MUSCULOSKELETAL SAFETY OF AGING WORKFORCE ENGAGED IN MANUAL HANDLING JOBS

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To my family...

Abstract

Manual handling tasks are common in many industries. Occupational health and safety risks of manual handling tasks are mainly associated with musculoskeletal problems or disorders. Aged workforce is significant in several regions. Risks of the aged workers engaged in lifting and lowering related manual handling (MH) tasks are serious concerns in several industries. The aim of this research is to develop a framework for assessing musculoskeletal safety of aged workers engaged in lifting and lowering MH tasks. This research has: (i) benchmarked work related MSD risks in lifting/ lowering MH tasks; (ii) explored relationships between (a) personal attributes (such as age, body mass index, and physical abilities), job demands (such as weight, repetition, and duration of lifting), postural requirements (e.g. extent of bending), and work environment (mainly vibration from surface/ floor and tools/ equipment handled), and (b) work related MSDs; (iii) developed a suite of multinomial regression models for predicting probabilities of work related MSD occurrences from lifting/ lowering MH tasks; (iv) developed a biomechanical modelling and virtual reality (VR) simulations based assessment system for quantifying lumbar joint contact force and lumbar joint torque values from specific lifting/ lowering MH tasks; (v) proposed an ergonomic risk assessment framework for decision support to ensure musculoskeletal safety from lifting/ lowering MH tasks. Main research methods include structured questionnaire survey, task analyses through field observations and videos, 3-D motion capture in VR, bio-mechanical modelling, and isokinetic trunk strength measurement. Models to predict probabilities of work related MSDs and quantification of lumbar joint loads will be useful for decision support in ergonomic designing and modifying MH tasks/ workplaces. Moreover, the integrated risk assessment framework proposed in this thesis will be useful for safely engaging aging workforce in physically demanding trade works in industries such as construction and manufacturing.

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Declaration

The author hereby declares that this thesis:

- is candidate's own work
- contains no material which has been accepted for the award to the candidate of any other degree or diploma at any university, and to the best of the candidate's knowledge contains no material previously published or written by another person except where due reference is made in the text of the examinable outcome.
- properly met all conditions to the ethics clearance. This research been approved by Swinburne's Human Research Ethics Committee (approval number SHR Project 2015/138) in line with the National Statement on Ethical Conduct in Human Research in Australia.

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Table of Contents

List of Figures

List of Tables

List of Acronym

MH	Manual handling
MSD	Musculoskeletal disorder
AERA	Advanced ergonomic risk assessment
WMSD	Work related musculoskeletal disorder
GRF	Ground reaction force

1. INTRODUCTION

1.1. Chapter overview

This chapter includes: a discussion on background for this research, research statement including aim and objectives, a summary of research methodology, an overview of the scope of research, and a summary of thesis structure.

1.2. Background of the research

1.2.1. Manual handling tasks and musculoskeletal disorders

Manual handling (MH) tasks include lifting, lowering, pushing, pulling, and carrying (Work Safe Australia 2000). MH tasks are one of the main root causes for work related musculoskeletal disorders (MSDs) or injuries. Working abilities are physical, psychological and cognitive. Physical abilities of individuals have direct significance for health and safety in MH tasks (Ilmarinen, Tuomi and Seitsamo 2005). According to Safe Work Australia (2013), the lifting and lowering MH tasks are the top ranked (Safe Work Australia 2013). For example, 43% of manual handling related injuries in the workplace are sprains and strains of joints/ adjacent muscles and another 33% of injuries are due to muscular stress arise from lifting objects (Australian Bureau of Statistics 2012a; Hoy et al. 2014) due to MH tasks. Previous studies revealed that lifting/ lowering of different weights along with associated demands of repetition (frequency) and postural requirements are the leading causes for work related musculoskeletal disorders (MSDs) (Mital, Nicholson and Ayoub 1993; da Costa and Vieira 2010). The occupational health risks of lifting/ lowering MH tasks are mainly associated with the musculoskeletal system of individuals, which often lead to various MSD problems and injuries to body parts such as bones, discs, joints, ligaments, muscles, nerves and tendons in arm, back, elbow, knee, neck, shoulder, wrist. According to 2013-2014 Australian Workers' Compensation Statistics, body stressing in daily tasks is the leading root cause (Safe Work Australia 2015). Furthermore, leading forms of MH related MSDs include: muscle sprain and strain, disorders in back, wrists, shoulder, neck, and knee (Safe Work Australia 2016).

1.2.2. Aging workforce

With advanced healthcare facilities and living conditions, life expectancies in various regions have been vastly improved. An overview of global trend of ageing population has been presented in Appendix A. Aged workforce in several countries including Australia is significant. Approximately 2.5 million people in Australia are still willing to work even after their retirement age of 65 (Australian Bureau of Statistics 2012b). Table 1.1 presents a summary of aged workforce in Australia who is still working in the different sectors. For example, the average age at retirement in the Australia-based construction and manufacturing industries are 58.8 and 57.4. However, 51.5% and 48.5% of the workforce in these industries are old aged, i.e. 60 and above (Australian Bureau of Statistics 2012b).

Table 1.1 Elderly workforce in Australia (extracted from, Australian Bureau of Statistics 2012b, 2015, 2016)

Industry	Total number of workers '000	Average age at retirement (Years)	60 to 64 '000	65 and above '000	Total aged Workforce '000	Total aged Workforce %
Manufacturing	298.8	57.4	104.2	40.7	144.9	48.5
Whole sale and retail trade	276.8	57.7	78.1	46.4	124.5	45.0
Health care and social assistance	244.8	57.1	65.2	42.9	108.1	44.2
Construction	151.4	58.8	48.1	29.8	77.9	51.5
Arts. Recreation and other services	129.3	59.9	54.7	22.2	76.9	59.5
Agriculture, forestry, fishing	99.9	63.4	25.8	50.8	76.6	76.7
Transport, postal and warehouse	167.9	57.7	52.5	23.3	75.8	45.1
Education and training	165.3	58.2	37.2	37.0	74.2	44.9
Professional, scientific and technical services	103.4	60.6	28.4	35.6	64.0	61.9
Other industries	138.5	57.1	24.0	26.3	50.3	36.3
Administration and support services	84.9	55.9	18.0	10.4	28.4	33.5
Accommodation and food services	104.4	54.4	22.3	4.6	26.9	25.8
Mining	26.0	59.4	10.3	3.9	14.2	54.6
Utility companies (electricity, gas, water, waste)	29.0	58.1	6.0	5.0	11.0	37.9

The Australian Government has recognized that participation of aged workforce is significantly important for the economic and social welfare in the country. Accordingly, the Australian government has taken initiatives to facilitate healthy participation of aged workers in various industries.

1.3. Age-related issues for working ability

Ageing can influence an individual's working abilities in MH tasks. Physical abilities are significantly lower in older ages (Tuomi et al. 2001; Ketcham et al. 2002; Roper and Yeh 2007). Donato et al. (2003) mentioned that physical abilities start decreasing from age 40 especially muscular functions, between the age of 40 and 60 around 20% age-related decline of physical ability occurs. After 50 years of age, remarkable decrease occurs in several cases (Donato et al. 2003). People aged over 65 may have half of the physical ability of 25 year age group (Viitasalo et al. 1985; Shephard 1999). Although the physical ability reduction with aging is natural, it can be hazardous when elderly people are working in MH tasks (Kawakami et al. 2000; Farrow and Reynolds 2012). Literature review revealed following ageing related physical ability changes:

(i) Sensory functioning*

1. Vision- with aging eye shows age related decline in performance
2. Hearing- hearing loss due to age an additional occupational hazard
3. Balance- balance deteriorates with age

(ii) Psychomotor functioning**

1. Response time- age is positively related with response time

(iii) Anthropometry and physical functioning

1. Anthropometry- anthropometry decrease gradually with age (Muñoz et al. 2010)
2. Strength and flexibility- strength and flexibility decrease with age

(iv) Cognitive and intellectual functioning

1. Memory and learning- memory decreases in older adults
2. Attention- age has both positive and negative effect on attention

(v) Age-related changes in attitudes and beliefs

*The skin senses, olfaction and taste, and **time tracking do not affect most of the MH tasks

Table 1.2 provides a summary of physical strength declining with ageing.

Table 1.2 Physical strength decline with aging

Physical ability	Decline in physical strength	Related references
Wrist strength (both hand)	Wrist strength of workers aged 50 and above is found to be 17% lower than workers aged less than 40 years.	Gall and Parkhouse (2004): Laboratory measurement, cross-sectional study, N=40,
Trunk strength	Among people aged over 60 years, the person engaged in lower physical workload had better extension and flexion strength than those engaged in higher physical workload.	Savinainen, Nygård and Ilmarinen (2004b): Laboratory measurement, longitudinal study, N=95,
Knee strength	Knee strength of elderly (age > 50) workers is found to be significantly lower than the workgroup (<50 years of age).	Nygård et al. (1987): Laboratory measurement, cross-sectional study, N=129
Shoulder strength	Elderly workers' (age > 47 years) shoulder abduction-adduction, and elevation strength is found to be significantly lower than that of the younger adults (age <30 years)	Schibye et al. (2001): Laboratory measurement, cross-sectional study, N=47

Elderly workers are more vulnerable than a younger generation as far as musculoskeletal disorders/ injuries are concerned (Silverstein 2008; NSW Work Cover Authority 2014). The musculoskeletal disorder risk and consequences of elderly workers are severe (Silverstein 2008; NSW Work Cover Authority 2014). Silverstein (2008) noted that "in some ways, older workers are the most skilled and most productive employees, but in others, they are the most vulnerable".

1.4. Research statement

Literature review revealed that existing risk assessment frameworks do not comprehensively integrate the requirements of "ageing" workforce, especially to minimise MH related MSD. The aim of this research is to develop a framework for assessing musculoskeletal safety of aged workers engaged in lifting and lowering MH tasks.

