabilities. This will make sure that the assigned tasks do not cause negative effects on workers' health and reduce the risk of WMSDs development. Therefore, this study will investigate the effect of energy expenditure and back posture in performing MMH tasks at CNC workstation. Thus, the understanding on the relation of energy expenditure and back posture among CNC workers can be provided.

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CHAPTER 3: METHODOLOGY

3.1 Introduction

The methodology used in this study will be explained in depth in this chapter. The selected methods and the explanations behind the selection are explained in this chapter. This chapter includes the flow chart of research, the explanation on the criteria of subject's selection, the instrument used for measurement, the experimental design, the procedure of experimental tasks and data analysis as well as the statistical methods used in this study. At the end of this chapter, a summary of methodology is provided. It shall be highlighted that all the protocol and procedures employed in this study have been authorized by the University Malaya Research Ethics Committee (UMREC) (Appendix A).

Figure 3.1 shows the flowchart of this research. This research is conducted in two phases. The first phase is through industrial survey and the second phase is experimental. In the first phase, the industrial survey questionnaire will be distributed among manual material handling workers at CNC workstation. For the second phase, pilot test will be conducted before proceeding to the actual experiment.

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3.2 Flow of Research

The process of this study is summarized and presented in flow chart in Figure 3.1.

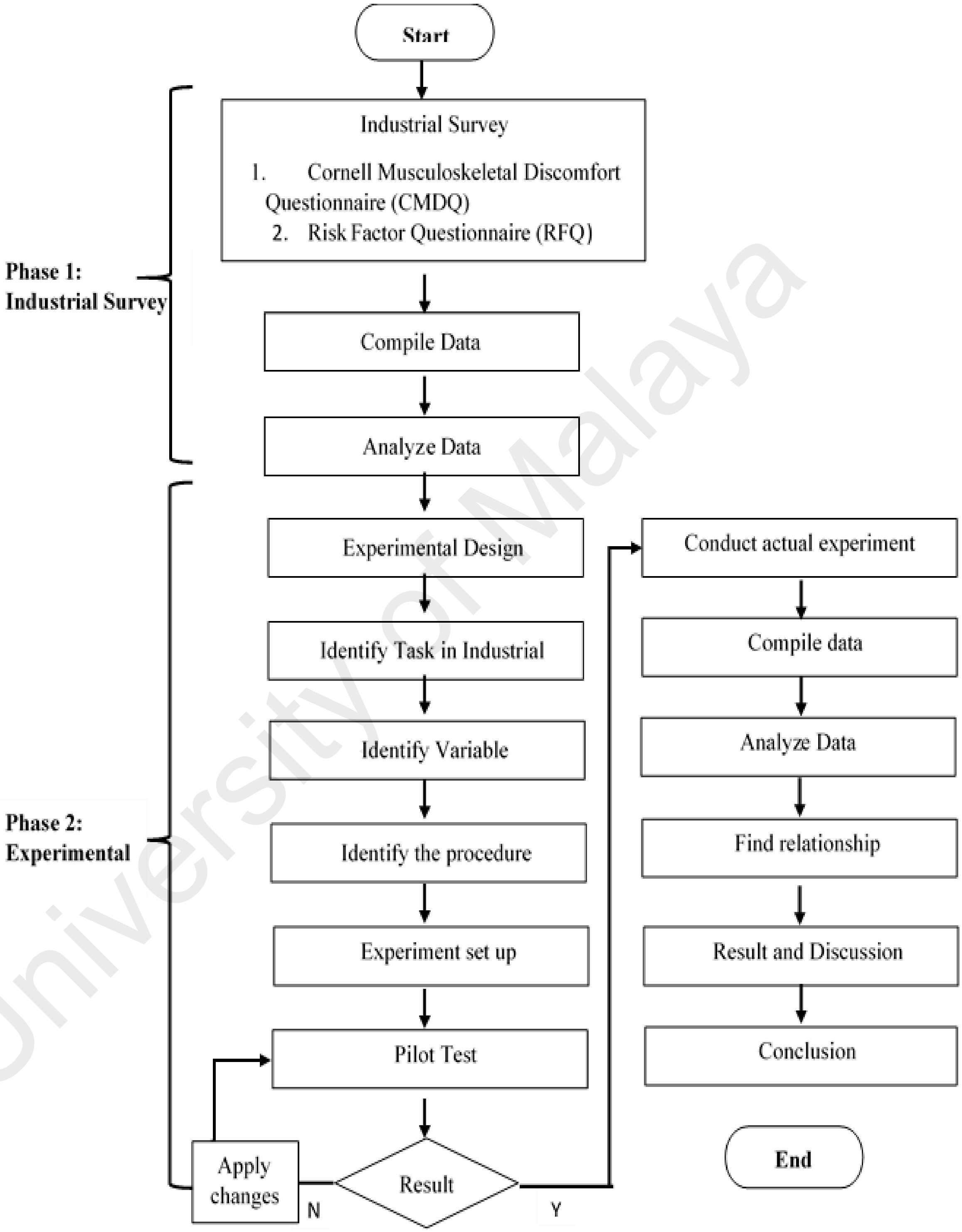

Figure 3.1: Flow chart of research

3.3 Industrial Survey

Questionnaires were distributed to identify the prevalence of MSDs among MMH workers at AMT workstation in Malaysian automotive industry. 10 automotive industries in West of Malaysia were determined from the Malaysian Industrial Development Authorities (MIDA) list and requested to involve in this survey according to the major work process in manual material handling of metal fabrication and the practices of advanced machining in their industries. Out of 10 automotive industries, 3 companies agreed to participate in this survey. The survey was conducted individually in the workplace during working hours. The participants completed the survey voluntarily. Two types of self-administered questionnaire which were adopted from Cornell Musculoskeletal Discomfort Questionnaire (CMDQ) (Hedge et al., 1999) and Risk Factor Questionnaire (RFQ) (Halpern et al., 2001) were distributed.

3.3.1 Survey Instrument

Cornell Musculoskeletal Discomfort Questionnaire (CMDQ) was used to investigate the prevalence of MSDs among MMH workers. This questionnaire compares the pain or discomfort across 12 body regions including neck, shoulders, upper back, upper arm, lower back, forearm, wrists, hips/buttocks, thighs, knees, lower legs and feet. For all body parts, the workers were asked about the frequency of experiencing the discomfort level in the past 7 days, the uncomfortable level on the region (slightly uncomfortable, moderately uncomfortable and very uncomfortable) and interference of discomfort to their daily routines (not at all, slightly interfered or substantially interfered). The subjects were also questioned if they feel discomfort due to their work (yes, no, maybe or partly) and whether they had ever discontinued from work due to the experienced discomfort.

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The Cornell Musculoskeletal Discomfort Questionnaire (CMDQ) is given in Appendix B.

The Risk Factor Questionnaire (RFQ) was adopted to investigate the physical risk factors that might be related to work-related musculoskeletal disorders. In this questionnaire, the participants were asked about the frequency of postures adopted during manual material handling activities which include lifting, pushing, pulling and carrying in the workplace. Six scores rating was used as a rating scale which includes never, rarely, sometimes, moderately, constantly and all the time. This questionnaire also asked the participants regarding the frequency of the weight lifted in the workplace. The Risk Factor Questionnaire (RFQ) is provided in Appendix C.

3.3.2 Industrial Survey subject

113 male industrial automotive workers who practice MMH tasks at CNC machine participated in this study. It is perceived that the data are sufficient for this study since a sample size of 30–500 is appropriate for most studies (Roscoe, 1975). The objective of each questionnaire was briefly explained to workers. The workers gave full consent to participate in this study and they were paid for their time and participation in this study. The selection criteria of the workers to participate in the industrial survey are:

- Male
- Practicing MMH task while working at CNC workstation as their daily routine.
- Main tasks of their daily activities are loading part to machine and unloading part from machine.
- Without any acute musculoskeletal problem reported.

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3.4 Experimental Design

The real MMH tasks at CNC workstation in automotive manufacturing industry were designed and simulated in a laboratory. The details of the experimental design in this study is summarized in Table 3.1.

Table 3.1: Experimental design in this study

	Variable	Levels and Condition
Independent Variable	Load	1 kg and 3 kg
	Subject	14 industrial workers 14 novice subjects (someone with a minimum experience in the domain)
	Posture	Bending and Squatting
Dependent Variable	Angle	Degree
	Energy Expenditure	Kcal/min
	Subjective Rating	Rating Perceived Exertion (Borg' Scale)
Control Variable	Task Duration	20 minutes/each session
	Sample	Automotive part (oil filter and steering rack)
	Cycle Time	1 minute per cycle
	Coupling	Good
	Laboratory experiment	24-25˚C

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3.4.1 Experimental Subjects

Two groups of male subjects were recruited. The first group consisted of 14 novices and the second group consisted of 14 expert workers. The selection subject's variation was based on definition by Hoffman et al., (1995) and Plamondon et al., (2014). Novice subjects were selected based on:

1. Someone with minimum experience (3 to 6 months) and very little exposure in MMH tasks.
2. No injury in the year preceding the study.

The selection of the expert workers was based on:

1. Workers who has one year and above of working experience on MMH tasks at CNC workstation.
2. Minimum occurrence of back injuries (less than three times diagnosed by clinic).
3. No injury in the year preceding the study that could affect the normal performance of their work.

All novice subjects were recruited from staffs and students at University of Malaya and expert worker subjects were recruited from automotive industrial workers who directly engaged with CNC workstation and practiced MMH task as their main activity in daily work routine. In this study, 28 of subjects were involved in experimental tasks. The number of subjects is sufficient to determine the normal exposure of the investigated group in an experiment (David, 2005). Several issues related to facilities, financial and time limitations may cause less participated subjects enlisted for the experimental tasks.

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3.4.2 Experimental Task

MMH tasks adopted in the experiment were simulated from actual automotive industrial setting at AMT workstation. It consisted several workstations which were loading and unloading workstation, inspection workstation and sorting workstation. The combined MMH tasks involved in this experiment were lifting, carrying, lowering and holding. Overall tasks consisted of 11 tasks which were defined as one complete cycle. The details of tasks for one complete cycle is presented in Table 3.2. All subjects had to repeat the same 11 tasks for both loads; 1 kg and 3 kg. Cycle time to complete 11 tasks was set to be 1 minute. Detailed explanation on description of task is given in Appendix D..

Table 3.2: Tasks for one complete cycle

Task	Types of MMH	Task details
1	Lifting	Subject takes part, loads part into machine 1 (M1) Subject closes the door, and pushes the start button
2	Holding	Subject takes part on table, cleans the part
3	Carrying	Subject walks to inspection table while carrying the part Subject puts the part on inspection table
4	Lowering	Subject walks to machine 2 (M2) Subject presses the stop button, opens the door, unloads part from machine
5	Lifting	Subject takes part, loads part into machine 2 (M2) Subject closes the door, and pushes the start button
6	Holding	Subject takes part on table and cleans the part
7	Carrying	Subject walks to inspection table while carrying the part
8	Holding	Subject inspects the part
9	Carrying	Subject walks to sorting station while carrying the part
10	Lowering	Subject puts part into sorting bin
11	Lowering	Subject walks to machine 1 (M1) Subject presses the stop button, opens the door and unloads part

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Each subject was instructed to perform two different postures while performing task 10 which were bending and squatting. For the first session, subject was required to complete all tasks (11 tasks) with the bending posture for task 10 within 1 minute cycle and repeat the same tasks within 20 minutes. After 20 minutes break, the subject was required to repeat the same experimental tasks as the first session in the second session with the squatting posture for task 10. The summary of the experimental task is presented in the Figure 3.2.

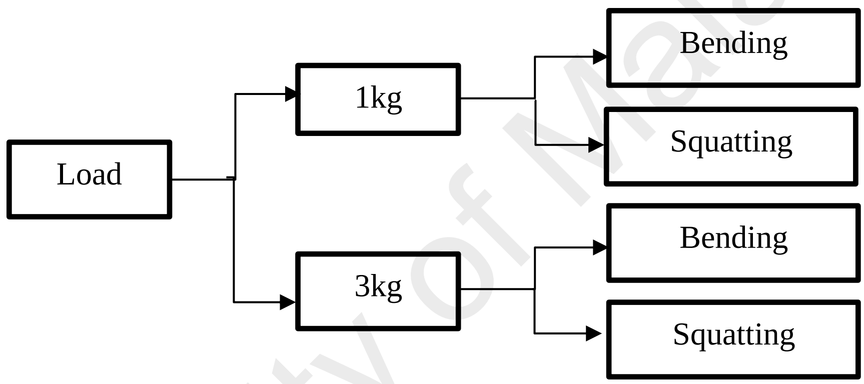

Figure 3.2: Summary of experimental task

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3.4.3 Experimental Procedure