1.4.1. Objectives of this research

1. Benchmarking work related MSD risks in lifting/ lowering MH tasks.
2. Exploring relationships between (a) personal attributes (such as age, body mass index, and physical abilities), job demands (such as weight, repetition, and duration of lifting), postural requirements (e.g. extent of bending), and work environment (mainly vibration from surface/ floor and tools/ equipment handled); and (b) work related MSDs.
3. Developing a suite of multinomial regression based models for predicting occurrences of work related MSDs from lifting/ lowering MH tasks.
4. Developing an assessment model for quantifying lumbar joint contact force and lumbar joint torque values from specific lifting/ lowering MH tasks.

5. Proposing an ergonomic risk assessment framework for decision support to ensure musculoskeletal safety from lifting/ lowering MH tasks.

1.5. Research methods

Figure 1.1 portrays methods adopted in this research.

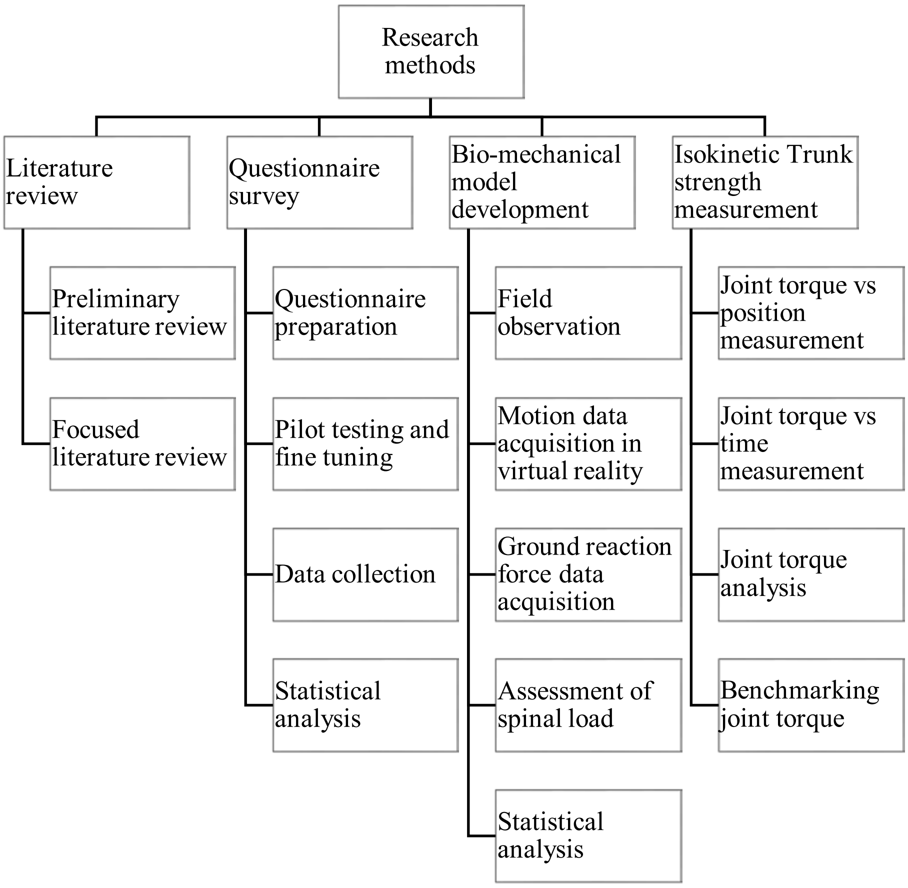


Figure 1.1 Research methods

1.5.1. Literature review

Preliminary literature review was undertaken for designing the questionnaire. Scopus, Web of Science, and Google scholar databases were searched using the following keywords: manual handling, musculoskeletal disorders, aged workers, health and safety, ergonomics, risk assessment, musculoskeletal disorder questionnaire. Search results were screened by scanning title, abstract, and key words of the article. All type of documents published in last 30 years were reviewed. Literature review directed to Benchmark work related MSD risks in lifting/ lowering MH tasks. Details are given in chapter 2. Focused literature review served all objectives and was undertaken to consolidate available models and frameworks. Details are given in chapter 5. Focused literature review led to construct a new advanced ergonomic risk assessment (AERA) framework.

1.5.2. Questionnaire survey

For meeting the objective 2 and 3, a questionnaire survey was conducted. Workers engaged in lifting/ lowering tasks from different organizations in construction and manufacturing industries were the target respondents of the survey. The questionnaire (Appendix B) was distributed along with an information and consent statement. Further details are consolidated in chapter 3. In line with the National Statement on Ethical Conduct in Human Research in Australia, this research been approved by Swinburne's Human Research Ethics Committee (approval number SHR Project 2015/138). Appendix D of this thesis providing evidence of ethics clearance for this research (Appendix D).

1.5.3. Bio-mechanical model development

For meeting the objective 4, biomechanical modelling and virtual reality simulation are considered. A set of field observation have been conducted for task details and simulations. Then a set of selected lifting/ lowering manual handling tasks were performed in the laboratory settings. Workers 3-dimentional motion data, and ground reaction force data were obtained to develop biomechanical model of the observed task. Biomechanical model was undertaken to obtain spinal loads (lumber joint contact force and joint torque) during lifting/ lowering manual handling tasks. Further details are in chapter 4.

1.5.4. Isokinetic trunk strength measurement

Trunk strength was tested in laboratory settings. To determine maximum strength throughout the range-of-motion isokinetic testing was considered. Further details (testing protocol, experimental design) are covered in chapter 4. This method was adopted to benchmark trunk strength to integrate into trunk musculoskeletal safety of lifting/ lowering related manual handling tasks.

1.6. Research scope

Manual handling tasks include lifting, lowering, carrying, pulling, and pushing. This research focused on lifting lowering MH tasks in construction and manufacturing industries. Carpentry, metal fitter and machinists, and bricklayer trades in construction and manufacturing industries included in this research. Questionnaire survey focused on workers' perception on physical factors in lifting/ lowering MH tasks in construction and manufacturing industries. Biomechanical modelling included carpentry, metal fitter and machinists, and bricklayers lifting/ lowering MH tasks. MSDs can happen in different parts of the body such as, neck, shoulder, elbow, wrist, and knee. This research covered back problems/ disorders from lifting lowering MH tasks. This research focussed on ergonomic principles and practices as they pertain to MSDs prevention in different occupations. Physical abilities decline with age in a greater rate than that of the decrease of mental abilities (Ilmarinen 1997). Although psychological and psychosocial factors influence health and safety in manual handling task, these were not considered as a physical factor.

1.7. Thesis organization

- Chapter 1 includes background of the research, details of research problem including aim and objectives, research methodology, scope of the research, and thesis outline.
- Chapter 2 presents summary of the critical literature review, which includes benchmarking work related MSD risks in lifting/ lowering MH tasks.
- Chapter 3 includes multinomial logistic regression based models for predicting occurrences of work related back MSDs from lifting/ lowering MH tasks.
- Chapter 4 presents developing an assessment model for quantifying lumbar joint contact force and lumbar joint torque values from specific lifting/ lowering MH tasks. Carpentry, bricklayer, and metal fitter and machinist trades are considered for model development. The model development includes 3-D motion capturing in virtual reality (VR), biomechanical modelling, and regression.
- Chapter 5 includes review of existing ergonomic risk assessment models and frameworks in manual handling task, and proposed a new Advanced Ergonomic Risk Assessment (AERA) framework for aging workforce engaged in lifting/ lowering manual handling tasks.
- Chapter 6 presents conclusions and recommendations of this research.

2. RISKS IN MANUAL HANDLING TASKS

2.1. Chapter introduction

This chapter presents summary of the critical literature review, which includes benchmarking work related MSD risks in lifting/ lowering MH tasks.

2.2. MSD risks in lifting/ lowering MH tasks

Risk factor inherent in the worker is:

- physical ability; physical ability is an ability to perform lifitng lowering MH task against task demand (Hildebrandt et al. 2000)

Risk factors integral in the lifitng lowering MH tasks are:

- Loads (Faber et al. 2009; Spallek et al. 2010)
    - weight of the load (Andersen, Haahr and Frost 2007)
    - repetitive lifting of the load (Ciriello et al. 1999)
    - repetitive lifting of the load to a certain extent (Ilmarinen 2002)
    - duration of lifting lowering taks(Pinder, Reid and Monnington 2001; Wells et al. 2007)
- Postural demand
    - repetitive awkward posture of the upper and lower limb (i.e. back, upper arm/ shoulder, head/ neck, wrist, and knee) (Ng, Hayes and Polster 2016)
    - static awakward posture of the limb – keep uper and lower limb posture for a period of time in a fixed awkward position (Svensson and Andersson 1989; Coenen et al. 2016)

Risk facotrs integral in the environment is:

- vibration; vibratibn from floor and tools is linked to carpal tunnel syndrome. Prolonged exposure to vibration forces may create choronic MSDs (Johansson and Rubenowitz 1994; Putz-Anderson et al. 1997)
- Temperature, noise, and light influence MSDs (Evans and Johnson 2000; Gold et al. 2009)

2.2.1. Physical ability and musculoskeletal disorder

Physical ability influences on performing manual handling tasks (Savinainen, Nygård and Ilmarinen 2004a). Literature review revealed that static and dynamic strength is required for MH task (Rantanen et al. 1998; Foldvari et al. 2000; Tiedemann, Sherrington and Lord 2005; Fiser et al. 2010), and any deficiency of static and dynamic strength reduces safety (Verbrugge and Jette 1994; Fried and Guralnik 1997; Fried et al. 2004; Montero-Odasso et al. 2011). Reduced trunk strength creates fatigue during MH tasks. Manual handling tasks functional limitation is the consequences of static, dynamic, and trunk strength reduction (Savinainen et al. 2004). Manual dexterity and multi-limb coordination are also required performing MH tasks, any deficiency of it creates MSD risks in the workplace such as disorder, disability (Guralnik et al. 2000; Kenny et al. 2008), dependency (Guralnik et al. 1994; Penninx et al. 2000), and mortality (Guralnik et al. 1994; Studenski et al. 2011). Flexibility, body equilibrium, stamina, arm hand steadiness, and finger dexterity abilities are reduced with the increasing of the age (Faulkner et al. 2007). Safe material lifting and lowering of elderly people is subject to the loss of physical abilities.