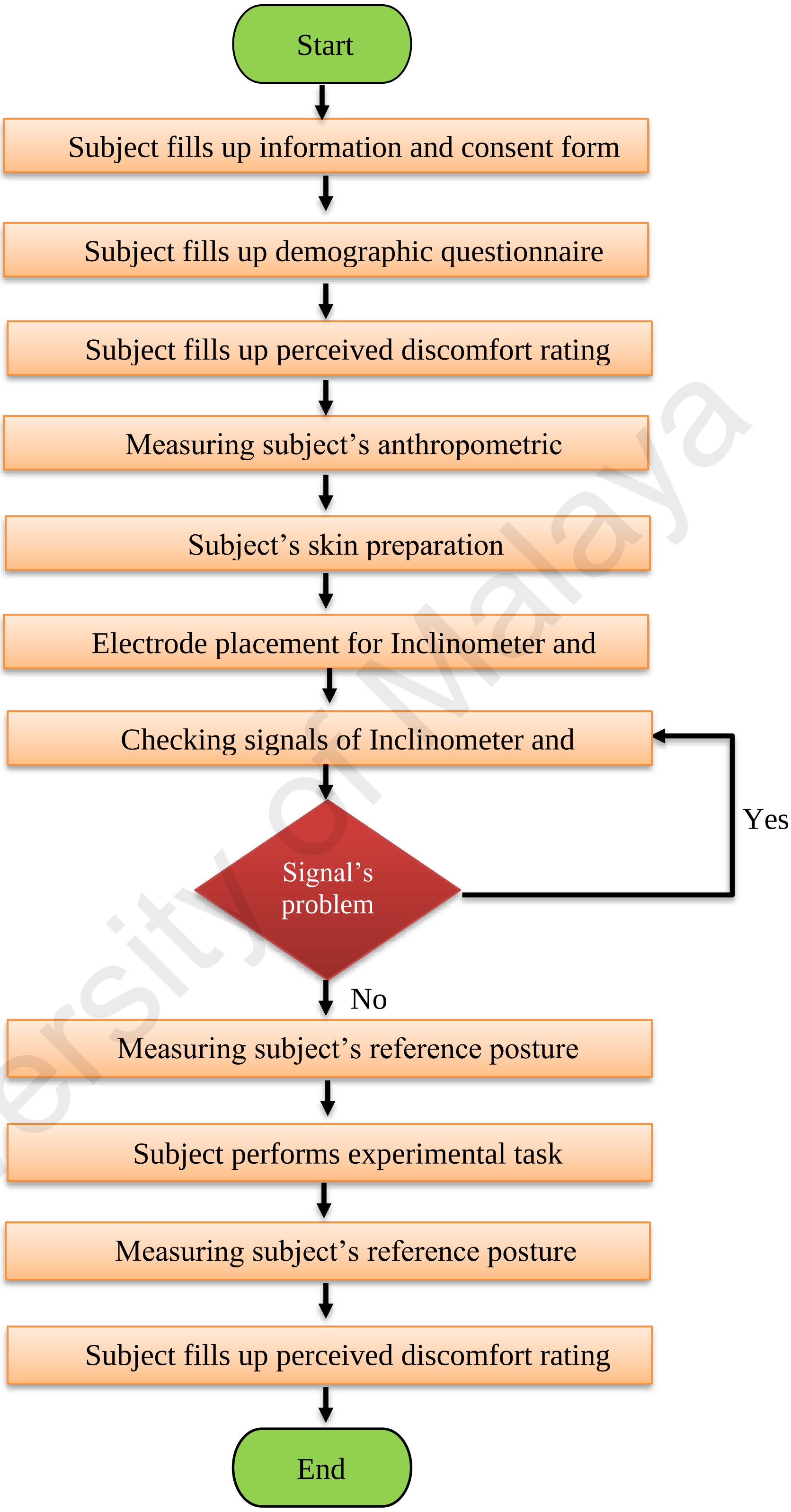

Figure 3.3: Flow chart of experimental procedure

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The procedure of the conducted experiment was as shown in Figure 3.3. Before the experiment started, all subjects were briefly explained regarding the equipment which would be used and the flow of the experiment. Information sheet regarding their involvement and the possible risks in the study was provided to the subjects (Appendix E). The consent form was given and filled in by the subject to ensure their agreement for participating in this study (Appendix F).

Demographic questionnaire and perceived discomfort rating were required to be filled by each subject before starting the experiment. 15 relevant body dimensions linked mainly to the MMH tasks were measured through anthropometric measurements. The skin of the subjects was then cleaned thoroughly and prepared before it was fitted with Actiheart sensors and inclinometer sensors.

The measurement of the subjects' reference body postures was obtained. Two reference body postures were taken. First, the subject was instructed to relax and stand upright (0°) with the eyes fixed looking at a mark at eye level (Hansson et al., 2006). Second, the subject was instructed to bend forward in a sagittal symmetric (90°). Reference body postures were measured before and after the experiments within 45 seconds. The average of the measured angles was calculated and used for calibrating the data normalization.

The subject was required to perform two distinct loads for the experimental tasks, 1kg and 3 kg. The subject was required to perform each task for two sessions; bending posture and squatting posture within 20 minutes for each session. Each experiment session was divided by 20 minutes break. The subjects were asked to rate their perceived discomfort rating before and after completing each session of experimental tasks. The familiarization session was held before the experiment began for the subjects to familiarize themselves

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with the experimental tasks and procedures. Approximately 5 to 10 minutes were taken for familiarization session. The experiment was started after the subject was ready.

3.4.3.1 Duration of Experiment

This experiment was designed to be completed by each subject within 2 hours and 30 minutes. The duration of experiment was 2 hours and 30 minutes which included the time to complete the electrodes and devices placement on the body of the subject, 20 minutes for each experimental task session and 20 minutes for breaks after each session ended. The duration of this experimental tasks was adequate to investigate the posture during manual material handling.

3.4.3.2 Experimental Workstation

The experiment workstation was constructed at the Advanced Cutting Machine Lab in Department of Engineering, University of Malaya. The environment of the laboratory was regulated to avoid noise interference to the equipment's signals (inclinometer and Actiheart). The workstation was set up similar to the actual industrial setting at AMT workstation as presented in Figure 3.4. The layout of the experimental workstation is presented in Figure 3.5.

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Figure 3.4: Experimental parts and workstation

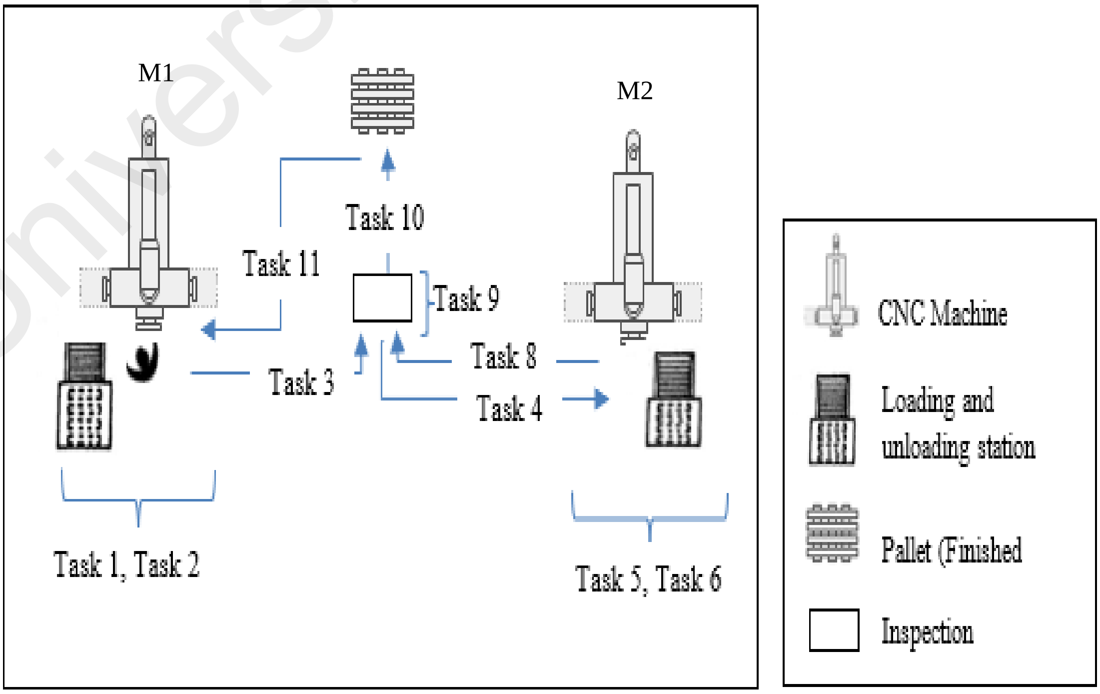

Figure 3.5: Experiment Layout

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3.5 Equipment

The equipment used in the experimental tasks are listed below:

1. Inclinometer. Inline 2D inclinometer was used to measure the back postural deviation angle during experiments. The size of inclinometer sensors used is 3.05 cm (width) × 3.05 cm (height) × 3.05 cm (depth), with a weight of 45.5 g. The inclinometer sensors were attached to the trunk (T12) and lumbar (L5); and were connected to Noraxon Telemyo 2400 system using small signal transmitter which was carried on a belt by the subjects. The signals were picked up by the inclinometer sensors and transmitted telemetrically to a receiver which was connected to a computer via wireless transmission. The inline 2D inclinometer sensors and the Noraxon Telemyo 2400 system were shown in Figure 3.6.

Figure 3.6: Inline 2D inclinometer sensors and Noraxon Telemyo 2400 system (Noraxon Inc. USA)

2. Actiheart. Actiheart monitoring device was used to capture energy expenditure during experimental tasks (CamNtech, 2010). During the experimental tasks, the device was attached to the subject’s chest as presented in Figure 3.7. The device consists of two electrodes connected by a short lead cable, which can be simply clipped onto two standard electrocardiography (ECG) pads. The device is suitable

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for ambulatory activities and heart rate activity recording because it is a self-contained instrument.

Figure 3.7: Actiheart monitoring device (CamNtech Ltd., Cambridge,UK).

3. Anthropometry Set. The anthropometry set as shown in Figure 3.8 was used to measure the body dimension of the subjects. It comprises of stadiometer and caliper.

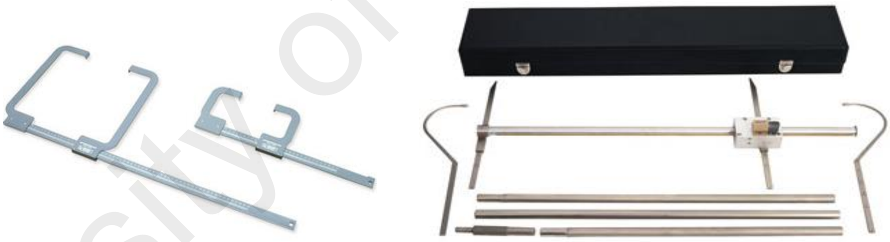

Figure 3.8: Anthropometry set (Source: galaxyscientificindia.com and www.prohealthcareproducts.com)

3.6 Data Collection

Measurements of energy expenditure and back postural angle during experimental tasks were collected. The data were collected from demographic characteristics, perceived discomfort rating and anthropometric throughout the experiment.

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3.6.1 Back Postural Angle

Back postural angle was measured using inclinometer sensors. The placement of sensors on the subjects and reference posture measurement is presented below.

3.6.1.1 Placement of sensors

Back postural angles measurements were captured from T12 and L5. Location of T12 and L5 are presented in Figure 3.9. The inclinometers were tightly attached at T12 and L5 by surgical tape to record the trunk movement. The bony landmarks were identified manually (Keith & Dalley, 2005).

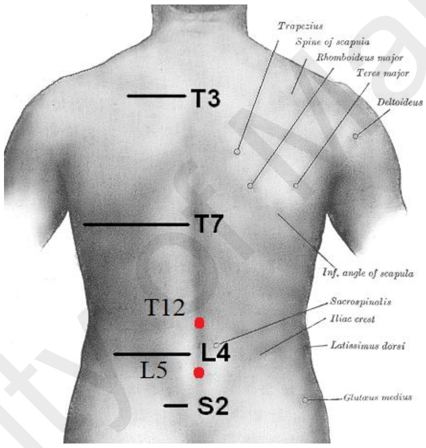

Figure 3.9: Location of T12 and L5 (Keith & Dalley, 2005)

3.6.2 Energy Expenditure Measurement

Recorded data which collected by Actiheart monitoring device throughout experimental task were transferred into a laptop using Actiheart software. Then, the obtained data were exported to Microsoft Excel. The energy expenditure values were determined through the exported data. Next, the average of energy expenditure during experimental task was computed for further analysis.

3.6.3 Rating Perceived Exertion (RPE)

The data obtained from the Rating Perceived Exertion (RPE) was compiled as a direct indicator to measure the extend of subjects' fatigue during the experimental tasks. The RPE scale used was as presented in Table 3.3. The RPE was the common method used to assess the subjective qualities during a physical work. The RPE was rated by the subject for the entire body, upper back, middle back, lower back, hip, upper leg (right and left), lower leg (right and left), ankle (right and left), knee and foot (Borg,1998). The RPE was rated by the subject before the experiment was started and after the experiment was completed for each of experimental session.

Table 3.3: Borg's RPE Scale

Score	Verbal Anchor	Catergory
0	Nothing at all	
0.5	Extremely weak	Just
1	Very weak	
2	Weak	Light
3	Moderate	
4		
5	Strong (Heavy)	Heavy
6		
7	Very strong	
8		
9		
10	Extremely strong	Maximal

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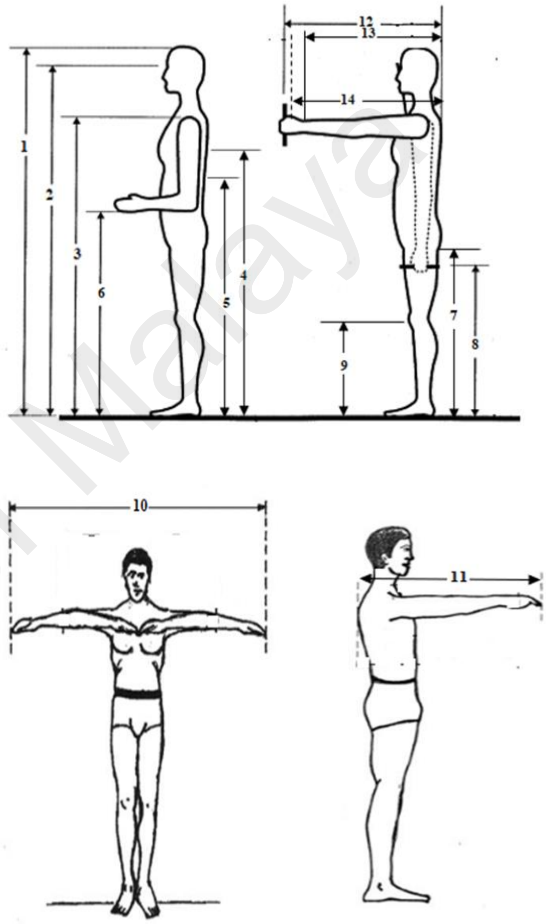
3.6.4 Anthropometric Measurement

There are several anthropometric measurements of subjects compiled by following the guideline by Pheasant (1996). The 14 primarily related body dimensions to standing workstation were included in this study, which are as follows;

1. Height
2. Standing eye height
3. Standing shoulder height
4. Standing chest height
5. Standing waist height
6. Standing elbow height
7. Standing wrist height
8. Standing knuckle height
9. Standing knee height
10. Span
11. Arm reach forward
12. Thumb tip reach
13. Wrist wall length
14. Wrist wall length extended



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3.7 Data Analysis

A statistical analysis was carried out in order to analyze the collected data obtained from the industrial survey and experiments. The statistical tool was used to analyze the collected data using Statistical Package for Social Sciences (SPSS) software (v24.0, IBM Corp., New York, USA). Before the data were analyzed using any analysis, the data were checked for normality using skewness and kurtosis. Normality test was required to determine the distribution of data. Then the appropriate analysis can be assigned for further analysis. All variables were initially analyzed using descriptive analysis.

A reliability analysis was then carried out for survey questionnaires. The Cronbach's alpha coefficient was used for the reliability measurement to determine the internal reliability of the survey. The association between risk factors and WMSDs symptoms in the survey questionnaires were determined using non-parametric analysis which was Chi-square test. A *p*-value of less than 0.05 is regarded as statistically significant.

A Pearson product-moment correlation coefficient was used to measure the strength of the linear association between load (1 kg and 3 kg) and energy expenditure for both subjects. The same analysis was also performed to determine the strength of the linear association between load (1 kg and 3 kg) and back postural angle for both subjects in both postures. All analysis was performed with the significant level defined at *p*-value is <0.01.

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3.8 Summary

The explanation on the methodology adopted in this study has been presented in depth in this chapter. CMDQ (Hedge et al., 1999) and RFQ (Halpern et al., 2001) were the two types of questionnaires being used in the industrial survey. The CMDQ was adopted to assess the WMSDs during MMH tasks at CNC workstation while RFQ was adopted in identifying the physical risk factors which may be related to the WMSDs. The experimental tasks were conducted in two sessions which were in bending session and squatting session, for over a 30 minutes per session including the time for equipment settings. The inclinometer device was adopted to determine the back postural deviation angle in the experimental tasks while Actiheart monitoring device was used to measure the energy expenditure throughout the experiment. Borg's CR-10 Scale was adopted to assess perception of discomfort throughout the experimental tasks. The appropriate statistical analysis was carried out to examine the data variation.

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CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the analysis and discussion on the data collected from survey and experimental measurement. The prevalence of musculoskeletal discomfort among manual material handling (MMH) workers at CNC workstation was determined using the survey. The results and analysis of the survey were being used to design the experimental tasks in order to cater the main objectives of the study.

The analysis of the collected data from the experimental tasks is also discussed in this chapter. The results pertaining to demographic characteristics of the subject's, rating perceived exertion (RPE), energy expenditure and back postural angles, are all presented in this section. Statistical analysis using Pearson product moment coefficient is conducted to determine the strength of the correlation between load and energy expenditure; and the correlation strength between load and back postural angle for both subjects, novice and experienced workers.

Hence, the results and discussion of the data gathered through industrial survey and experimental tasks are presented in this chapter. Comparisons were made for the obtained results with previous studies and the summary is presented towards the end of this chapter.

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4.2 Industrial Survey Results

An industrial survey was carried out to identify the prevalence of musculoskeletal discomfort among MMH workers at CNC workstation. The industrial survey was also conducted to identify the significant ergonomic risk factors of the MMH tasks which will lead to WMSDs risk.

4.2.1 Reliability of data

The industrial survey was checked for internal reliability using Cronbach's alpha coefficient. It is most commonly reported measure of internal reliability and the Cronbach's alpha coefficient of 0.7 means that the research is acceptable (Pallant, 2013). In this study, the values of Cronbach's alpha for the result of the survey is 0.816. This indicates that the instrument has a very good internal consistency reliability.

4.2.2 Demographic Data of Subjects in Industrial Survey

The 113 subjects involved in industrial survey in this study are Malaysian male operators. The subjects perform the MMH tasks at CNC workstation as their main activity in their daily routine for the whole day. The obtained demographic questionnaires results are presented in the sub-sections below. Detailed demographic is presented in the Appendix J.

Age distribution

All participated subjects aged between 18 to 50 years old (mean ± SD: 55 years ± 6.59 years). The percentage of age distribution is presented in Figure 4.1. It can be observed that majority of subjects are within 21-30 years old which constitute 53.1%.

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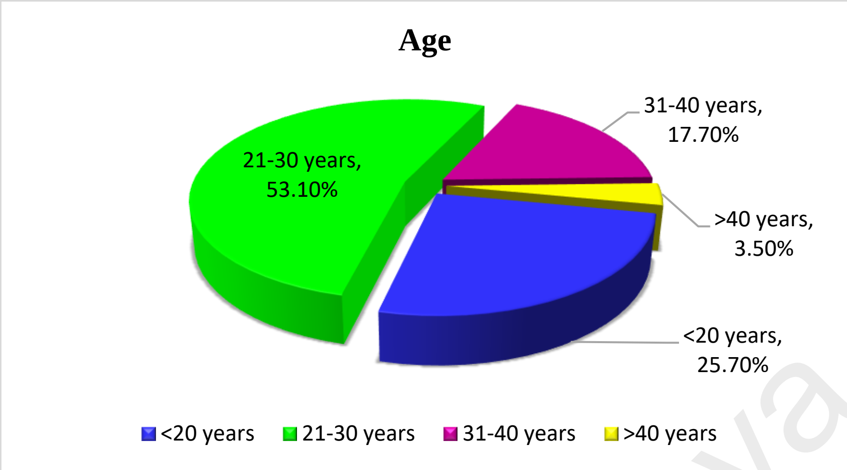

Figure 4.1: Age distribution

Working Experience

The subjects' working experience is presented in Figure 4.2. Working experience of subjects is ranged between 0.5 to 24 years (mean ± SD: 2.73 years ± 4.06 years). 48.7% of the subjects have less than 1 year working experience, 44.2% of subjects have 1-5 years of working experience and 7% of subjects have more than 5 years working experience.

Figure 4.2: Percentage of subjects based on working experience

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Working hours per day

The duration of working time of the participated subjects is also measured in this study. The working time duration of the participated subjects reflects their posture at work. The percentage of total working time that subjects spend for MMH tasks at CNC workstation in their daily activity is presented in Figure 4.3. The results show that most of the participated subjects spend between 8-12 hours per day which constitute 81.4% of subjects performing MMH tasks including loading and unloading at CNC workstation. The mean of working hours per day is 10.72 hours with standard deviation of 1.95 hours.

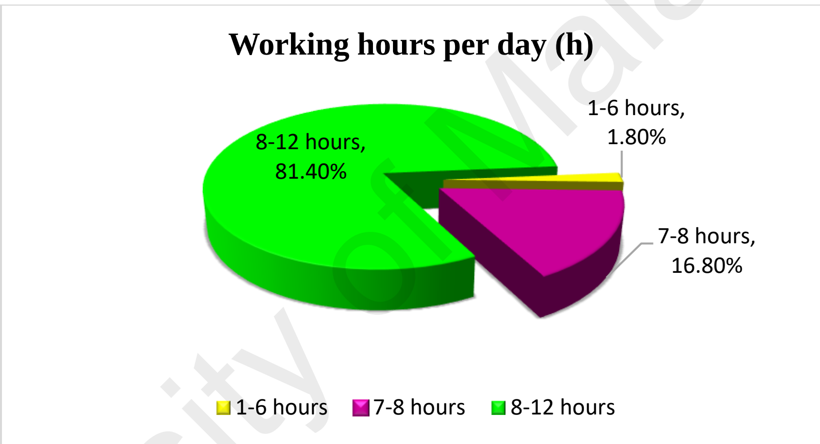

Figure 4.3: The percentage of subjects based on working hours per day (h)

4.2.3 Prevalence of Work-related Musculoskeletal Disorders (WMSDs)

The prevalence of WMSDs symptoms among workers for the last seven days is summarized in Table 4.1. It is discovered that the occurrence of WMSDs symptoms varies from 70.8 – 85.8%, depending on the body region. The results show that the prevalence is highest at the lower back (85.8%), followed by neck (85%), upper back (79.6%), upper arm (79.2%), forearm (77.9%) and shoulders (77.5%) and least of all, the knee (72.2%).

Table 4.1: The prevalence (%) of musculoskeletal symptoms among MMH workers (n=113)

Body region (R-right; L- left)	Symptoms last seven days
Neck	85.0
Shoulder R/L	78.8/76.1
Upper Back	79.6
Upper Arm R/L	81.4/77.0
Lower back	85.8
Forearm R/L	78.8/77.0
Wrist R/L	74.4/72.6
Hip	77.0
Thigh R/L	78.8/70.8
Knee R/L	70.8/73.5
Lower leg R/L	70.8/76.1
Foot R/L	72.6/75.2

The results indicate that 78.8% of the workers experienced WMSDs on various body regions. The calculation is shown below:

$$= \frac{n\ respondent\ had\ symptoms\ of\ at\ least\ one\ body\ region}{Total\ of\ respondents} \times 100\%$$

$$= \frac{89}{113} \times 100\%$$

$$= 78.8\ \%$$

4.2.4 Physical Risk Factors among MMH workers at CNC workstation

The percentage of physical adopted postures during MMH activity at CNC workstation is determined using Risk Factor Questionnaire (RFQ), which is presented in Figure 4.4. It shall be noted that this measurement is taken during the daily MMH activities at CNC workstation for the whole day.

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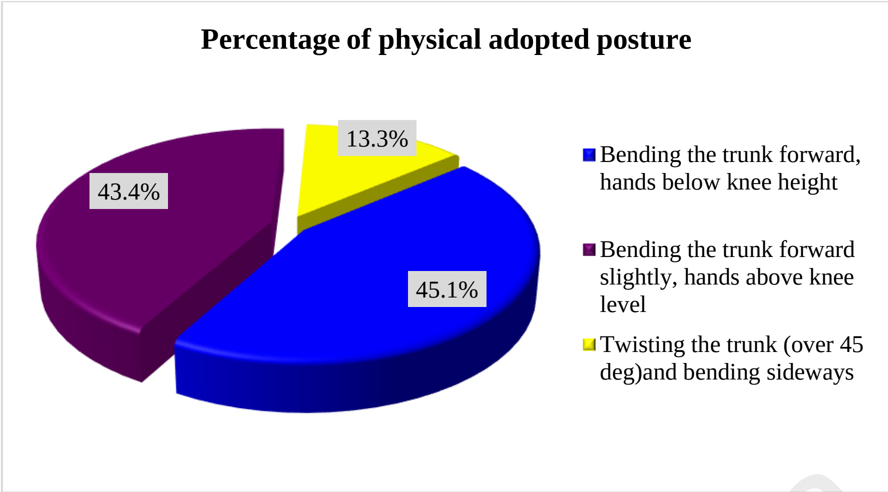

Figure 4.4: Physical risk factor characteristic

The results reveal that the majority of the workers adopted the trunk twisting (over 45°) and sideways bending (45.1%), as well as the trunk bent slightly forward with hands above the knee level (43.4%) postures during their working time. Meanwhile, only 13.3% of workers adopted the trunk forward with hands below the knee level.

The frequency of lifting is measured to determine the most load part lifted by workers. The measurement of frequency is taken within one hour and it has the highest frequency which is over than 30 times per hour. The result for the lifting frequency presented in Figure 4.5.

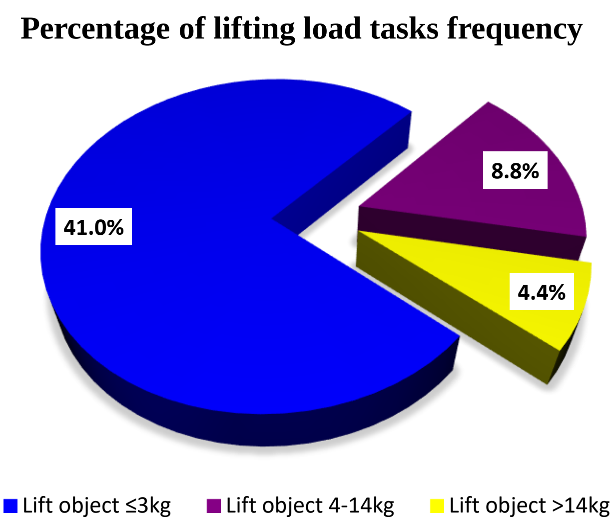

Figure 4.5: The percentage of lifting load tasks frequency

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The results reveal that 41.0% of the workers lift loads weighing ≤ 3kg, for over than 30 times within an hour. While, 8.8% of workers lift loads weighing within the range of 4-14 kg and the remaining 4.4% workers lift loads weighing more than 14kg. These results proved that most of MMH workers at CNC workstation deal with light load part (≤ 3 kg) in their daily routine.

4.2.5 The association of Risk Factors and WMSDs

The association between risk factors (individual risk factors and physical risk factors) and WMSDs is determined using Chi-square test. This test compares the expected observed frequencies if there is any risk factor associated to WMSDs. The association between these two variables is presented in Table 4.2.