2.2.2. Loads and frequency of lifting/ lowering

Handling loads is a risk factors for Musculoskeletal problems/ disorders (Bernard 1997; Faber et al. 2009). Handling varying size of the loads has relationship with MSDs, e.g. 5 kg, 10 kg once a day at least, and 20 kg (Frymoyer et al. 1983; Ohisson et al. 1995; Punnett and Wegman 2004). Under optimal condition 20 to 23 kg is the maximum weight a person can carry (Waters et al. 1993). International standard has mentioned safe lifting weight which is 15 kg for both young and elderly people. Code of Practice for manual handling has advised to keep the weight within 16-20 kg or below this range. To categories weight, different ranges of load have been mentioned in the literature: (i) 0–2 kg, 2–10 kg, >10 kg (McAtamney and Nigel Corlett 1993) (ii) 1–5 kg, 6–15 kg, 16–45 kg, >45 kg (Kilbom 2000) (iii) <10 kg, 10–20 kg, >20 kg (Kivi and Mattila 1991). Light and heavy loads have been defined differently in the literature (Genaidy et al. 1998). Hence it is uncertain which level of physical strength is required to keep the level of exposure minimal during lifting/ lowering tasks (Kumar et al. 2001). A study has found that frequent lifting is a risk for MSDs (Faber et al. 2009; Spallek et al. 2010). According to the international standard, lifting frequency is a risk factor for WMSDs of the back, shoulder, wrist, neck, and knee (International Standards Organizations 2003). The standard recommended that the maximum lifting frequency is 15 lifts per minutes for 7 kg weight lifting (International Standards Organizations 2003). The International Standards Organizations has also mentioned that lifting lowering MH tasks duration should not be exceeded more than an hour (International Standards Organizations 2003).

2.2.3. Extent (height) and frequency of lifting/ lowering tasks

Extent of lifting associated with muscle exertion, which is a risk factor in lifting/ lowering tasks (Waters et al. 1993; De Zwart et al. 1997). The standard lifting height is 75 cm from the floor. But this varies according to the person's anthropometric data. If the location of the load is near the floor, some studies suggested increased spinal load (Bean, Chaffin and Schultz 1988). Increased prevalence of musculoskeletal injuries found during lifting for the load located near/ on the floor (Punnett et al. 1991). Lifting from floor needs greater energy spending than lifting/ lowering from higher heights (Garg, Chaffin and Herrin 1978). With the increasing of the vertical height of the load workers lose their ability to lift maximum load (Snook and Ciriello 1991).

2.2.4. Back posture during lifting lowering tasks

There is a correlation between forward bending during lifting (trunk flexion) and back MSDs (Vandergrift et al. 2012). Spinal loading during lifting lowering tasks is a risk factor for back MSDs (Burdorf and Sorock 1997; Bakker et al. 2007). During lifting/ lowering (trunk flexion and extension) spinal column bending (forward/ backward bending) enhance the risk of MSDs (Keyserling, Punnett and Fine 1988; Hoogendoorn et al. 2000b; Eriksen, Bruusgaard and Knardahl 2004). 20 degree or less forward bending has not been correlated with back problems/ disorders (Aarås 1994; Aarås et al. 1997). Moderate number of cases of back musculoskeletal disorder were claimed for the back forward bending between 21^0 and 45^0. More than 45^0 of forward bending created severe MSD problems/ disorders (Punnett et al. 1991). Back forward bending between 21^0 and 45^0 is too narrow range to observe accurately for the observer (McAtamney and Corlett 1993). It was found that low back muscle activity was high, due to the lifting activities (trunk flexion phenomenon) (Jansen, Morgenstern and Burdorf 2004; Mork and Westgaard 2009). A study by O'Sullivan et al. (2006) has found that forward bending on lifting (flexion spinal posture) and lower back musculoskeletal disorder is positively correlated to each other. Peak trunk forward bending (flexion) angle, peak trunk velocity (degree per second), average trunk velocity (degree per second), repetition require, and time require in trunk forward bending (flexion) significantly related with the back musculoskeletal problems/ disorder (Thorbjörnsson et al. 2000; Neumann et al. 2001a; Neumann et al. 2001b). Repetition of back flexion/ extension during lifting/ lowering related manual handling task is related to the risk of musculoskeletal disorders (Bernard 1997; Sullivan et al. 2009). When workers worked for a long hour shift with this postural stress, they claimed more back problems/ disorders (Westgaard and Aarås 1984). The International Standards Organizations (2000) categorised back movement frequency into two exposure levels, which is less than, and more than 5 times per minute. Back flexion and extension was related with repetition (Sullivan et al. 2009). It was reported that frequent lifting increased the risk of back MSD (Beach, Coke and Callaghan 2006), since repetition creates fatigue in muscles (Dolan and Adams 1998).

2.2.5. Head/ neck posture during lifting lowering tasks

A common risk factor for head/ neck problems/ disorder is the posture of the head/ neck (Larsman et al. 2006; Straker et al. 2009). Awkward head/ neck posture kept for a duration is risky for head/ neck problems/ disorders (Bernard and Putz-Anderson 1997; Arvidsson et al. 2008; Szeto, Straker and O'Sullivan 2009). Greater than 30 degrees of inclined head/ neck creates fatigue/ physical discomfort. On the one hand, when working with 15 degrees of head neck inclination, minimal subjective or EMG discomfort were recorded (Chaffin 1973). On the other hand, another study found that 15 degrees of head/ neck inclination is associated with considerable level of disorder (Ohisson et al. 1995). Neck MSDs attributed to the forwarded head/ neck posture during upper arm/ shoulder extension/ flexion (Holmstrom, Lindell and Moritz 1992; Ohisson et al. 1995; Skov, Borg and Ørhede 1996; Cassou et al. 2002; Weon et al. 2010). Observer mentions difficulty in determining specific head/ neck angle. Descriptive terms (twisted and/ or bent minor/ moderate/ excessive) are more acceptable compared to mention a specific value of angles (Li and Buckle 2000; Wahlström et al. 2004). 5 degrees of flexion of head/ neck relative to the trunk had no effect on the neck problems/ disorders (Burgess-Limerick et al. 1999). Work methods are mainly responsible for awkward posture of the head/ neck. Occurrences of awkward head/ neck postures are found common in 70 percent jobs (Linton 1990; Keyserling, Brouwer and Silverstein 1992b). There is positive relationship between head/ neck posture and the head/ neck problems/ disorders (Visser et al. 2000). Neck bone and muscle has a vital role in lifting/ lowering tasks at shoulder level (Nimbarte et al. 2010). Angular angle of the head/ neck awkward/ inclined posture been categorised in previous study, such as 0 to 10 degrees of flexion is categorised to the score 1, 10 to 20 degrees of flexion is categorised to score 2, and more than 20 degrees is categorised to the score of 3 (McAtamney and Corlett 1993). According to the International Standard, neck flexion/ extension up to 25^0 is acceptable with 1 to 8 minutes acceptable holding time, more than that is not recommended (International Standards Organizations 2000).

2.2.6. Shoulder/ upper arm posture during lifting lowering tasks

Physical demand in the lifting lowering tasks created shoulder MSDs (Pope et al. 2001). Shoulder or upper arm abduction/ adduction/ elevation more than 60 degrees increases the risk of shoulder and upper arm MSDs. Upper arm elevation, particularly working above shoulder height, increases the load on shoulder muscle (Wiker, Chaffin and Langolf 1989; Masaharu 2002). Arm elevation greater than 60 degrees repeatedly or holding for a duration increases the risk of shoulder discomfort (Bernard 1997). Posture was categorised into two, below and above the shoulder height that is angle between upper arm and body less than 90 degrees or greater than 90 degrees (Ketola, Toivonen Iv and Viikari-Juntura 2001). In another study, shoulder/ upper arm elevation had been categorised into four (30, 60, 90, and 120 degrees), and found that upper arm/ shoulder posture influences the musculoskeletal loading of the shoulder (Antony and Keir 2010). Upper arm posture had also been categorised into four i.e. score 1 for 20 degrees flexion/ extension, score 2 for 20 to 45 degrees of flexion/ extension, score 3 for 45 to 90 degrees of flexion/ extension, score 4 for more than 90 degrees of flexion/ extension (McAtamney and Corlett 1993; Hignett and McAtamney 2000). According to the International Standard, upper arm posture more than 60^0 is not recommended, 20^0 to 60^0 are acceptable with 1 to 4 minutes acceptable holding time, and up to 20^0 is acceptable (International Standards Organizations 2000).

It has been found that upper arm/ shoulder posture repetition increases the disorder of shoulder tendon . Shoulder/ upper arm movement more than 2.5 times per minute influences the risk of shoulder MSDs, but it had not been shown the significant relationship between frequencies of upper arm/ shoulder elevation and the subsequent musculoskeletal problems/ disorders (Kilbom 2000). Different shoulder musculoskeletal loading had been found during different level of flexion/ extension of the upper arm/ shoulder (Diederichsen et al. 2007).