Table 4.2: The association between risk factors and WMSDs

Risk Factor (n)	Musculoskeletal discomfort (%)		Chi-Square	Significant
	Discomfort	None Discomfort		
Age				
less than 20 (29)	82.8	17.2	x^2 = 0.597, df =3	p = 0.597
21-30 years (60)	75.0	25.0		
31- 40 years (20)	80.0	20.0		
more than 40 years (4)	100	0		
Experience				
<1 year (55)	80.0	20.0	x^2 = 0.236, df =2	p = 0.236
1-5 years (50)	74.0	26.0		
>10 years (8)	100	0		
Bending the trunk forward slightly, hands above knee level				
never (2)	100.0	0	x^2=19.427, df =5	***p* = 0.002***
rarely (1)	9.1	90.9		
frequently (12)	16.7	83.3		
moderate (12)	86.2	13.8		
constant (37)	87.5	12.5		
all the time (49)	94.6	5.1		

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Table 4.2: Continued

Risk Factor (n)	Musculoskeletal discomfort (%)		Chi-Square	Significant
	Discomfort	None Discomfort		
Bending the trunk forward, hands below knee level			x^2=9.844, df =5	p= 0.080
never (40)	87.5	12.5		
rarely (42)	73.8	26.2		
frequently (14)	57.1	42.9		
moderate (9)	100	0.0		
constant (6)	83.3	16.7		
all the time (2)	50.0	50.0		
Twisting the trunk (over 45°) and bending sideways			x^2=19.427, df =5	***p* = 0.002***
never (2)	100	0		
rarely (1)	100	0		
frequently (12)	33.3	66.7		
moderate (12)	100	0		
constant (37)	83.8	16.2		
all the time (49)	78.8	21.2		
Pushing/pulling loads			x^2=9.367, df =5	p = 0.095
never (19)	89.5	10.5		
rarely (25)	60.0	40.0		
frequently (11)	72.7	27.3		
moderate (11)	90.9	9.1		
constant (6)	66.7	33.3		
all the time (41)	85.4	14.6		
Carrying objects 4- 14 kg			x^2=6.965, df=5	p =0.223
never (55)	80.0	20.0		
rarely (26)	73.1	26.9		
frequently (5)	40.0	60.0		
moderate (15)	86.7	13.3		
constant (3)	100	0.0		
all the time (9)	88.9	11.1		
Lift object ≤ 3 kg			x^2=16.050, df =4	***p* = 0.003***
Almost never (7)	28.6	71.4		
Less than once an hour (10)	60.0	40.0		
1-10 times an hour (17)	94.1	5.9		
11-30 times an hour (56)	80.4	19.6		
Over 30 times an hour (23)	87.0	13.0		
Lift object 4 kg-14kg			x^2=7.081, df =4	p = 0.132
Almost never (81)	75.3	24.7		
Less than once an hour (15)	86.7	13.3		
1-10 times an hour (13)	92.3	7.7		
11-30 times an hour (1)	0	100		
Over 30 times an hour (3)	100	0		

$\chi 2$=chi square, df = degrees of freedom
* p < 0.05= was considered statistically significant at 5% level.

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The results show that there are significant association between physical risk factors and musculoskeletal discomfort ($p<0.05$). It is revealed that the significant factors which lead to WMSDs are the adoption of the following posture: lifting light load ($\leq$ 3 kg) in awkward postures, trunk bent slightly forward with hands above the knee level ($p<0.05$), and trunk twisted (over 45°) while bending sideways ($p<0.05$).

From the industrial survey results, the highest body region reported to have WMSDs is back region (85.5%). The back body region is the highest recorded which might be due to the poor CNC workstation design and poor working methods adopted by workers. At CNC workstation, workers are exposed with trunk twisting and sideways bending posture during loading and unloading parts to machine. Workers are required to twist their trunk to take part and unload part to CNC machine. This is supported by the result found throughout the industrial survey in this study which found that nearly 50% of workers adopted trunk twisting over than 45° and sideways bending and bending the trunk slightly forward with hand above the knee level. It is reported that trunk twisting and sideways bending as well as trunk bending has a strong correlation to the WMSDs (Lind et al., 2017; Punnett et al., 1991; Keyserling et al., 1988).

Other than loading and unloading part to CNC machine, workers also need to perform other tasks such as clamping part into workpiece, cleaning the machined part from dust or unwanted materials, inspecting and transferring part to pallet. These tasks expose worker to vibration and static posture. Awkward position, vibration of tools, awkward grip or handling movement over time put high risk to muscular discomfort in the back region (Widanarko et al., 2012).

Besides that, workers also need to operate the control and display terminals. Within the cycles (normal cycle is below than 1 minutes), the workers also need to operate another CNC machine concurrently. The applied tasks and the cycle time set at CNC

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machine is the same with another machine. It means that each worker is required to operate two CNC machines concurrently and workers are required to move faster to complete all MMH tasks at both machines. This working condition continues throughout 8-12 hours of their daily working hours. Furthermore, tasks at CNC workstation are not self-chosen and this situation forces workers to work based on machine demands. The repetitive and continuous movement increase the mechanism of load acts on spine and joints which lead to WMSDs on back and other body regions (Lind et al., 2017; da Costa & Vieira, 2010). The findings of this study are in line with the findings by Deros et al., (2010) who has discovered that the highest occurrence of WMSDs due to MMH task are recorded at the lower back region.

The second highest prevalence of WMSDs is on neck region. The factor that contribute to neck discomfort is due to the tasks of operating control and display terminals. The variation of height of control panel and display mounted at CNC machine requires workers to sustain their neck while performing those tasks. According to Muthukumar et al., (2012b), height of control terminal is related to the neck discomfort.

Another important finding in this study is the factors that contribute to WMSDs which are lifting light load (≤ 3 kg) in awkward postures, trunk bent slightly forward with hands above the knee level and trunk twisted (over 45°) while bending sideways. These findings have a good agreement with Yahya et al., (2014), who has found that lifting weight (<5 kg and 11-23 kg) with slight bending was associated with prevalence of WMSDs among automotive industrial worker in 12 months.

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4.2.6 Summary of Industrial Survey Result

The current trend of the MMH workers at CNC workstation is practicing an awkward posture during the whole day of their working routine. The awkward postures indicate the posture with bending the trunk slightly forward with hands above the knee level and twisting the trunk over than 45° while bending sideways. These adopted postures put high risk of musculoskeletal discomfort at back region.

4.3 Experimental Task Results

The result of experimental tasks is divided into several sections; demographic characteristics, rating perceived exertion (RPE), energy expenditure and back postural angle (trunk angle and lumbar angle). All results are shown in this section.

4.3.1 Demographic Characteristics

28 male subjects consisting of 14 novices and 14 workers participated in this study. It shall be mentioned that the selection criteria for novice is someone who has very little exposure to the MMH tasks and is considered as apprentice which refers to someone who is learning (Hoffman et al., 1995, reported in (Plamondon et al., 2014). While, the selection criteria for expert is to have at least one year working experience in MMH tasks at CNC workstation (Plamondon et al., 2014).

The demographic data of the experimental subjects is presented in the Table 4.3 and the details of the anthropometric measurements is presented in Appendix G.

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Table 4.3: Demographic data of the subjects

Variable	Subject	N	Mean	SD
Age (years)	Novice	14	28.93	7.20
	Worker	14	27.14	7.79
Weight (kg)	Novice	14	69.53	12.35
	Worker	14	66.43	12.49
Height (cm)	Novice	14	168.13	6.31
	Worker	14	168.81	7.69

4.3.2 Rating Perceived Exertion (RPE)

The RPE among subjects was rated by using the Borg CR-10 scale after the experimental tasks. The result of the RPE rated by subjects after the experimental tasks for bending session and squatting session is shown in the Figure 4.6 and Figure 4.7 respectively.

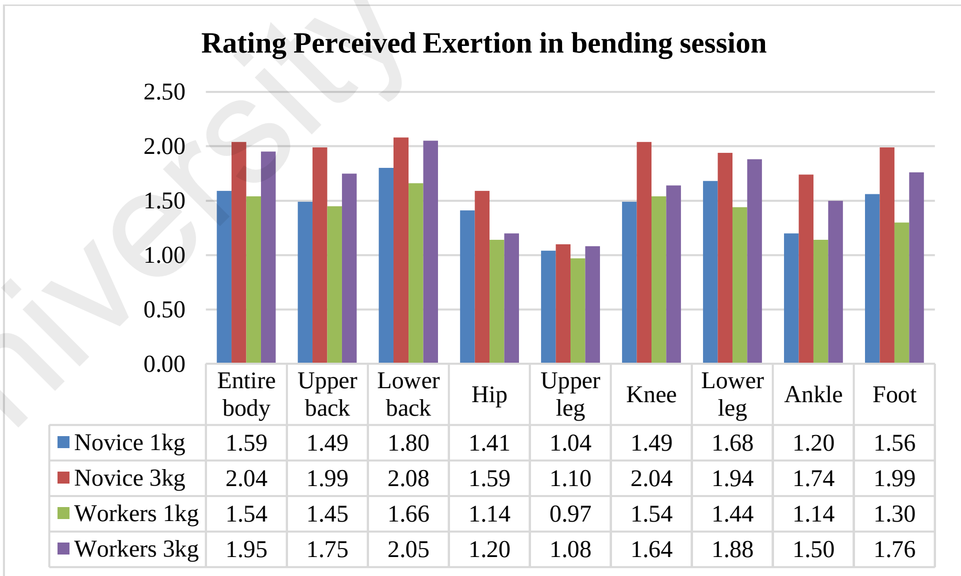

Figure 4.6: The mean of RPE for different body parts with different load and subject during bending session

The graph in Figure 4.6 presents the mean of RPE after experimental tasks during bending session. From the graph, it shows that RPE for all body parts increases with the

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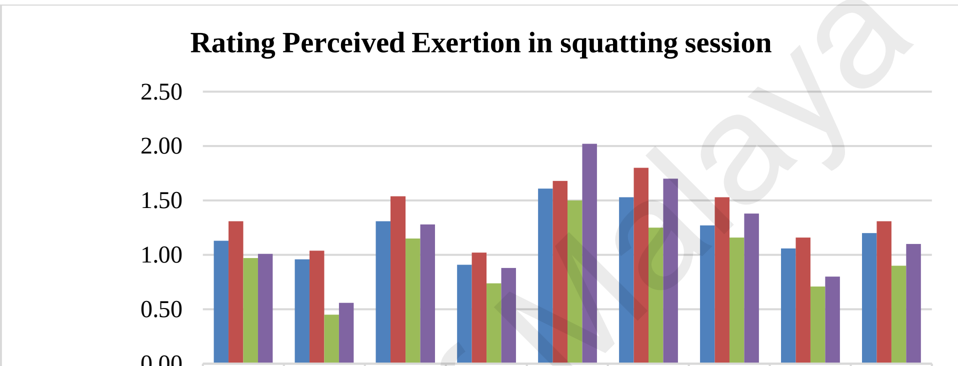
increasing of load lifted. The RPE increases in a range of 6-45% for novice and 5-35% for workers for all body parts from 1 kg load tasks to 3 kg load tasks. The highest RPE was observed at lower back region. RPE rated by the subjects varies from 0.97 to 2.08 for both loads which refers to extremely weak to weak. It means that the tasks were not considered as stressful tasks for the subjects. Thus, the 1kg load tasks and 3kg load tasks are considered as light task.



	Entire body	Upper back	Lower back	Hip	Upper leg	Knee	Lower leg	Ankle	Foot
Novice 1kg	1.13	0.96	1.31	0.91	1.61	1.53	1.27	1.06	1.20
Novice 3kg	1.31	1.04	1.54	1.02	1.68	1.80	1.53	1.16	1.31
Workers 1kg	0.97	0.45	1.15	0.74	1.50	1.25	1.16	0.71	0.90
Workers 3kg	1.01	0.56	1.28	0.88	2.02	1.70	1.38	0.80	1.10

Figure 4.7: The mean of RPE for different body parts with different load and subjects for squatting session

The graph in Figure 4.7 presents the mean RPE after experimental task for squatting session. From the graph, it shows that the RPE for all body parts increases from 1kg to 3 kg load lifted. The RPE increases in a range of 4-20% for novice and 4-36% for workers for all body parts from 1 kg load tasks to 3 kg load tasks. The highest RPE was observed at upper leg region, followed by knee and lower leg. RPE rated by the subjects is varies from 0.45 to 2.02 which refers nothing at all to weak. It means that the tasks were not considered as stressful tasks for the subjects. Thus, the 1kg load tasks and 3kg load tasks are considered as light task.

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By comparing both sessions, the total mean RPE rated by all subjects during squatting session was higher compared to bending session in various body regions. These findings are similar with the study conducted by Lad et al., (2018), Li et al., (2009) and Straker & Duncan (2000) which reveals that the squat posture requires more perceived exertion than bending posture. This can be concluded that the squat posture results more discomfort than bending posture. Discomfort is very useful as a risk predictor in observing muscle soreness following fatigue or connective tissue discomfort with strain or microtrauma. Squat lifting present higher in overall risk of injury than stoop lifting and put the lower risk injury in low back and hamstring structures but put a greater risk for injury to knee and quadriceps structures (Straker & Duncan, 2000).

4.3.3 Energy Expenditure

The mean and standard deviation of energy expenditure for both subjects during bending and squatting sessions are summarized in Table 4.4. The result shows that energy expenditure is increased with the increasing of load throughout both sessions.

Table 4.4: Mean of Energy Expenditure during bending and squatting of novice and worker with different level of loads

Subject	Load (Kg)	Mean Energy Expenditure	
		Bending Mean± SD (kcal/min)	Squat Mean± SD (kcal/min)
Novice	1 kg	3.54±0.72	3.87±0.55
	3 kg	4.32±0.63	4.95±0.41
Worker	1 kg	2.73±0.63	3.23±0.87
	3 kg	3.64±0.63	4.39±0.91

The maximum energy expenditure during bending posture is obtained when the novices and workers executed 3kg load tasks which are 4.32kcal/min and 3.64kcal/min

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respectively. The energy expenditure is found to be increased as a load increases from 1kg to 3kg load tasks (novice: 22.03%; workers:33.33%).

By comparing in both sessions, the maximum energy expenditure during squatting posture is obtained when the novices and workers executed 3kg load tasks which are 4.95kcal/min and 4.39kcal/min respectively. The energy expenditure is found to be increased as a load increases from 1kg to 3 kg load tasks (novice: 27.91%; workers: 35.91%).

Bending posture requires less energy expenditure than squatting posture for both of load tasks where 1kg load tasks (novice:9.32%; worker:18.31%) and 3 kg load tasks (novice: 14.58%; worker: 20.60%). The results also found that novice exhibits higher energy expenditure compared to worker (bending:23.73%; squatting: 16.53%) for 1 kg of load tasks (bending: 15.74%; squatting: 11.31%) for 3 kg load tasks.

4.3.3.1 Correlation of Load and Energy Expenditure

The correlation of load and energy expenditure was conducted using Pearson Product-Moment Coefficient analysis. It shall be highlighted that the purpose of performing a correlation analysis was to measure the strength of correlation between load and energy expenditure. Table 4.5 and Table 4.6 show the correlation between load and energy expenditure for novice and workers during bending and squatting respectively.

Table 4.5: Pearson's Correlation between load and Energy Expenditure during bending

	Energy expenditure			
	Novice		**Worker**	
Load	Pearson Correlation, *r*	Sig. (2-tailed), *p*	Pearson Correlation, *r*	Sig. (2-tailed), ***p***
	0.597	0.001**	0.509	0.006**

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Table 4.6: Pearson's Correlation between load and Energy Expenditure during squatting

	Energy expenditure			
	Novice		Worker	
Load	Pearson Correlation, *r*	Sig. (2-tailed), *p*	Pearson Correlation, *r*	Sig. (2-tailed), ***p***
	0.560	0.002**	0.755	0.001**

The results show a significant positive correlation and strong relationship between load and energy expenditure for both subjects in both postures (p<0.01;2-tailed). This relationship shows that the energy expenditure increases with the increasing of load. Similar findings are also found in the previous study conducted by Calzavara et al., (2016) and Yusuff et al., (2016) who have found that the weight of load lifted is linearly related to the energy expenditure. This also proves that the perceived exertion rated by the subjects exhibits higher value when dealing with heavier objects. This shows that subjects required more energy as weight of load increases. When greater work demand puts more burden on the active muscles, the muscles require more oxygen. This will force cardiopulmonary systems to work faster to pump and supply the oxygen to the active muscles. Hence, it will increase the potential of having WMSDs.

Result of this study also revealed that energy expenditure was higher for squatting posture compared to bending posture. This finding has a good agreement with findings in study conducted by Kamarudin et al., (2019), Li et al., (2009), Straker (2003) and Garg et al., (1978) who found that squatting requires greater energy expenditure in performing MMH tasks. This could explain that squat lifting places greater demand on the cardiovascular system than the stoop lifting, as it requires additional activation of the leg musculature (Revuelta et al., 2000). Furthermore, squatting increases the change in potential energy of the lifter's body, and it is more tiring than bending lifting posture.

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4.3.4 Back Postural Angles

Back postural angles were measured for trunk and lumbar. The deviation of trunk angle and lumbar angle from the neutral position in the sagittal plane is considered as flexion or extension. The positive values indicate the flexion of trunk or lumbar whereas the negative values indicate the extension of trunk or lumbar. The deviation of trunk angle and lumbar angle from the neutral position of the transverse plane is considered as twisting. The positive values indicate the trunk or lumbar twist to the right whereas the negative values indicate the trunk or lumbar twist to the left.

Back postural angles were examined throughout 20 minutes of the MMH tasks at CNC workstation in both experimental tasks sessions which are bending and squatting. It shall be highlighted that MMH tasks consist of 11 subtasks for one cycle time. After the experimental tasks were completed, the statistical analysis was carried out using Pearson product moment coefficient to identify the significant correlation between loads and back postural angles deviation.

The results of the back postural angles were divided into the following sections, back postural angle during flexion/extension and back postural angle during twisting.

4.3.4.1 Back postural angles during Flexion/Extension

Back postural angles during flexion/extension are divided into trunk flexion angle and lumbar flexion angle.

Trunk flexion angle

The mean trunk flexion angles for Task 1 to Task 11 are summarized in Table 4.7. The results are categorized into bending posture and squatting posture, according to weight of load lifted for each subject.

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Table 4.7: The mean trunk flexion angle

Task	Bending Posture				Squatting Posture			
	1kg		3kg		1kg		3kg	
	Novice (°)	Worker (°)	Novice (°)	Worker (°)	Novice (°)	Worker (°)	Novice (°)	Worker (°)
T1	8.23	2.53	12.01	4.28	10.76	0.73	11.37	3.14
T2	9.03	2.38	11.19	3.57	8.98	0.52	14.13	3.32
T3	9.38	2.97	14.61	2.85	10.37	0.27	14.05	4.09
T4	11.65	4.48	13.21	3.67	14.60	6.00	15.57	5.40
T5	8.63	2.70	12.00	5.08	11.02	0.63	13.15	5.04
T6	14.42	2.17	13.46	3.27	11.07	1.17	13.43	3.37
T7	17.61	3.49	11.43	5.12	8.06	1.39	17.78	4.24
T8	14.13	5.55	12.90	8.96	9.64	1.30	13.98	6.61
T9	18.70	10.88	18.77	9.21	11.17	2.40	21.34	8.83
T10	22.02	11.69	37.06	9.48	13.57	3.75	21.56	9.30
T11	10.40	4.99	14.50	7.35	11.17	1.07	14.26	4.33

Then, the graphs are plotted based on the mean trunk flexion angle value in Table 4.7. Figure 4.8 and 4.9 present the distribution of the mean trunk flexion angle during bending and squatting session for each task according to the weight of load lifted for both subjects. Figure 4.8 shows the trunk flexion angle during bending.

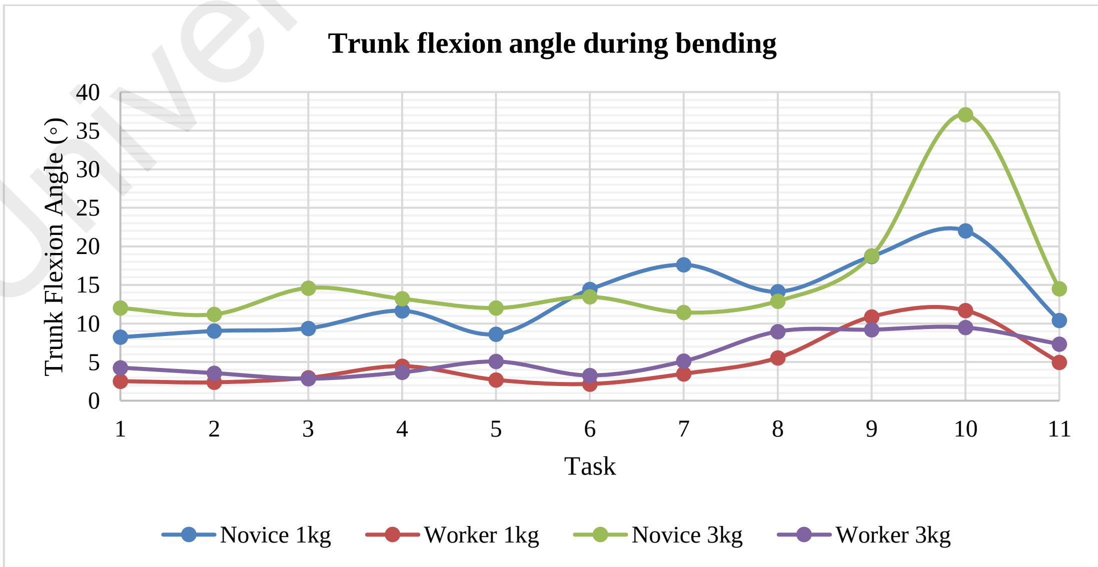

Figure 4.8: Trunk flexion angle during bending

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As seen in Figure 4.8, the trunk flexion angles are varied for 1kg load tasks (novice: 8.23°-22.02°: worker: 2.17°-11.69°) and 3 kg load tasks (novice: 11.19°-37.06°: worker: 2.85°-9.48°). From these values, novice exhibits higher trunk flexion angle compared to worker and the trunk flexion angles increase as the load lifted increases throughout the series of tasks. The highest of trunk flexion angles occurred at Task 10 which refers to the lowering task. Based on the graph, novice exhibits higher trunk flexion angles compared to workers for lowering task at Task 10. The result also shows that the greater the weight of load lifted, the greater the deviation of trunk flexion angle from the neutral axis.

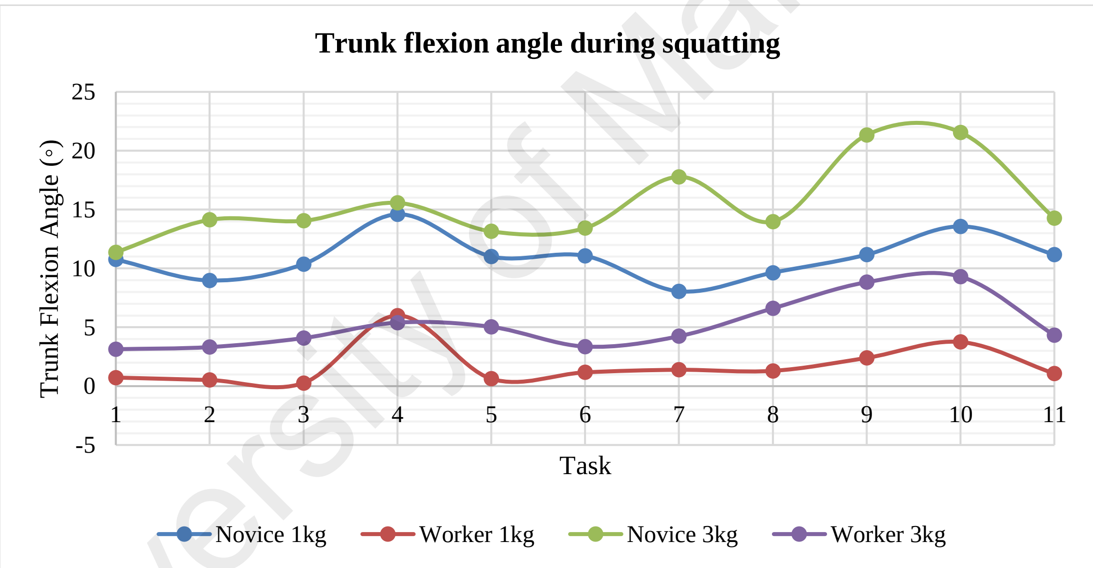

Figure 4.9: Trunk flexion angle during squatting

Figure 4.9 presents the trunk flexion angles during squatting session. As seen, the trunk flexion angles are varied for 1kg load tasks (novice: 8.06°-14.60°: worker: 0.27°-3.75°) and 3 kg load tasks (novice: 11.37°-21.56°: worker: 3.14°-9.30°). From these values, novice exhibits higher trunk flexion angle compared to worker and the trunk flexion angles increase as the load lifted increase throughout the series of tasks. The highest trunk flexion angles occur at Task 10 which refer to the lowering task. Based on the graph, novice exhibits higher trunk flexion angles compared to workers for lowering task at Task 10. The result also shows that the greater the weight of load lifted, the greater the deviation of trunk flexion angle from the neutral axis.

Lumbar flexion angle

The mean lumbar flexion angles for Task 1 to Task 11 are summarized in Table 4.8. The results are categorized into bending posture and squatting posture, according to weight of load lifted for each subject.

Table 4.8: The mean lumbar flexion angle

Task	Bending				Squatting			
	1kg		3kg		1kg		3kg	
	Novice (°)	Worker (°)	Novice (°)	Worker (°)	Novice (°)	Worker (°)	Novice (°)	Worker (°)
T1	2.04	0.64	3.41	2.22	1.26	0.64	1.55	2.22
T2	1.18	-0.82	0.08	1.73	4.52	1.73	1.19	1.07
T3	3.38	0.07	3.47	1.27	0.44	3.07	2.62	0.90
T4	1.26	0.35	4.02	1.68	-0.41	1.97	1.04	1.44
T5	2.93	0.73	2.78	2.15	2.32	2.15	2.63	0.97
T6	4.28	0.66	5.12	2.26	0.35	2.26	1.02	1.99
T7	4.34	2.11	5.89	4.27	1.07	2.77	1.67	1.83
T8	1.71	3.68	2.73	4.61	2.58	1.23	1.65	1.73
T9	1.80	0.74	2.70	4.96	0.53	2.49	2.08	2.62
T10	18.50	13.76	23.87	15.96	9.03	10.64	14.34	14.26
T11	3.19	2.47	3.95	3.53	1.87	3.53	1.77	1.43

Then, the graphs are plotted based on the mean lumbar flexion angle value in Table 4.8. Figure 4.10 and 4.11 present the distribution of the mean lumbar flexion angle during bending and squatting session for each task according to the weight of load lifted for both subjects. Figure 4.10 presents the lumbar flexion angle during bending session.