2.2.7. Wrist posture during lifting lowering tasks

More than 20 degree of wrist deviation with respect to ulnar increases MSD risk (Silverstein, Fine and Armstrong 1986; Stal et al. 2003). Wrist posture along with repetition and duration is a risk factor for work related wrist MSDs (Malchaire, Cock and Robert 1996). Wrist flexion/ extension from its neutral position increases the wrist disorders/ problems. Neutral position of the wrist had been defined differently for example, in one study no more than 25 degree wrist extension/ flexion is neutral (Moore and Garg 1994), in another study no more than 45 degrees is defined as neutral (Colombini 1998), and less/ more than 20 degrees is also defined as a posture of good/ bad (McAtamney and Corlett 1993). The more the flexion the more the discomfort is. This discomfort increases in the increasing of other factors such as external load weight (Carey and Gallwey 2002). Other upper and lower limb awkward posture along with wrist awkward posture intensified wrist MSDs. Wrist posture in combination with other external factors increased the risk twice compared to the risk only for the posture of the wrist (Khan, O'Sullivan and Gallwey 2010). MSDs such as, reduction in carpal tunnel area takes place with the flexion and extension of the wrist (Wu et al. 2005). In investigating MSDs, it had been found that carpal tunnel area more reduced in extended wrist posture compared to flexion wrist posture (Chen et al. 2006; Mogk and Keir 2008). Wrist posture had been categorised into three for example, score 1 was for neutral position, score 2 was for 0- 15 degrees of flexion/ extension, and score 3 was for more than 15 degrees flexion/ extension (McAtamney and Corlett 1993). According to the International Standard, more than 90^0 range is the extreme wrist posture (International Standards Organizations 2000). Strain and stress injury was accounted for repetitive awkward wrist posture (Latko et al. 1999), the probability of injury enhance in combination with other risk factors such as force and posture. If cycle time of a task less than 30 seconds, it has been defined as a ‘Highly repetitive’ tasks (Silverstein, Fine and Armstrong 1986). 10 times per minute of wrist movement was defined as low level exposure (Kilbom 1994). The more the rate of wrist flexion/ extension the greater chance of having wrist musculoskeletal problems/ disorder (Ciriello et al. 2001). Even if the task does not need forceful exertion of the wrist, the frequency of wrist bending can cause severe MSDs (Arvidsson, Åkesson and Hansson 2003).

2.2.8. Knee posture during lifting lowering tasks

Knee posture is associated with weight of the load (Fong et al. 2009). A study suggested that, the more the knee angle the more the risk score was set to assess knee musculoskeletal problems or disorders (Keyserling, Brouwer and Silverstein 1992a; Hignett and McAtamney 2000; Favre et al. 2008). For example, bearing the unilateral weight is riskier compared to bilateral weight. For knee angle between 30° and 60°, the score was one unit more than normal. If the angle of the knee is greater than 60^0 the score was 2 units more than normal.

2.2.9. Work environment and musculoskeletal disorder

Vibration from floor and tools is linked to carpal tunnel syndrome and back MSDs (Lings and Leboeuf-Yde 2000; Tiemessen, Hulshof and Frings-Dresen 2008). Duration of exposure to vibration: prolonged exposure to vibration forces may create chronic stress and sometimes even permanent damage of body musculoskeletal systems particularly back MSDs (Mirbod, Inaba and Iwata 1997; Palmer et al. 2003). Tool vibration is an important determinants of MSD risk associated with operation of powered hand tools (McDowell et al. 2006; Besa et al.

2007). It has been indicated that the vibrating tools may cause direct damage to back musculoskeletal system (Wilder and Pope 1996; Necking et al. 2004). Prolonged exposure to hand-transmitted vibration has been related to an array of WMSDs of the musculoskeletal systems in the upper extremity (Burström and Sörensson 1999; Dong et al. 2003).

2.3. Mechanisms of musculoskeletal disorders

Work-related musculoskeletal disorders (WMSDs) is linked to joints and bones within the human body in lifting lowering activities (Aptel, Aublet-Cuvelier and Cnockaert 2002). WMSDs happens through exposure to MH risks (Armstrong et al. 1996) which generate physical stresses/ strain (Johansson 1994; Radwin, Marras and Lavender 2001; Lapointe et al. 2009). Armstrong et al. (1996) introduced a conceptual model for the process of WMSDs development due to lifting lowering MH tasks (Armstrong et al. 1996). The model's distinguished characteristic that WMSDs are believed to emanate from complex interrelationships between the three variable sets namely capacity, lifting lowering load and exposure to risks in MH tasks (Armstrong et al. 1996). For instance, exposure towards factors such as forceful exertion and inappropriate posture during lifting lowering MH tasks generates internal loads denoting musculoskeletal stress (Waters and MacDonald 2001; Leroux et al. 2005; Grandjean et al. 2006; Waters et al. 2007). Musculoskeletal disorder emerges if responses to such loads surpass the human physical ability. Additionally, proposed a multivariate interaction theory, which asserts that WMSDs is an interactive procedure involving physical task requirements, and postural requirements in manual handling tasks (Kumar 2001). The level of stress is influenced by the kind of MH tasks undertaken and the biomechanical risk factors. Researchers identified the correlation existing amongst WMSDs risk factors (Radwin, Marras and Lavender 2001), research explained the loads generated within the physical work setting are transferred to the body via a biomechanical pathway. For instance, the loads, which constitute physical stresses that include force, generate internal weights on anatomical structures and tissues. Because of physiological responses, the internal weights create fatigue and mechanical strain, which cause MSDs.

3. PREDICTING WORKERS MUSCULOSKELETAL DISORDERS

3.1. Chapter introduction

This chapter includes a suite of multinomial logistic regression based models for predicting occurrences of work related MSDs from lifting/ lowering MH tasks. Specific details for three trades category are included in this chapter.

3.2. Concept development

3.2.1. Review of current models

Subjective (i.e. mainly perceptions based) models were adopted to assess MSDs from lifting lowering MH risks (Karwowski et al. 1999; Shoaf et al. 2000; Ma et al. 2009). Self-assessment methods were included to develop subjective models. Examples of self-assessment methods include Position Analysis Questionnaire and the labour Survey Procedure for Activity Analysis (Arbeitswissenschaftliches Erbungsverfahren Zur Tatigkeitsanalyse (AET)) (Brauchler 1998; Karwowski and Marras 1998; Landau, Brauchler and Rohmert 2003). Following these methods, physical exposure to MH risk factors were investigated (Kadefors and Forsman 2000; Dane et al. 2002). These methods deal with different variables such as, demographic, pain/ ache/ discomfort symptoms, and respondent's physical exposure. Table 3.1 portrays main factors considered into previous study where subjective/ perception based methods were adopted.

Table 3.1 Main factors considered into previous study

Main factors	*Sub-factors*	*Researcher*
Load and it's characteristics	• Weight of the object • Physical characteristics (size and shape) of the object • Distance covered	(Viikari-Juntura et al. 1996b; Spielholz, Silverstein and Stuart 1999; Balogh et al. 2001; Hildebrandt et al. 2001; Dane et al. 2002)
Posture	• Action and posture such as, Bending and/ or twisting the back and/ or neck • Frequency and duration of tasks	(Pope et al. 1998; Kadefors and Forsman 2000; Spielholz et al. 2001)
Environment	• Luminous intensity (Lux), and Ventilation • Climate- temperature, and humidity	(Lemasters et al. 1998; Balogh et al. 2004)

3.2.2. Conceptual model

Most of existing MSD risk prediction models do not link the special requirements for "ageing" workforce, to avoid/ minimise MH tasks related MSD risks. Existing models are explained, the current model is compared and highlighted differences with existing models in section 5.2 on page 172. The conceptual model systematically integrates all requisite components into the model such as personal attributes, task demands, postural demands, and environmental demands. Figure 3.1 portrays conceptual model for predicting MH tasks related MSDs.

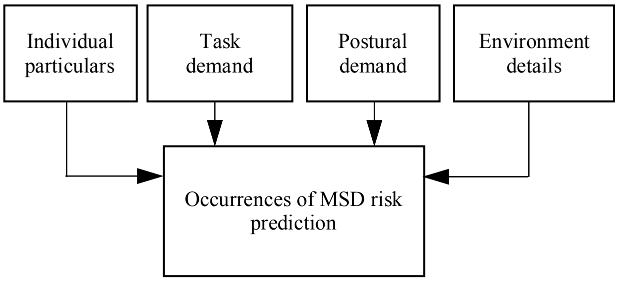


Figure 3.1 A conceptual model for MSD risk assessment

Model for predicting MH related MSD risks is derived from (a) individual particulars (body mass index (BMI), and physical ability) (b) task demand including details of object(s) to be handled and particulars of tasks to be performed (c) postural demands and (d) environment in which MH tasks performed. If a person's current physical abilities are lower than the MH task requirement, MSDs can take place. For example, adverse exposures on some body organs due excessive exertions can eventually cause disorder/ injuries of an individual's musculoskeletal system. However, developing relevant model for predicting occurrences of MSD can be a useful solution to reduce MSD risks. Details of a new perception based subjective model is presented in this chapter with specific details of three trades category. It has been found that physical factors are mainly responsible for musculoskeletal disorders from lifting/ lowering manual handling tasks, hence some factors were not considered. This research did not consider combined effect of individual particulars such as, combined effect of medical condition, physical ability, and pharmacology. Lifting/ lowering object characteristics was not considered in this research. Weather condition such as temperature and humidity were not considered in this research.

3.3. Data collection

3.3.1. Questionnaire design

Questionnaire items were derived after reviewing the literature thoroughly. The questionnaire contained six sections; these are (i) respondents' background (ii) respondents' physical ability (iii) frequency of lifting/ lowering tasks (iv) posture during lifting/ lowering tasks (v) environment when performing lifting/ lowering MH tasks (vi) musculoskeletal disorder symptoms and conditions. The questionnaire was written and arranged in a way which was suitable for the level of the respondents (engaged in lifting/ lowering). According to the domain experts advise, complex statement and wording were removed from the questionnaire.

3.3.1.1. Background information

The background questions were about respondent's height, weight, age, gender, race, industry, occupation, and experience. These background information provides sub-grouping in the data analysis phase.

3.3.1.2. Physical ability

Respondents perceived information about their physical ability for manual handling tasks were collected which been assessed using ten items, these are (i) manual dexterity – i.e. ability to use hand and arm, for example to grasp, manipulate, or assemble objects (ii) static strength – i.e. ability to perform manual handling tasks such as lifting and carrying objects (iii) dynamic strength – i.e. ability to perform the manual handling tasks repeatedly or continuously over time (iv) trunk strength – i.e. ability to safely use trunk to support the manual handling tasks (v) flexibility – i.e. ability to bend, stretch, twist, or reach with body, arms, and/or legs (vi) body equilibrium – i.e. ability to keep or regain body balance or stay upright during manual handling tasks (vii) stamina – i.e. ability to exert physically without getting winded or out of breath (viii) arm hand steadiness – i.e. ability to keep hand and arm steady while performing manual handing tasks (ix) finger dexterity – i.e. ability to perform coordinated movements of the fingers of one or both hands, for example to grasp, manipulate or assemble small objects (x) multi limb coordination – i.e. ability to coordinate limbs (for example, two arms, two legs, or one leg and one arm) while performing manual handling tasks. These ten items were assessed using a 5-point Likert scale (i.e. 'Very poor', 'Poor', 'Moderate', 'Good', and 'Very good').

3.3.1.3. Loads and frequency of lifting/ lowering

Four levels, i.e. <5 kg, 6 to 10 kg, 11 to 15 kg, and 16 to 20 kg, of load/ weight were selected. Participants were asked to provide information regarding lifting/ lowering repetition requirements (Low, i.e. less than 5 times per minute; moderate i.e. 5 to 8 times per minute; high, i.e. 9 to 12 times per minute; and very High i.e. more than 12 times per minute) for loads (less than 5 kg; 6 to 10 kg; 11 to 15 kg; and 16 to 20 kg) in their daily job routines. The method has been used in this research is well established as self-evaluation of manual handling tasks (Kadefors and Forsman 2000) and online questionnaire survey using Borg scale have been used as methods in research for recent few years (Borg 1990; Krawczyk 1996; Dane et al. 2002; Stock et al. 2005). The responses for weight categories are in broad 5-kg bandwidth. Basic knowledge and information on weights handled is available in the common body of knowledge and engineering standards/ industry practice. Most of the respondents are experienced practitioners. In addition, the display of weight information is common in most job settings (including objects/ machineries handled in manual handling tasks). Hence, reasonable response accuracy is expected. Moreover, the Psychophysical method employed in this research is customary in academic research as well as industry applications.

3.3.1.4. Back posture

In this research posture categories were defined as “Neutral” – i.e. almost no bending (less than 20 degrees), “Moderate” – i.e. moderately flexed (20 to 60 degrees), “Extreme” – i.e. extremely flexed (more than 60 degrees). The question layout was clear with the corresponding diagram, Figure 3.2, which provided to enable the user to differentiate between postures of the back, where workers do not use personal protective equipment (PPE).

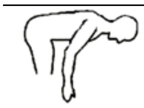
Pose	***Description***
	*Neutral – i.e. almost nil (less than 20 degrees)*
	*Moderate – i.e. moderately flexed (20 to 60 degrees)*
	*Extreme – i.e. extremely flexed (more than 60 degrees)*

Figure 3.2 Back postures during lifting/ lowering MH tasks

Information regarding posture of back and information regarding repetition (low, moderate, high, very high) requirements for back flexion/ extension (neutral, moderate, extreme) when lifting/ lowering were asked to the participants. In this research, four categories of repetition were defined with the descriptive terms to assess back movement: “Low”- i.e. less than 5 times per minute, “Moderate”- i.e. 5 to 8 times per minute, “High”- i.e. 9 to 12 times per minute, “Very High”- i.e.

more than 12 times per minute. Predicaments also given the information regarding the duration of inclined (neutral, moderate, extreme) back in the lifting/ lowering tasks in their daily MH tasks routines.

3.3.1.5. Vibration during lifting/ lowering task

Environmental factor such as exposure to vibration were assessed by having information from the participants that how long (duration- less than 1 hour, 1 to 2 hour, 2 to 3 hour, 3 to 4 hour, and more than 4 hours) they expose into vibration and what is the source (tools, floor) of vibration.

3.3.1.6. Musculoskeletal disorder symptoms and conditions questionnaire

To select the body regions covered in the musculoskeletal disorder symptoms and conditions questionnaire, previous questionnaire were reviewed (Kuorinka et al. 1987; Hlatky et al. 1989; Waters et al. 1993; Torgén et al. 1999; Balogh et al. 2001; Morgeson and Humphrey 2006; David et al. 2008). Musculoskeletal disorder symptoms and conditions in upper back, and lower back were obtained through the survey. Back musculoskeletal problems/ disorder symptoms were assessed by asking participants to response nil/ sometimes (Acute)/ regular (Chronic) occurrence of any muscle and/ or bone related problems (i.e. musculoskeletal disorders) in recent 12 months in their 11 body regions. In the same question work related MSDs were assessed by asking participants (work related reasons for occurrences) to response very likely/ somewhat likely/ likely/ not likely/ very unlikely. Work related information were taken to separate work related back MSDs.

3.3.2. Questionnaire survey

A structured questionnaire survey was conducted for data collection. The target respondents are workers engaged in lifting and lowering MH tasks in their daily works. From the Australian B2B database (Australian Business to Business 2016) 3123 organisations in the construction and manufacturing industries were identified. The human resources manager or directors in those organisations were contacted with a request letter to identify relevant persons in their organisations and distribute the invitation, survey questionnaire and the consent information. Informed consent was noted by the survey participation. 720 worker's responses were received; among 720, 674 were completed responses as 46 responses were incomplete, 26 irrelevant responses were identified since these responses were come from different industry context. Finally, 648 responses (from manufacturing and constructions) were taken to analyse.

3.4. Data analyses and modelling

3.4.1. Correlations

To assess the relationships, depending on the type of data (ordinal), Spearman's correlation (r_s) was run. To mention effect size of the variables on work related musculoskeletal disorders/ discomforts, Cohen's constitution was used (Chen and Popovich 2002; Field 2013). Odds ratio of Back MSDs was also used for seeing effect size of the predictors to the model (Sainani 2011).

- Correlation coefficient $r = .00 - .19$ "very weak"
- Correlation coefficient $r = .20 - .39$ "weak"
- Correlation coefficient $r = .40 - .59$ "moderate"
- Correlation coefficient $r = .60 - .79$ "strong"

- Correlation coefficient $r = .80 - 1.0$ “very strong”

3.4.1.1. Relationships between age and back musculoskeletal disorders

The age of the workers working in manufacturing and construction industries and engaged in manual handling tasks, mainly lifting/ lowering, significantly related with the work related occurrences of upper ($r = .50, p < .001$) and lower ($r = .21, p < .001$) back musculoskeletal disorders.

3.4.1.2. Relationship between physical abilities and back MSDs

The rank of physical abilities of the workers is very poor (1), poor (2), moderate (3), good (4), and very good (5). Table 3.2 shows that

- There was a significant negative correlation between work related lower back musculoskeletal disorder and physical abilities (static strength, dynamic strength, flexibility, body equilibrium, and stamina) of the workers irrespective of the age. Negative correlation means that lower back MSD increases with the decreasing of the physical abilities.
- There was a significant correlation between work related lower back musculoskeletal disorder and physical abilities of the workers age less than 40 years.
- There was strong effect of physical abilities (except flexibility) on work related lower back musculoskeletal disorder of the workers age between 40 and 60 years, which was significant.
- Physical abilities significantly associated with the work related lower back musculoskeletal disorder for the workers age more than 60 years.

Table 3.2 Relationship between physical abilities and lower back MSDs

Physical abilities	***Lower back MSD by age***							
	All (N = 624)		***< 40 (N = 216)***		***40-60 (N = 201)***		***> 60 (N = 207)***	
	Coef.	***Sig.***	***Coef.***	***Sig.***	***Coef.***	***Sig.***	***Coef.***	***Sig.***
Manual dexterity	-.057	.057	-.166**	.007	-.674**	.000	-.044*	.034
Static strength	-.080*	.023	-.153*	.012	-.601**	.000	-.115*	.040
Dynamic strength	-.079*	.024	-.372**	.000	-.622**	.000	-.042*	.001
Trunk strength	-.065	.051	-.398**	.000	-.583**	.000	-.068*	.045
Flexibility	-.215**	.000	-.306**	.000	-.340**	.000	-.091*	.036
Body equilibrium	-.069*	.044	-.284**	.000	-.729**	.000	-.070*	.039
Stamina	-.071*	.039	-.308**	.000	-.700**	.000	-.083*	.008
Arm hand steadiness	-.065	.053	-.433**	.000	-.643**	.000	-.048*	.007
Finger dexterity	-.045	.052	-.255**	.000	-.667**	.000	-.055*	.041
Multi limb coordination	-.004	.061	-.271**	.000	-.607**	.000	-.084*	.014

*. Correlation is significant at the 0.05 level (1-tailed). **. Correlation is significant at the 0.01 level (1-tailed).

Table **3.3** shows that

- For all age group, there was negative correlation between physical abilities and work related upper back musculoskeletal disorders, which was statistically significant.
- For less than 40 years old age group of workers, there was a strong statistically significant negative correlation between physical abilities and work related upper back musculoskeletal disorders, except stamina, and multi limb coordination.
- Strong correlation was found between physical abilities (except flexibility) and work related upper back musculoskeletal disorder for the workers age between 40 and 60 years which was statistically significant.

- There was statistically significant correlation between more than 60 years old workers' physical abilities (except manual dexterity and static strength) and occurrences of work related upper back musculoskeletal disorders.