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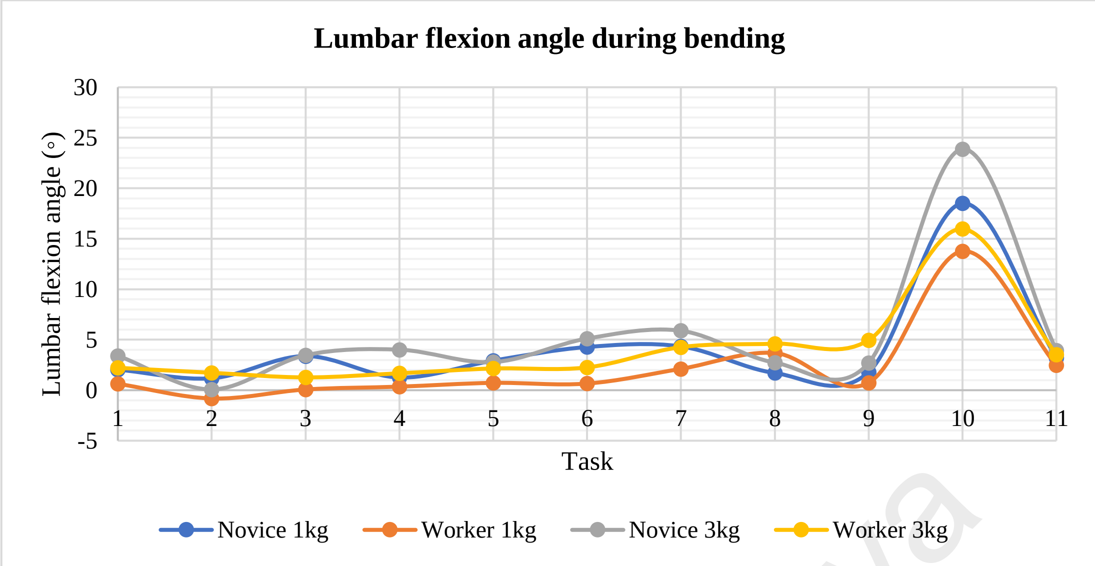

Figure 4.10: Lumbar flexion angle during bending

As seen in Figure 4.10, the lumbar flexion angles are varied for 1kg load tasks (novice: 1.18°-18.50°: worker: -0.82°-13.76°) and 3 kg load tasks (novice: 0.08°-23.87°: worker: 1.27°-15.96°). The highest lumbar flexion angle is obtained at Task 10 which referred to the lowering task. Based on the graph, novice exhibits higher lumbar flexion angles compared to workers for lowering task at Task 10. The result also shows that the greater the weight of load lifted, the greater the deviation of lumbar flexion angle from the neutral axis.

Figure 4.11 presents the lumbar flexion angle during squatting session. As seen, lumbar flexion angles are varied for 1kg load tasks (novice: -0.41°-9.03°: worker: 0.64°-10.64°) and 3 kg load tasks (novice: 1.02°-14.34°: worker: 0.90°-14.26°). The highest lumbar flexion angle is obtained at Task 10 which refers to the lowering task. Based on the graph, novice exhibits higher lumbar flexion angles compared to workers for lowering task at Task 10. The result also shows that the greater the weight of load lifted, the greater the deviation of lumbar flexion angle from the neutral axis.

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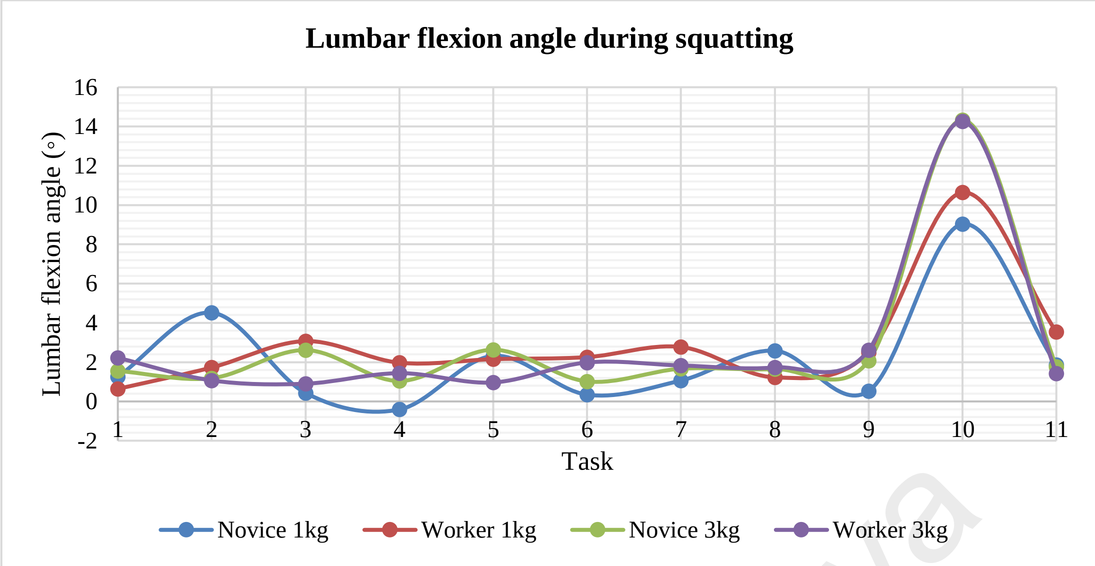

Figure 4.11: Lumbar flexion angle during squatting

4.3.4.2 Relationship Between Loads and Back Postural Angles (Flexion/Extension)

The relationship of load and back postural angles during flexion/extension was obtained by using Pearson Product-Moment Coefficient. This analysis was conducted to measure the strength between load and back postural angles (trunk and lumbar flexion/extension). Table 4.9 shows the significant correlation of load and back postural angles (trunk flexion angles and lumbar flexion angles) based on task.

Table 4.9: Pearson's Correlation between Load and Back Postural Angle

	Load	
Trunk Flexion Angle	**Pearson Correlation, *r***	**Sig. (2-tailed), *p***
T5 - Lifting (Worker Squatting)	0.433**	0.021
T7 - Carrying (Novice Squatting)	0.535**	0.003
T9 - Carrying (Novice Squatting)	0.508**	0.006
T10- Lowering (Novice Bending)	0.535**	0.003
T10- Lowering (Novice Squatting)	0.534**	0.003
T10- Lowering (Worker Bending)	0.454*	0.015
T10- Lowering (Worker Squatting)	0.426*	0.024
Lumbar Flexion Angle		
T1 – Lifting (Novice Bending)	0.590**	0.001
T4 - Lowering (Novice Bending)	0.417**	0.027
T9 - Carrying (Worker Bending)	0.482**	0.009
T10- Lowering (Novice Bending)	0.539**	0.003
T10 - Lowering (Novice Squatting)	0.486**	0.009
T10- Lowering (Worker Bending)	0.405*	0.033
T10- Lowering (Worker Squatting)	0.459*	0.014

It is found that several back postural angles show a positively correlated relationship with load in both postures in both subjects (judged at $p<0.01$ and $p<0.05$; 2-tailed). From the obtained results, the trunk flexion and lumbar flexion angles are positively correlated with load mostly at T10 which refers to lowering tasks.

The results show that the deviation of trunk and lumbar flexion angles from the neutral axis increase as the weight of load lifted increase in both sessions. This finding is in line with the previous study conducted by Plamondon et al., (2010) and Ulrey & Fathallah, (2013) showing that as the weight of load lifted increases, the greater the mechanical loads acts at the back which results to greater back loading. When workers exposed to the continuous MMH tasks, their ability to perform will be decreased drastically due to accumulated fatigue (Callaghan, 2006).

By comparing both subjects, novice shows the greater trunk flexion and lumbar flexion angles compared to worker. This could be explained by the posture style adopted in performing MMH tasks. Workers tend to bring part closer to their body. As the worker bring the part closer, they will bend more at their knees and compensate bend less at their trunk and lumbar region. Trunk and lumbar flexion are associated with the lumbar flexibility. Lumbar flexibility is influenced by the age and expertise.

The results also reveal that the deviation of trunk and lumbar flexion angles are higher in bending session compared to squatting session with the highest angle recorded at Task 10 (lowering task). The squat lift or lower posture requiring the bent knee and the straight trunk in bringing the part closer to the body would be reducing the extra demand on the back muscles while counterbalancing the moments of external loads (Shojaei et al., 2016). The squatting posture also minimizes the erector spinae muscle tension when load is initially moved closer to the body and close to the feet (Herrin, 1979). Greater the back loading is found during bending posture due to the gravitational effect. Bending posture

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generates additional moment contribution to the upper body mass (Hoozemans et al., 2008).

4.3.4.3 Back postural angles during Twisting

Back postural angles during twisting are divided into trunk twisting angles and lumbar twisting angles.

Trunk twisting angle

The mean trunk twisting angles for Task 1 to Task 11 are summarized in Table 4.10. The results are categorized into bending posture and squatting posture, according to weight of load lifted by each subject.

Table 4.10: The mean trunk twisting angle

Task	Bending				Squatting			
	1kg		3kg		1kg		3kg	
	Novice (°)	Worker (°)	Novice (°)	Worker (°)	Novice (°)	Worker (°)	Novice (°)	Worker (°)
T1	61.92	2.98	29.42	-19.35	55.13	-12.08	21.09	0.63
T2	66.72	66.72	23.61	23.61	83.72	83.72	32.75	32.75
T3	62.22	3.15	23.61	-5.96	77.92	1.13	41.41	-13.03
T4	73.94	9.34	23.61	-5.96	77.92	1.13	28.07	-11.72
T5	49.97	5.30	33.17	-12.52	67.69	18.63	-3.59	-11.72
T6	53.08	53.08	19.06	19.06	66.38	66.38	32.67	32.67
T7	53.08	11.89	19.06	-22.02	45.27	4.86	21.79	-9.98
T8	51.09	11.99	24.99	-5.33	58.79	-2.01	27.35	-14.22
T9	57.73	6.05	24.30	0.30	76.78	19.70	26.12	6.88
T10	56.94	7.21	19.65	-20.53	82.13	11.03	26.12	8.67
T11	63.72	5.31	15.13	-12.34	76.52	-5.84	32.72	-6.72

Then, the graphs are plotted based on the mean trunk twisting angle value in Table 4.10. Figure 4.12 and 4.13 present the distribution of the mean trunk twisting angle during bending and squatting session for each task according to the weight of load lifted for both subjects. Figure 4.12 shows the trunk twisting angle during bending.

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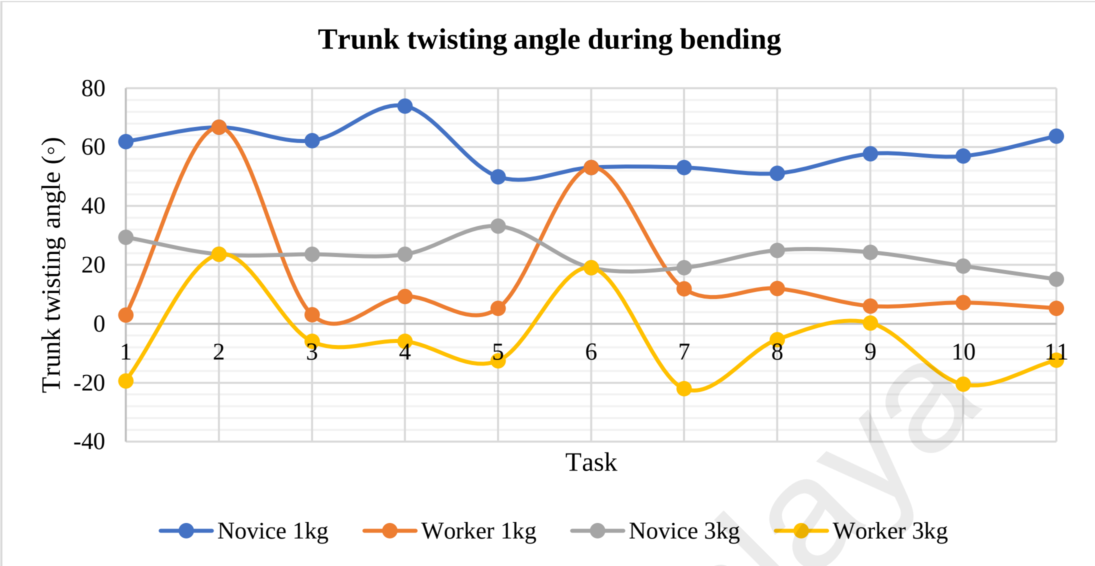

Figure 4.12: The mean trunk twisting angle during bending

As seen in Figure 4.12, the trunk twisting angles are varied for 1kg load tasks (novice: 49.97°-73.94°: worker: 2.98°-66.72°) and 3 kg load tasks (novice: 19.06°-29.42°: worker: -22.02°-23.61°) during bending session. Based on the graph, the pattern of Task 1 until Task 11 is quite similar for the same subject for the both subjects. Task 2 and Task 6 which refer to the tasks of holding part while cleaning exhibit higher trunk twisting angle for workers in performing 1kg and 3kg load tasks. The results also show that the trunk twisting angles for novice are higher compared to others for all tasks. The obtained results also show that the greater the weight of load lifted, the lower the deviation of the trunk twisting angle from the neutral axis.

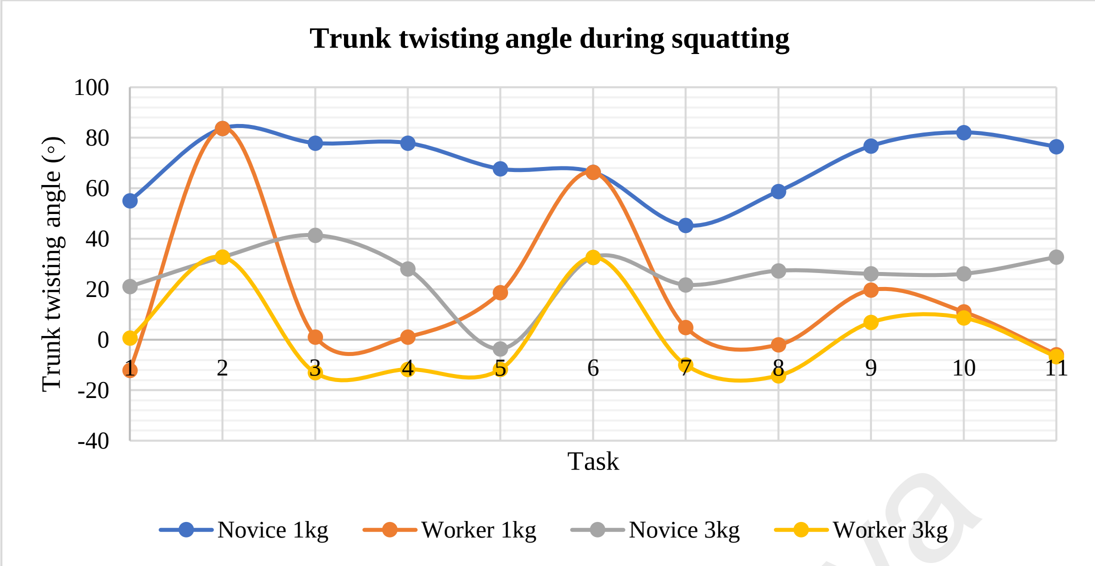

Figure 4.13: The mean trunk twisting angle during squatting

As presented in Figure 4.13, it is observed that the trunk twisting angles are varied for 1 kg load tasks (novices: 45.27°-83.72°; workers: -12.08°-83.72°) and 3kg load tasks (novices: -3.59°-41.41°; workers: -14.22°-32.75°) in squatting session. The graph shows the similar pattern of trunk twisting angles obtained for the same subjects and for both subjects. However, Task 2 and Task 6 exhibit higher values for workers during 1kg and 3kg load tasks. Task 2 and Task 6 refer to the task where subject is required to hold part while cleaning. The graph also shows that the fluctuation of the graph for novice 1kg load tasks is significantly higher compared to others. The results also show that the greater the weight of load lifted, the lower the deviation of the trunk twisting angle from the neutral axis.