Table 3.3 Relationship between physical abilities and upper back MSDs

Physical abilities	***Upper back MSD by age***							
	All (N = 617)		***< 40 (N = 215)***		***40-60 (N = 199)***		***> 60 (N = 203)***	
	Coef.	***Sig.***	***Coef.***	***Sig.***	***Coef.***	***Sig.***	***Coef.***	***Sig.***
Manual dexterity	-.325**	.000	-.569**	.000	-.590**	.000	-.206*	.045
Static strength	-.311**	.000	-.588**	.000	-.635**	.000	-.494*	.021
Dynamic strength	-.187**	.000	.279**	.000	-.638**	.000	-.367**	.009
Trunk strength	-.127**	.001	.234**	.000	-.664**	.000	-.425*	.038
Flexibility	-.410**	.000	-.624**	.000	-.400	.060	-.520*	.044
Body equilibrium	-.242**	.000	-.639**	.000	-.670**	.000	-.223*	.040
Stamina	-.132**	.000	-.048	.241	-.652**	.000	-.447*	.018
Arm hand steadiness	-.161**	.000	-.481**	.000	-.614**	.000	-.557*	.013
Finger dexterity	-.262**	.000	-.566**	.000	-.634**	.000	-.602**	.002
Multi limb coordination	-.138**	.000	-.095	.083	-.632**	.000	-.536**	.000

*. Correlation is significant at the 0.05 level (1-tailed). **. Correlation is significant at the 0.01 level (1-tailed).

3.4.1.3. Relationships between (i) repetition of lifting, and repetition of lifting to an extent; and (ii) upper back musculoskeletal disorders

Lifting repetition is ranked as low (1), i.e. less than 5 times per minute; moderate (2), i.e. 5 to 8 times per minute; high (3) i.e. 9 to 12 times per minute; and very high (4) i.e. more than 12 times per minute. Extent of lifting is ranked as floor to knuckle (1), knuckle to chest (2), chest to shoulder (3), and above shoulder (4). Physical discomfort is ranked as nil (1), slight (2), moderate (3), high (4), very high (5).

Table 3.4 shows that

- In all age group, there was a positive significant correlation between lifting repetition and work related upper back MSD except less than 5 kg of weight lifting.
- In age group less than 40 years, and between 40 and 60 years, positive correlation was found. Strong effect of lifting repetition on MSD was found for repeated lifting of 6 to 10 kg, and 11 to 15 kg of weight.
- Lifting repetition from knuckle to chest positively correlated, which was significant except more than 60 years of age group, and it had moderate effect on work related upper back MSD.

Table 3.4 Relationship between (i) repetition of lifting, and repetiton of lifting to an extent; and (ii) upper back musculoskeletal disorders by age groups

Repetition and extent of lifting	***Upper back MSD***							
	All (N = 617)		***< 40 (N = 215)***		***40-60 (N = 199)***		***> 60 (N = 203)***	
	Coef.	***Sig.***	***Coef.***	***Sig.***	***Coef.***	***Sig.***	***Coef.***	***Sig.***
Less than 5 kg	.033	.204	.218**	.001	.522**	.000	.010	.444
6 to 10 kg	.264**	.000	.581**	.000	.651**	.000	.068	.168
11 to 15 kg	.351**	.000	.672**	.000	.389**	.000	.123*	.040
16 to 20 kg	.321**	.000	.023	.370	.373**	.000	.091	.099
Floor to knuckle	.046	.129	.446**	.000	-.314**	.000	.023	.370
Knuckle to chest	.357**	.000	.491**	.000	.416**	.000	.006	.464
Chest to shoulder	.033	.210	.237**	.000	.688**	.004	.121*	.043
Above shoulder	.252**	.000	.046	.253	.704**	.041	.093	.092

*. Correlation is significant at the 0.05 level (1-tailed). **. Correlation is significant at the 0.01 level (1-tailed).

3.4.1.4. Relationships between (i) repetition of lifting, and repetition of lifting to an extent; and (ii) lower back musculoskeletal disorders

Table 3.5 shows that

- For all age group, 16 to 20 kg of lifting repetition positively correlated (r=.603) with work related lower back musculoskeletal disorders, which was significant (p<.001). Very strong (r=.833) effect was found in the workers age less than 40 years, which was significant.
- 6 to 10 kg of repetited weight lifting by the workers aged between 40 and 60 had the strong effect on their lower back MSDs ($r = .709, p < .001$).
- In all age group, there was a positive correlation between above shoulder lifting repetition and lower back MSDs, which was significant ($P < .001$). the strong effect of it found in workers age from 40 to 60 years.
- For older workers, age more than 60 years, significant strong positive correlation found between floor to knuckle lifting repetition and lower back MSDs.

Table 3.5 Relationship between (i) repetition of lifting, and repetiton of lifting to an extent; and (ii) lower back musculoskeletal disorders by age groups

Repetition and extent of lifting	***Lower back MSD***							
	All (N = 624)		***< 40 (N = 216)***		***40-60 (N = 201)***		***> 60 (N = 207)***	
	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.
Less than 5kg	.785**	.000	.827**	.000	.956**	.000	.722**	.000
6 to 10kg	.264**	.000	.137*	.023	.709**	.000	.259**	.000
11 to 15kg	-.370**	.000	-.744**	.000	.537**	.000	-.105	.068
16 to 20kg	.603**	.000	.833**	.000	.799**	.002	.820**	.000
Floor to knuckle	.309**	.000	-.057	.201	.664**	.000	.711**	.000
Knuckle to chest	-.030	.228	.393**	.000	.531**	.000	.223**	.001
Chest to shoulder	-.580**	.000	-.667**	.000	.548**	.000	.050	.050
Above shoulder	.402**	.000	.623**	.000	.728**	.000	-.020	.390

**. Correlation is significant at the 0.01 level (1-tailed).

3.4.1.5. Relationship between lifting repetition and physical discomfort

Prolonged physical discomfort leads to chronic MSDs. This research collected data about physical discomfort for each musculoskeletal disorder risk factors. Physical discomfort is ranked as nil (1), slight (2), moderate (3), high (4), very high (5).

- Lifting repetition was significantly related to the workers (engaged in lifting/ lowering task) physical discomfort.
- There was positive correlation between lifting/ lowering repetition in manual handling job and physical discomfort of the workers.
- There was strong effect of 16 to 20 kg of weight and 6 to 10 kg of weight lifting/ lowering on physical discomfort. More details in Appendix C, Table A.1.

3.4.1.6. Relationship between repetition of lifting to an extent and physical discomfort

- There was significant positive correlation between reapeated lifting (from knuckle to chest, chest to shoulder, above shoulder) and physical discomfort of workers engeged in lifting/ lowering in all age group.
- In 40 to 60 years old age group of workers engaged in lifting/ lowering, repetition of lifting from floor to knuckle, knuckle to chest, chest to shoulder, and above shoulder positively related with physical discomfort, which was significant. Strong effect of repeated knuckle to chest lifting on physicl discomfort was found.
- Reapeated knuckle to chest and chest to shoulder lifting/ lowering are significantly related to the physical discomfort of the workers.

- In more than 60 years of aged workers engaged in lifting/ lowering task, repeated lifitng (from floor to knuckle, knuckle to chest, and above shoulder) was positively associated with physical discomfort of the workers, which was significant. More detais in Appendix C, Table A.2.

3.4.1.7. Relationship between lifting lowering physical discomfort and upper back musculoskeletal disorders

Respondents were asked to give information about physical discomfort against each MSD risks. The relationship between the physical abilities and MSDs in back is presented here.

- There was a significant positive association between physical discomfort from lifting/ lowering repetition and occurances of upper back MSD in all age groups.
- Physical discomfort of workers engaged in repeated lifitng was significantly associated with their upper back MSD in the workrs age less than 40, and between 40 and 60 years.
- Physical discomfort from lifting/ lowering strongky effected upper back MSD in the workers age between 40 and 60.
- No significant correlation between physical discomfort from lifitng/ lowering and upper back MSD in more than 60 years of old aged workers.
- Physical discomfort from repeated lifitng (floor to knuckle, knuckle to chest, chest to shoulder, and above shoulder) positively associated with upper back MSD of the workers of all age groups, which was significant.

- In less than 40 years old age group of workers, physical discomfort of repeated lifting (from floor to knuckle, knuckle to chest, and chest to shoulder) is significantly related with the occurances of upper back MSD.
- Physical discomfort from repeated lifting (from floor to knuckle, chest to shoulder, and above shoulder) is positively related with upper back MSD in moer than 60 years old age workers.
- In workers age between 40 and 60, discomfort from repeated lifting (form floor to knuckle, knuckle to chest, chest to shoulder, and above shoulder) is positively associated with upper back MSD. More detais in appendix C, Table A.3.

3.4.1.8. Relationship between lifting lowering physical discomfort and lower back musculoskeletal disorders

Discomfort had been considered as a risk factor developing WMSDs(Bongers, Kremer and Laak 2002; Rydstedt, Devereux and Furnham 2004). This term “discomfort” is more comprehensible to the workers therefore it had been used in the questionnaire instead of stress. In WMSDs risk questionnaire workers were asked about their perception of how discomfort they found in their work using five categories i.e. nil, slight, moderate, high, and very high.

- There was a significant positive association between physical discomfort from lifting/ lowering repetition and occurances of lower back MSD in all age group, less than 40 years age group, 40 to 60 years old age group.
- Physical discomfort from repetition of 11 to 15 kg and 16 to 20 kg of weight lifting was positively correlated with lower bcak msd in more than 60 years old age group.

- Physical discomfort from repeated lifitng (floor to knuckle, knuckle to chest, chest to shoulder, and above shoulder) positively associated with lower back MSD of the workers of all groups, which was significant.
- Physical discomfort from repeated lifting (from chest to shoulder and above shoulder) was positively correlated with lower bcak MSD in more than 60 years old age group.
- There was a significant positive association of physical discomfort from repeated lifting from knuckle to chest, chest to shoulder, and above shoulder and occurrences of lower back MSD in less than 40 years old age group of workers.
- In workers age between 40 and 60, physical discomfort from extent of lifting (from floor to knuckle, knuckle to chest, and above shoulder) positively related with lower back MSD, which was significant. More detais in Appendix C, Table A.4.

3.4.1.9. Relationship between back posture and lower back MSDs

Table 3.6 shows that

- Back bending (less than 20 degrees, 20 to 60 degrees, and more than 60 degrees) repetition (Low, i.e. less than 5 times per minute; Moderate i.e. 5 to 8 times per minute; High i.e. 9 to 12 times per minute; Very High i.e. more than 12 times per minute) is positively correlated to work related lower back musculoskeletal disorder in all age group of workers.
- There is a positive correlation between back bending and MSD in less than 40 years old age group of workers.

- Strong effect of back bending from 20 to 60 degrees on MSD found in workers age between 40 and 60 years.
- There is moderate to strong significant correlation between back bending and MSD in more than 60 years old age group.
- Lower back MSD is positively associated with duration of bending back. It is also positively associated with less than 20 degrees and more than 60 degrees of back bending in all age group of workers. There is significant correlation between these two variables in more than 60 years old age group of workers.

Table 3.6 Relationship between postural requirements and lower back musculoskeletal disorders by age groups

Frequency/ duration	***Back posture angle (degrees)***	***Occurrences of lower back MSD***							
		All (N = 624)		***< 40 (N = 216)***		***40-60 (N = 201)***		***> 60 (N = 207)***	
		Coef.	***Sig.***	***Coef.***	***Sig.***	***Coef.***	***Sig.***	***Coef.***	***Sig.***
Repetition requirement	*Less than 20*	.085*	.016	.712**	.000	.651**	.035	.453**	.001
	20 to 60	.250**	.000	.651**	.000	.770**	.000	.463*	.035
	More than 60	.223**	.000	.382**	.000	.490**	.000	.563*	.012
Duration requirement	*Less than 20*	.184**	.000	.570**	.000	.417**	.000	.621**	.002
	20 to 60	.045	.129	.291**	.000	.504**	.002	.412**	.008
	More than 60	.154**	.000	.040	.282	.684**	.000	.302**	.009

*. Correlation is significant at the 0.05 level (1-tailed). **. Correlation is significant at the 0.01 level (1-tailed).

3.4.1.10. Relationship between back posture requirements and work related upper back musculoskeletal disorders by age

Table 3.7 shows that

- There is a positive significant correlation between (i) less than 20 degrees and more than 60 degrees of repeated back bending; and (ii) work related upper back MSD in all age group.
- There is moderate effect of less than 20 degrees and more than 60 degrees of repeated back bending of MSD in less than 40 years old age group of workers.
- There is strong effect of 20 to 60 degrees of back bending on MSD in 40 to 60 years old age group of workers.
- No significant relationship was found in more than 60 years old age group of workers.
- Holding the back to a certain extent is positively associated with upper back MSD in all age group, which was significant.
- In less than 40 years old age group of workers, moderate to strong effect of holding (Less than 1 minute, 1 to 2 minutes, 2 to 3 minutes, 3 to 4 minutes, more than 4 minutes) the back on occurrences of upper back MSD was found. And the positive significant correlation between these was also found in this age group of workers. No significant association found in more than 60 years old age group of workers.

Table 3.7 Relationship between postural requirements and upper back musculoskeletal disorders by age groups

Frequency/ duration	*Back posture angle (degrees)*	***Occurrences of upper back MSD***							
		All (N = 617)		***< 40 (N = 215)***		***40-60 (N = 199)***		***> 60 (N = 203)***	
		Coef.	***Sig.***	***Coef.***	***Sig.***	***Coef.***	***Sig.***	***Coef.***	***Sig.***
Repetition requirement	*Less than 20*	.128**	.001	.490**	.000	.779**	.035	-.027	.353
	20 to 60	.055	.085	.089	.098	.708**	.000	.010	.442
	More than 60	.313**	.000	.506**	.000	.699	.082	.067	.171
Duration requirement	*Less than 20*	.144**	.000	.654**	.000	.562**	.000	-.032	.324
	20 to 60	.326**	.000	.821**	.000	.468**	.041	.022	.377
	More than 60	.391**	.000	.775**	.000	.615**	.044	-.039	.288

**. Correlation is significant at the 0.01 level (1-tailed).

3.4.1.11. Relationship between back posture repetition and physical discomfort

- 20 to 60 degrees of back posture is positively associated with the physical discomfort in all age group of workers.
- There is a significant positive association between back posture repetition (Low, i.e. less than 5 times per minute; Moderate i.e. 5 to 8 times per minute; High i.e. 9 to 12 times per minute; Very High i.e. more than 12 times per minute) and physical discomfort in less than 40 and between 40 and 60 years old age groups.
- 20 to 60 degrees back bending repetition is positively associated in all age group, which was significant.
- There was a significant positive correlation between less than 20 degrees of back bending repetition and physical discomfort in more than 60 years old age group. More details in Appendix C, Table A.5.

3.4.1.12. Relationship between back posture duration and physical discomfort

- Forward back bending between 40 and 60, and more than 60 degrees positively associated with physical discomfort in all age group, which was significant.
- Any degrees of forward back bending and holding that posture for a certain duration (Less than 1 minute, 1 to 2 minutes, 2 to 3 minutes, 3 to 4 minutes, more than 4 minutes) is positively associated with physical discomfort in less than 40 years old age group of workers, which was significant.
- There was a positive significant association between back bending (40-60 degrees, and more than 60 degrees) and physical discomfort in 40-60 years old age group of workers.
- More than 60 degrees of back bending was significant related with physical discomfort in more than 60 years old age group of workers. More details in Appendix C, Table A.6.

3.4.1.13. Relationship between physical discomfort from back posture repetition and duration; and upper back MSD

- Physical discomfort from back posture repetition is positively associated with work related occurrences of upper back MSD in all age group, less than 40 years, 40-60 years, and more than 60 years old age group of workers, which was significant.
- Physical discomfort for keeping back posture for a certain period of time is positively associated with work related occurrences of upper back MSD in all age group, and more than 60 years old age group of workers, which was significant.

- Holding back posture (less than 20 degrees) for a period of time strongly effect on upper back MSD in less than 40 years of age group of workers.
- There was a positive significant association between holding time of the back posture (more than 60 degrees) and upper back MSD in 40 to 60 years old age group of workers. More details in Appendix C, Table A.7.

3.4.1.14. Relationship between physical discomfort from back posture repetition and duration; and lower back MSD

- There was a positive significant relatinship between physical discomfort from back posture repetition and lowe back MSD in all age group and 40 to 60 years of aged older workers.
- Strong effect of physical discomfort from back posture (20 to 60 degrees and more than 60 degrees) repetition on work related lower back MSD was found in less than 40 years old age group of workers.
- There was a positive relationship between physical discomfort from back posture repetition and lower back MSD in more than 60 years old age group of workers. More details in Appendix C, Table A.8.

3.4.1.15. Relationships between exposure to vibration and work related musculoskeletal disorders

Table 3.8 shows that

- Duration of exposure from tool vibration positively correlated with work related upper back MSD in all age group, less than 40 years, 40 to 60 years, and more than 60 years of age group of workers, which was significant.

- There was a significant positive relationship between the duration of exposure from vibration and work related lower back MSD in all age group, less than 40 years, and 40 to 60 years of age group of workers.
- Tool vibration strongly effect on both lower and upper back musculoskeletal disorder in 4o to 6o years old of workers.

Table 3.8 Relationship between duration of vibration and back musculoskeletal disorder by age groups

Location of parameter	*All (N = 624)*		*< 40 (N = 216)*		*40-60 (N = 201)*		*> 60 (N = 207)*	
	Coef. (sig.)		*Coef. (sig.)*		*Coef. (sig.)*		*Coef. (sig.)*	
	Source of vibration							
	Surface	*Tool*	*Surface*	*Tool*	*Surface*	*Tool*	*Surface*	*Tool*
Occur of MSD lower back	.238** (.000)	.168** (.000)	.503** (.000)	.335** (.000)	.697** (.003)	.667** (.000)	.096 (.085)	.028 (.345)
Occur of MSD upper back	.348** (.000)	.181** (.000)	.519** (.000)	.411** (.000)	.585** (.000)	.681** (.000)	.196** (.003)	.284** (.016)

**. Correlation is significant at the 0.01 level (1-tailed).

3.4.1.16. Relationship between exposure from duration of vibration and physical discomfort by age group

- There was a significant positive relationship between duration of exposure from vibration (from surface/ floor and tools) and physical discomfort in all age groups of workers working in lifting and lowering.
- Moderate to strong effect of exposure to vibration from surface/ floor and tools on physical discomfort was found.

- Hand tool vibration strongly effect on physical discomfort in 40 to 60 years old age workers engaged in lifting/ lowering.
- Surface/ floor vibration and hand tool vibration positively associated with more than 60 years old age group of workers' physical discomfort, which was significant. More details in Appendix C, Table A.9.

3.4.1.17. Relationship between physical discomfort from duration of vibration and back MSD by age

- Exposure to vibration from surface/ floor and tool for a certain time of time is positively associated with upper back MSD in all age group of workers engaged in lifting/ lowering, which was significant. Surface/ floor vibration was significantly associated with lower back MSD in this group fo workres.
- In less than 40 years age group of workers, exposure to vibration from surface/ floor and tool for a certain time of time is positively associated with both upper and lower back MSD.
- In the age group of 40 to 60 years, hand tool bibration significantly associated with both upper and lower back MSD, which was significant.
- Duratin of exposure from surface vibration positively associated with work related upper back musculoskeletal disorder in more than 69 years old age group of workers. More details in Appendix C, Table A.10.