Lumbar twisting angle

The mean lumbar twisting angles for Task 1 to Task 11 are summarized in Table 4.11. The results are categorized into bending posture and squatting posture, according to weight of load lifted for each subject.

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Table 4.11: The mean lumbar twisting angle

Task	Bending				Squatting			
	1kg		3kg		1kg		3kg	
	Novice (°)	Worker (°)	Novice (°)	Worker (°)	Novice (°)	Worker (°)	Novice (°)	Worker (°)
T1	23.81	10.38	-9.90	-2.00	26.46	12.26	-21.62	-3.14
T2	37.25	9.43	-4.47	3.23	29.18	11.00	-14.76	-0.79
T3	25.66	8.07	-0.78	1.78	31.57	11.86	-10.94	-1.19
T4	27.14	8.58	-0.69	-0.03	26.39	11.70	-10.45	-0.91
T5	21.87	7.98	-2.59	-2.50	19.97	9.42	-13.06	-0.60
T6	26.73	8.20	-2.61	-1.39	28.79	11.13	-15.21	-2.62
T7	27.28	7.83	-5.92	1.11	33.21	11.72	-9.23	-2.94
T8	26.84	5.95	-9.00	0.37	33.66	12.66	-21.81	-2.46
T9	30.09	0.84	-0.05	2.36	22.80	20.22	-12.74	-4.94
T10	29.28	2.87	-8.76	0.32	25.61	12.75	-15.91	-3.03
T11	31.00	7.52	-7.13	1.21	27.81	9.17	-15.13	-1.16

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Then, the graphs are plotted based on the mean lumbar twisting angle value in Table 4.11. Figure 4.14 and 4.15 present the distribution of the mean trunk twisting angle during bending and squatting session for each task according to the weight of load lifted for both subjects. Figure 4.14 shows the trunk twisting angle during bending session.

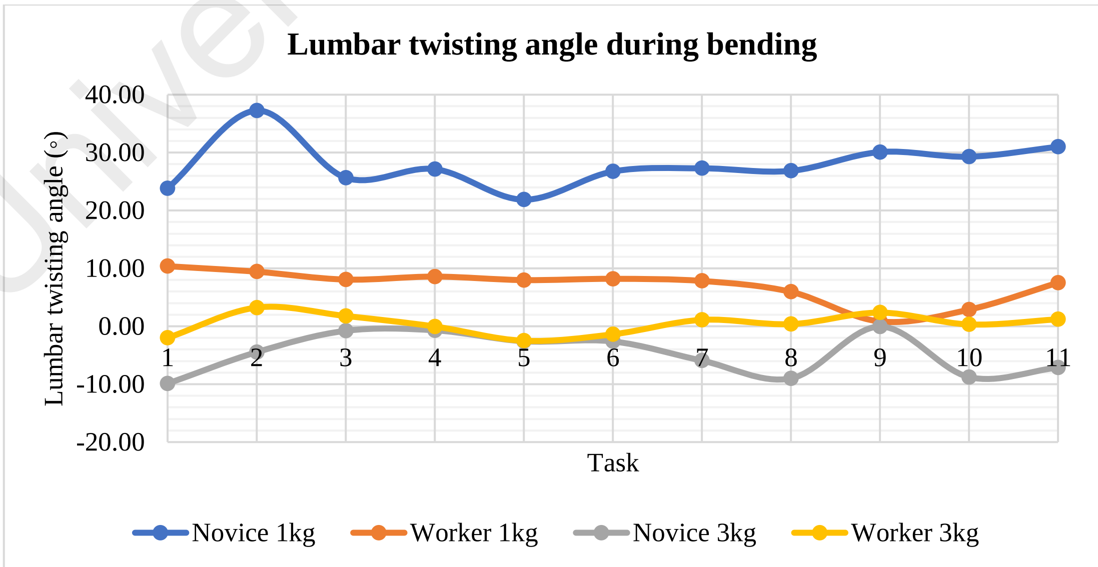

Figure 4.14: The mean lumbar twisting angle during bending session

As seen in Figure 4.14, the lumbar twisting angles are varied for 1kg load tasks (novice: 21.87°-37.25°: worker: 0.84°-10.38°) and 3 kg load tasks (novice: -9.90° to -0.05°: worker: -2.50°-3.23°) during bending session. Based on the graph, the pattern of Task 1 until Task 11 is quite similar for the same subject and for both subjects. The lumbar twisting angle is higher at Task 2 (holding part during cleaning process) for novice in performing 1 kg load tasks. The difference of lumbar twisting angle is due to the postures adopted by novice which are twisting and bending sideways at the right of back posture during cleaning process. The graph also shows that there is a deviation of lumbar twisting angle when the greater of weight lifted for both subjects.

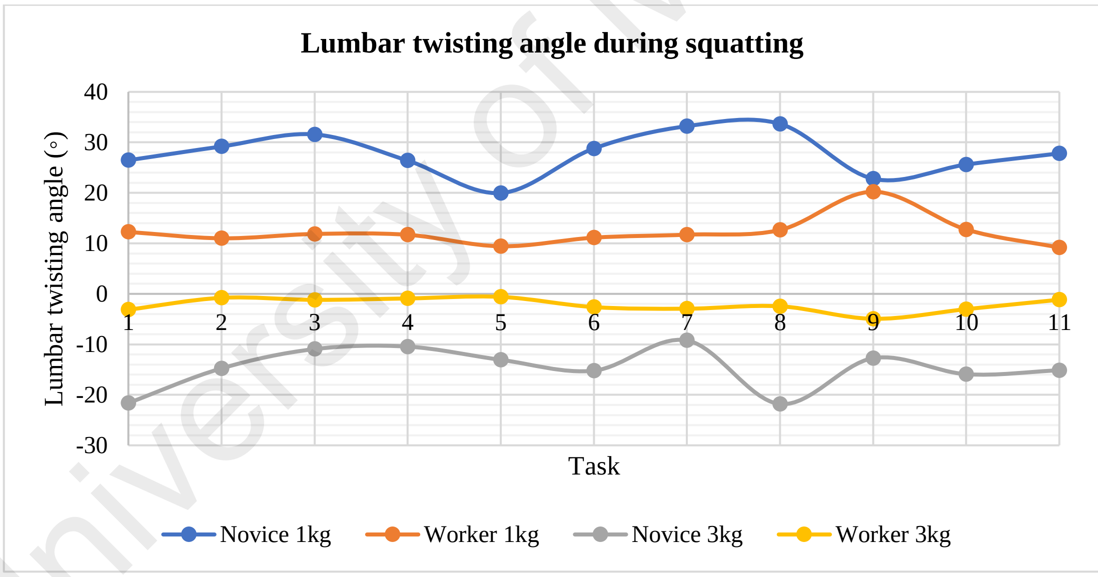

Figure 4.15: The mean lumbar twisting angle during squatting session

As seen in Figure 4.15, the lumbar twisting angles are varied for 1kg load tasks (novice: 19.97°-33.66°: worker: 9.42°-20.22°) and 3 kg load tasks (novice: -21.81° to -9.23°: worker: -4.94° to -0.79°) during squatting session. There are similar patterns of

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lumbar twisting angles for both subjects for 1kg and 3kg load tasks. Higher lumbar twisting angles are found for novice subject for 1kg load tasks.

4.3.4.4 Relationship Between Loads and Back Postural Angles (Twisting)

The relationship of load and back postural angles during flexion/extension was obtained by using Pearson Product-Moment Coefficient. This analysis is used to measure the strength between load and back postural angles (trunk and lumbar twisting angles) based on task. The significant correlation of load and back postural angles for novice and worker based on task is shown in Table 4.12.

Table 4.12: Pearson's Correlation between Load and Back Postural Angle

	Load	
Trunk Twisting Angle	**Pearson Correlation, *r***	**Sig. (2-tailed), *p***
T2- Holding (Novice Bending)	-0.666**	0.000
T2- Holding (Novice Squatting)	-0.476*	0.010
T2- Holding (Worker Bending)	-0.632**	0.000
T4- Lowering (Novice Bending)	-0.392**	0.039
T4- Lowering (Novice Squatting)	-0.393**	0.038
T5- Lifting (Novice Squatting)	-0.656**	0.000
T6- Holding (Novice Squatting)	-0.703**	0.000
T7- Carrying (Novice Squatting)	-0.579**	0.001
T9- Carrying (Novice Squatting)	-0.390**	0.040
T10- Lowering (Novice Squatting)	-0.422**	0.025
T11- Lowering (Novice Bending)	-0.939**	0.000
Lumbar Twisting Angle		
T1- Lifting (Novice Bending)	-0.421**	0.026
T1- Lifting (Novice Squatting)	-0.625**	0.000
T2- Holding (Novice Bending)	-0.642**	0.000
T3- Carrying (Novice Bending)	-0.376**	0.049
T3- Carrying (Novice Squatting)	-0.604**	0.001
T4- Lowering (Novice Bending)	-0.385**	0.043
T4- Lowering (Novice Squatting)	-0.483**	0.009
T5- Lifting (Novice Squatting)	-0.530**	0.004
T6- Holding (Novice Bending)	-0.433**	0.021
T6- Holding (Novice Squatting)	-0.627**	0.000
T7- Carrying (Novice Bending)	-0.472*	0.011
T7- Carrying ((Novice Squatting)	-0.625**	0.000
T8- Holding (Novice Bending)	-0.436**	0.020
T8- Holding (Novice Squatting)	-0.620**	0.000
T9- Carrying (Novice Squatting)	-0.625**	0.000
T10- Lowering (Novice Bending)	-0.385**	0.043
T10- Lowering (Novice Squatting)	-0.676**	0.000
T11- Lowering (Novice Bending)	-0.463**	0.013
T11- Lowering (Novice Squatting)	-0.614**	0.001

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It is found that several back postural angles show a negatively correlated relationship with load for novice subjects (judged at $p<0.01$ and $p<0.05$; 2-tailed). The trunk twisting angles that strongly correlated with load are attained during lowering tasks at Task 11 while lumbar twisting angles are found and strongly correlated with load during lowering tasks at Task 10.

The results show that the greater weight of load lifted results to the lower the deviation of the trunk twisting angle from the neutral axis. These findings were contradicted by the previous research conducted by Kamarudin et al., (2019) and Yusuff et al., (2016) who found that the twisting angles increased as the weight of load increased. The difference might happen due to the difference of experimental set up. The weight of load lifted in this study was differed with the previous studies where more than 10kg was applied in their study. Furthermore, the difference also might occur due to the work methods applied during experiment was differed from this study. However, there were similarity in terms of the posture. According to the Kamarudin et al., (2019), the deviation of back angles was higher in the squatting posture compared to bending posture. This result is support the findings in this study which also found that the deviation of twisting angles in squatting is reported to be higher compared to bending.

4.3.4.5 Relationship of Trunk Flexion/Extension Angle and Energy Expenditure

The correlations between trunk flexion/extension angles and energy expenditure is analyzed by determine the effects of the angles on the levels of energy expenditure generated in the experimental task. Trunk deviation angle at Task 10 which represents the lowering task is selected due to the strong relationship with load either in flexion or twisting. The deviation of trunk angle recorded in the experiments are divided into several categories which ranges ($\theta < -20°$, $20° \leq \theta \leq 45°$ and $\theta > 45°$). These categories represent

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several distinct modes of trunk at work in standing posture which are introduced by Keyserling (1986). Each range represents a different posture adopted by workers as listed in Table 4.13.

Table 4.13: Categories of back postural angles

Angle range	Posture
$\theta < -20°$	Trunk in extension
$0° < \theta < 20°$	Trunk in neutral posture
$20° \leq \theta \leq 45°$	Trunk in mild flexion
$\theta > 45°$	Trunk in severe flexion

The graph in Figure 4.16 and Figure 4.17 show the energy expenditure versus the trunk inclination angle. The level of energy expenditure with respect to the range of trunk angle for bending session is shown in Figure 4.16.

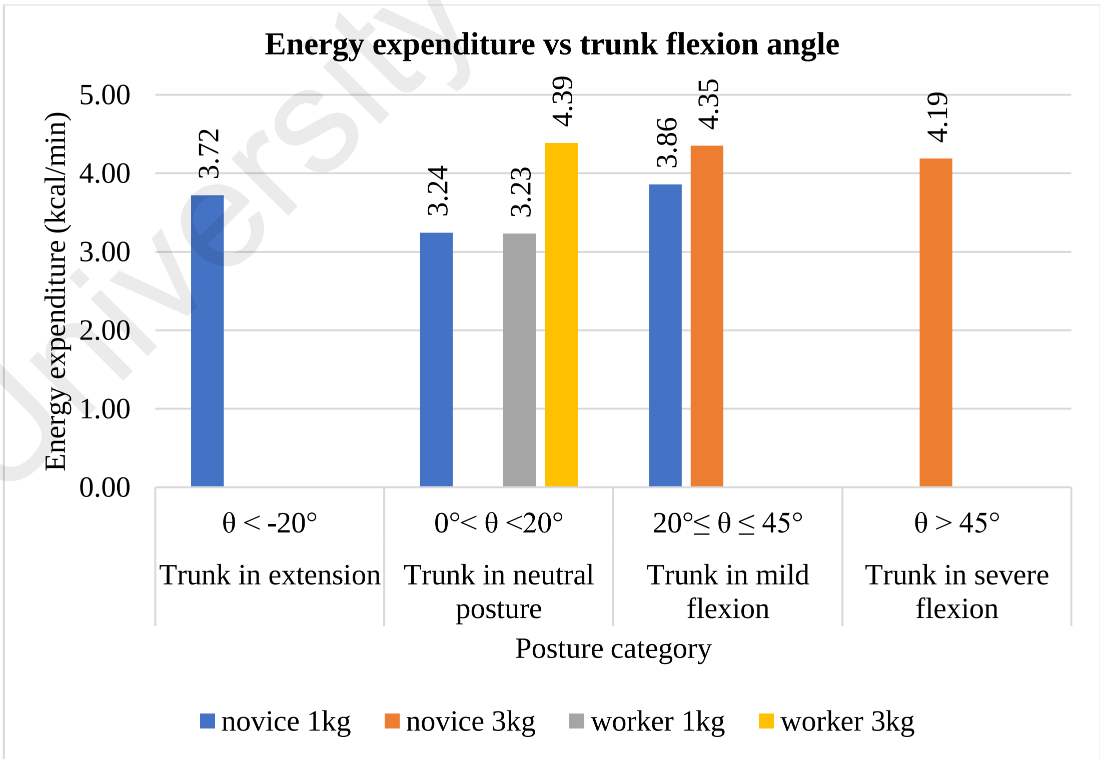

Figure 4.16: Level of energy expenditure versus angle (bending session)

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For novice subjects who performed 1kg load tasks, the result shows the lowest mean of energy expenditure is produced when the trunk angle deviates from the sagittal plane between 0° and 20°. This shows that the neutral trunk flexion posture results in the reduction of energy expenditure. The results also show that the highest energy expenditure occurs when trunk flexion angles are in between 20° and 45°. It is proven that there is an increase in energy expenditure when the subjects experience more trunk flexion angles.

For novice subjects performing 3kg load tasks, the lowest mean of energy expenditure is occurred when the trunk angle deviates from the sagittal plane more than 45° while the highest mean of the energy expenditure occurs when the trunk posture deviates in between 20° and 45°. It can be concluded that the level of energy expenditure decreases when the novice subjects experience trunk flexion when performing the tasks. The results also reflect that the mild flexion of trunk posture increases the level of energy expenditure.

Figure 4.17 shows the level of energy expenditure with respect to the range of trunk flexion angle during squatting session.

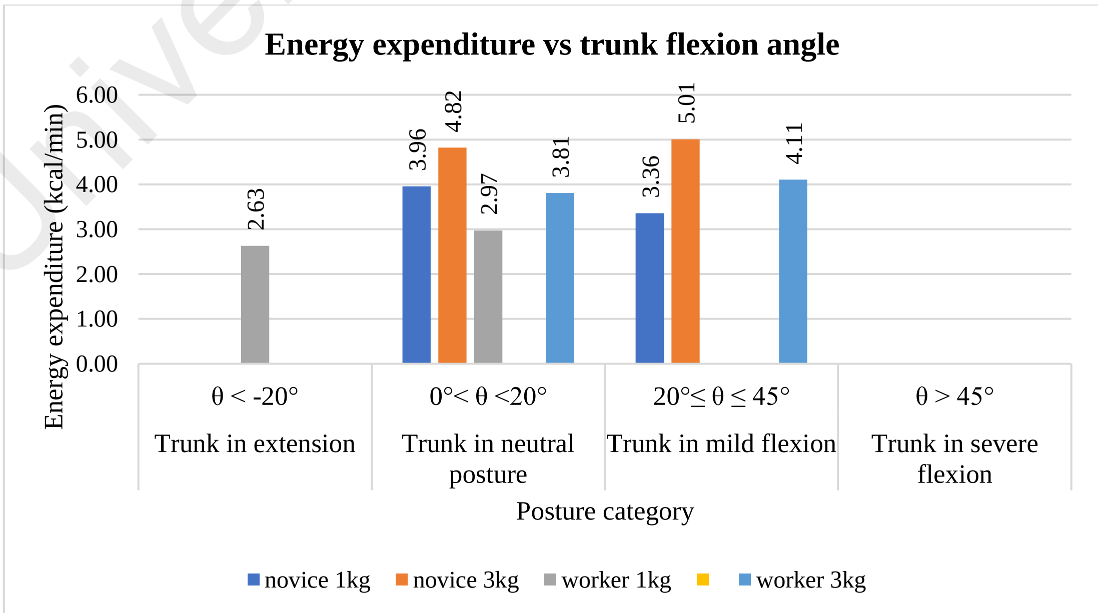

Figure 4.17: Level of energy expenditure versus angle (squatting session)

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For novice subjects performing 1kg load tasks, the results show that the lowest mean of energy expenditure is occurred when the trunk angle deviates from the sagittal plane in between 20° and 45°. This shows that the trunk in mild flexion posture reduces the level of energy expenditure. The results also reveal that the highest mean of energy expenditure is produced when the trunk flexion angle is in neutral posture. It means that the trunk flexion results in the reduction of energy expenditure and while the trunk in the mild flexion posture causes the increase in the level of energy expenditure.

For novice subjects performing 3kg load tasks, the result shows that the lowest mean of energy expenditure is occurred when the trunk angle deviates from the sagittal plane between 0° and 20°. It means that the neutral trunk flexion posture results in the reduction of energy expenditure. The highest mean of energy expenditure is attained when the trunk flexion angles are in between 20° and 45°. It is evident that there is an increase in energy expenditure when the novice experiences more trunk flexion angles in performing 3kg load tasks in squatting session.

For worker performing 1kg load tasks, the result reveals that the lowest mean of energy expenditure was produced when the trunk angle deviates from the sagittal plane less than 20°, whereas the highest mean of energy expenditure was produced when the trunk angle deviates from sagittal plane between 0° and 20°. It can be concluded that the level of energy expenditure decreases when the workers experience trunk extension in performing 1kg load tasks. The results also show that the neutral trunk posture increases the level of energy expenditure for workers.

For worker performing 3kg load tasks, the obtained result shows that the lowest mean of energy expenditure is produced when the trunk angle deviates from the sagittal plane

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between 0° and 20°. The highest mean of energy expenditure is produced when the trunk angle deviates from sagittal plane between 20° and 45°. This shows that the increase of energy expenditure occurs when the participants experience more trunk flexion angles in performing the tasks.

Effect of Neutral Trunk Flexion Posture on Energy Expenditure (0°< θ <20°)

The results show that the adopted neutral trunk flexion posture yields the minimum energy expenditure used. The neutral of trunk flexion assists in balancing the spine, which also discards most of the pressure from the spine and back muscles. In the neutral trunk flexion posture in which the angle deviates between 0° and 20°, the subjects can fully gain balance and proportion of their body mass and framework are based on their physical limitations while performing MMH tasks. The minimum energy is required to maintain the neutral trunk flexion either in the bending posture and squatting posture. The energy required is always related to the leg muscles activities. The minimum muscles activities show that less energy is needed to keep the body posture in the neutral position. This is due to those muscles which are at their optimum length while in neutral position. As a result, less muscles effort can produce a higher amount of force. Thus, it will reduce back pain and lessen the WMSDs.

The neutral trunk flexion angle was obtained for novice and worker performing MMH tasks with 1kg load tasks during bending posture. Neutral trunk posture also was attained for novice performing 1 kg load tasks, and novice and worker performing 3kg load tasks in squatting posture. As we can see from the results, the deviation angle of the trunk was more neutral or less deviation from neutral axis as the weight of load decreases. According to Davis et al., (2010) and Gallagher & Heberger (2015), the trunk remains more vertical as the heavier box approaches to the ground during lowering tasks. This

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result diminishes the mechanical loads acts at the back and directly reduce back loading and then reduce the risk of WMSDs.

4.4 Summary

The results and analyses of the data obtained from the industrial survey and experimental tasks have been shown in this chapter. The key findings are highlighted as follows.

From the industrial survey results, it is revealed that 78.8% of the workers experience the symptoms of WMSDs on different regions of their body with the highest recorded at lower back (85.5%). Neck is the second highest body region experienced of WMSDs followed by upper back, upper arms, forearms and shoulders. This shows that the highest prevalence of WMSDs among MMH tasks at CNC workstation was occurred at lower back. There are three potential physical risk factors found influencing the WMSDs in MMH tasks at CNC workstation which are bending the trunk slightly forward with hands above the knee level ($p < 0.05$), twisting the trunk (over 45°) while bending sideways ($p < 0.05$) and lifting object less than 3kg ($p < 0.05$).

From the experiment results, the energy expenditure is found to be higher for 3 kg load tasks (novices: 4.32kcal/min; workers: 3.64kcal/min) during bending and (novices: 4.95kcal/min; workers 4.39kcal/min) during squatting. The energy expenditure increases significantly as the weight of load increases in bending (novice: 22.03%; workers:33.33%) and squatting (novice: 27.91%; workers: 35.91%). Another significant finding needs to be highlighted is for 1 kg load tasks showing that novice requires 23.73% and 16.53% more energy in the bending posture and squatting posture respectively compared to workers. While for 3 kg load tasks, novice requires 15.74% and 11.31% more energy in the bending posture and squatting posture respectively compared to workers. In addition, energy expenditure was found to have positive correlation with load in both subjects in both postures (p<0.01;2-tailed).

Another important finding in the experiment is the trunk flexion angles which found to have more deviation from the neutral axis as the load increased. Novice exhibits higher deviation in trunk and lumbar flexion angles compared to workers, with the highest angles recorded during lowering task (Task 10). In addition, the deviation angles of trunk and lumbar twisting angle decreased as load was increased. Novice indicated higher in trunk and lumbar twisting angles compared to workers with the highest angles which occurred at lowering task (Task 10). Higher of back postural angles in flexion and twisting was observed during squatting posture compared to bending posture. In terms of the correlation, back postural angles in flexion have positive correlation with load while back postural angles in twisting have negative correlation with load (judged at p<0.01 and p<0.05; 2-tailed). Strong relationship was examined between load and back postural angles in flexion and twisting.

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CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The first objective of this study is to identify the prevalence of musculoskeletal discomfort among MMH workers at CNC workstation. The result of the industrial survey reveals that 78.8% of the CNC workers experience the WMSDs on different body regions. The highest prevalence of musculoskeletal discomfort was found at lower back (85.5%), followed by neck, upper back, upper arms, forearms and shoulders. There were three potential physical risk factors during MMH tasks at CNC workstation which identified to contribute to WMSDs. There was trunk slightly forward with hands above the knee level ($p < 0.05$), twisting the trunk (over 45°) while bending sideways ($p < 0.05$) and lifting object less than 3kg ($p < 0.05$).

The second objective of this study is to determine the relationship of loads and energy expenditure during MMH tasks at CNC workstation. The result found shows that load has significant positive correlation with energy expenditure for both subjects in both postures ($p<0.01$;2-tailed) which means that energy expenditure increased as load was increased. Another significant finding found through this study is novice required 23.73% and 15.74% more energy compared to worker for 1kg and 3 kg load tasks respectively during bending. While novice required 16.53% and 11.31% more energy compared to worker for 1kg and 3 kg load tasks respectively during squatting. In other words, novice required more energy demand compared to worker within a range of 11.31% - 23.73% throughout both activities.

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The third objective of this study is to determine the relationship of load and back postural angles namely trunk and lumbar angles during flexion and twisting. This study found that load has significant have positive correlation with trunk and lumbar flexion angles whereas negative correlation with trunk and lumbar twisting angles. This means that, as load increased from 1 kg to 3 kg, the back flexion angles was increased. On the other hand, back twisting angles was decreased. It is discovered that there is strong relationship between load and back postural angles in flexion and twisting at lowering task. Furthermore, novice indicated higher trunk and lumbar twisting angles compared to workers. This highlighted that working experience is the important criteria to reduce twisting and bending angles that contribute to the muscles fatigue which directly reducing the WMSDs.

From overall results, eliminating the potential physical risk factors during MMH tasks at CNC workstation is the most important to reduce the WMSDs. It is suggested that the workstation design or task design at CNC workstation could be improved to eliminate the awkward working postures such as severe trunk flexion and twisting during MMH tasks. The findings in this study can be used as a guidance to an organization to design MMH tasks at the CNC workstation.

5.2 Recommendation

Several issues have not been addressed in this study due to practical limitations and it can be considered in the future studies. The use of inclinometers and Actiheart monitoring device are cost-efficient and effective methods in measuring the movement of back postural angles and to capture the energy expenditure during MMH tasks. Thus, it is recommended that the current study is continued and applied in the real working environment using combination of other equipment such as the electromyography (EMG) to improve the findings. EMG can be used to measure the muscles activities during MMH

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tasks. Through combination of these equipment, the relationship of muscles activities and energy expenditure during MMH activities at CNC workstation could be determined.

The extended assessment is also recommended in the future studies by including both gender male and females. Other parameters such as foot displacement and knee flexion angles can be measured quantitatively to enhance the findings. Since the knee flexion is always connected to inclination of back postural angles, it is worthy to include this parameter in the future studies in order to get better understanding of optimum working posture for bending and squatting during MMH tasks and directly reduce the WMSDs.

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LIST OF PUBLICATIONS AND PAPERS PRESENTED

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1. Nor Suliani Abdullah, Siti Zawiah Md Dawal, Abu Bakar Mahat. Work- related Musculoskeletal Disorders among Batik Workers in Malaysia: Focusing in Batik Activity. Published in proceedings of The 17th International Conference on Industrial Engineering Theory, Applications and Practice. Busan, Korea, 6 - 9 October 2013

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