3.4.2. Hypotheses testing

Kruskal-Wallis tests (and Jonckheere-Terpstra tests for ordered alternatives) with 95% confidence interval and significance level $p < 0.01$ were conducted for grouping categories such as age, gender and occupation. The participants are from different groups with respect to age (i.e. less than 40, 40 to 59, 60 and above), gender (i.e. male, female), and occupations (i.e. brick layers, carpenters, plasterers, plumbers, roof slaters/ tilers, roof slaters/ tilers, structural steel welders, wall and floor tilers). To ascertain the differences between several independent groups of participants, following six null hypotheses were verified by Kruskal-Wallis test with significance level 0.01:

H1: The distribution of lower back MSD is same across categories of age (years)

H2: The distribution of upper back MSD is same across categories of age (years)

H3: The distribution of lower back MSD is same across categories of gender

H4: The distribution of upper back MSD is same across categories of gender

H5: The distribution of lower back MSD is same across categories of occupation

H6: The distribution of upper back MSD is same across categories of occupation

As presented in Table 3.9, all hypotheses except those related to age (i.e. H1 and H2) have been retained according to the Kruscall-Wallis test results. Also, the hypotheses findings are same as per Jonckheere-Terpstra Test for Ordered Alternatives for testing the trends. In addition, the findings of this research revealed that potentials for acute and chronic MSD problems are noted as higher among older workers.

Table 3.9 Summary of independent samples hypothesis test

MSD	***Group details***	***Kruskal-Wallis test***			***Hypothesis test outcome***
		Test statistic	***df***	***Asymptotic Sig. (2-sided test)***	
Low back	*Age (years)*	67.537	2	.000	Reject the null hypothesis (H1): The distribution of Lower back MSD is same across categories of Age (years)
	Gender	6.588	1	0.010	Retain the null hypothesis (H3): The distribution of Lower back MSD is same across categories of Gender
	Occupation	7.006	6	0.320	Retain the null hypothesis (H5): The distribution of Lower back MSD is same across categories of Occupation
Upper back	*Age (years)*	100.527	2	.000	Reject the null hypothesis (H2): The distribution of Lower back MSD is same across categories of Age (years)
	Gender	1.304	1	0.254	Retain the null hypothesis (H4): The distribution of Lower back MSD is same across categories of Gender
	Occupation	13.752	6	0.033	Retain the null hypothesis (H6): The distribution of Lower back MSD is same across categories of Occupation

3.4.3. Multinomial logistic regression based probability prediction model of workers MSD occurances

Probability of occurrence of a musculoskeletal problem/ disorder (P_{ik})

$$P_{ik} = \frac{1}{1 + e^{-(b_{0k} + \sum_{a=1}^{A}(b_{ak} \times X_{ia}) + \sum_{f=1}^{F}(b_{fk} \times X_{if}) + \sum_{t=1}^{T}(b_{tk} \times X_{it}) + (b_{v1k} \times X_{iv1}) + (b_{v2k} \times X_{iv2}) + (b_{mk} \times X_{im}))}}$$

Where,

• i	Reference identifier for a person
• k	Musculoskeletal injury index
• b_{0k}	Model intercept for each k
• A	Total number of predictor variables related to physical abilities
• a	Indices for predictor variables related to physical abilities, with set $a = \{1, 2, 3, \dots, A\}$
• X_{ia}	Input of predictor variables related to physical abilities for $a \in A$, i, and $X_{ia} = \{1,2,3,4,5\}$
• b_{ak}	Coefficient or weight attached to the predictor variables related to physical abilities for $a \in A, and\ k$
• F	Total number of predictor variables related to frequency (i.e. repetition) of lifting/ lowering manual handling (MH) work requirement in daily job routines
• f	Indices for predictor variables related to frequency of lifting/ lowering MH work requirement, with set $f = \{1, 2, 3, \dots, F\}$

• X_{if}	Input of predictor variables related to frequency of lifting/ lowering MH work requirement for $f \in F$, i, and $X_{if} = \{1,2,3,4\}$
• b_{fk}	Coefficient or weight attached to the predictor variables related to frequency of lifting/ lowering MH work requirement for $f \in F, and\ k$
• T	Total number of predictor variables related to back postures repetition during lifting/ lowering MH tasks (i.e. extent of back bending)
• t	Indices for predictor variables related to back postures repetition during lifting/ lowering MH tasks, with set $t = \{1, 2, \ldots, T\}$
• X_{it}	Input of predictor variables related to back postures repetition during lifting/ lowering MH tasks for $t \in T$, i , and $X_{it} = \{1,2,3,4\}$
• b_{tk}	Coefficient or weight attached to the predictor variables related to back postures repetition during lifting/ lowering MH tasks for $t \in T, and\ k$
• $v1$	Index for predictor variable related to vibrations from the surface in workplace
• X_{iv1}	Input of predictor variables related to vibrations from the surface in workplace for i, and $X_{iv1} = \{1,2,3,4\}$
• b_{v1k}	Coefficient or weight attached to the predictor variables related to vibrations from the surface in workplace for $v1\ and\ k$
• $v2$	Index for predictor variable related to vibrations from the tools handled in the job

• X_{iv2}	Input of predictor variables related to vibrations from the tools handled in the job for i, and $X_{iv2} = \{1,2,3,4\}$
• b_{v2k}	Coefficient or weight attached to the predictor variables related to vibrations from the tools handled in the job for $v2$ *and* k
• m	Index for predictor variable related to the Body Mass Index (BMI) of a person
• w_i	Weight of a person i, in which w_i is in kilograms
• h_i	Height of a person i, in which h_i is in meters
• X_{im}	Input of predictor variables related to the BMI of a person i, where $X_{im} = \{(w_i)/(h_i{}^2)\}$
• b_{mk}	Coefficient or weight attached to the predictor variables related to the BMI of a person *and* k
• P	Probability of occurrence of a musculoskeletal injury for i, $a \in A$, $f \in F, t \in T$, m and k

Locations of musculoskeletal problems/ disorders are given in Table 3.10.

Table 3.10 Musculoskeletal injury index (k)

k	***Locations of musculoskeletal problems/ disorders***
1	Neck
2	Left shoulder
3	Right shoulder
4	Upper back
5	Lower back
6	Left upper arm
7	Right upper arm
8	Left wrist
9	Right wrist
10	Left knee
11	Right knee

3.5. Sample models

3.5.1. Model for metal fitter and machinists

3.5.1.1. Study population characteristics

Metal fitter and machinists were the respondents of this structured questionnaire survey. Lifting/ lowering manual handling task is the main activities of the metal fitter and machinists in their daily routine work. 181 metal fitter and machinists responded the questionnaire. Table 3.11 shows a summary of the participants.

Table 3.11 Summary of participants

Category	*Sub-category*	*Total*
Age (years)	Less than 40	59
	40 to 59	66
	60 and above	56
Experience (years)	Less than or equal to 10	24
	11 to 20	118
	More than 20	39

3.5.1.2. Significant predictors to predict lower back MSD

Table 3.12 shows manual dexterity, static strength, dynamic strength, trunk strength, arm hand steadiness, physical discomfort for 6 to 10 kg of lifting, physical discomfort for 16 to 20 kg of lifting, physical discomfort for lifting from knuckle to chest, physical discomfort for lifting from chest to shoulder, physical discomfort for back posture (20 to 60 degrees) repetition, physical discomfort for back posture (more than 60 degrees) repetition, physical discomfort for back posture (20 to 60 degrees) duration, physical discomfort for back posture (more than 60 degrees) duration, and physical discomfort for hand tool vibration are the significant predictors to predict the lower back musculoskeletal problems/ disorders. Exposure to physical discomfort due to repeated back flexion and extension (moderate i.e. 20 to 60 degrees to extreme i.e. more than 60 degrees) had a significant main effect on work related lower back MSD. Similarly, holding the back posture to a certain extent (moderate i.e. 20 to 60 degrees to extreme i.e. more than 60 degrees) also had a significant main effect on work related lower back MSD. As back posture had a significant main effect on lower back MSD, ability to safely use of trunk to support lifting lowering task significantly predict lower back MSD, $\chi^2(2) = 6.462, p < .05$.

Table 3.12 Likelihood ratio test for ascertain the significance of predictors to predict lower back MSDs

Effect	*Model Fitting Criteria*	*Likelihood Ratio Tests*		
	-2 Log Likelihood of Reduced Model	***Chi-Square***	***df***	***Sig.***
Intercept	154.506	25.106	2	.000
Manual dexterity	140.905	11.505	2	.003
Static strength	145.940	16.541	2	.000
Dynamic strength	152.537	23.138	2	.000
Trunk strength	135.861	6.462	2	.040
Flexibility	129.688	.288	2	.866
Body equilibrium	130.203	.803	2	.669
Stamina	134.662	5.263	2	.072
Arm hand steadiness	136.124	6.724	2	.035
Finger dexterity	135.036	5.636	2	.060

Effect	*Model Fitting Criteria*	*Likelihood Ratio Tests*		
	-2 Log Likelihood of Reduced Model	*Chi-Square*	*df*	*Sig.*
Multi limb coordination	134.011	4.611	2	.100
Physical discomfort for < 5 kg of lifting	130.971	1.571	2	.456
Physical discomfort for 6 to 10 kg of lifting	136.345	6.945	2	.031
Physical discomfort for 11 to 15 kg of lifting	132.126	2.726	2	.256
Physical discomfort for 16 to 20 kg of lifting	138.046	8.647	2	.013
Physical discomfort for lifting from floor to knuckle	131.578	2.178	2	.337
Physical discomfort for lifting from knuckle to chest	135.988	6.588	2	.037
Physical discomfort for lifting from chest to shoulder	135.714	6.314	2	.043
Physical discomfort for lifting above shoulder	129.442	.043	2	.979
Physical discomfort for back posture (< 20 deg.) repetition	134.784	5.384	2	.068
Physical discomfort for back posture (20 to 60 deg.) repetition	140.116	10.716	2	.005
Physical discomfort for back posture (> 60 deg.) repetition	142.155	12.756	2	.002
Physical discomfort for back posture (< 20 deg.) duration	132.128	2.729	2	.256
Physical discomfort for back posture (20 to 60 deg.) duration	135.542	6.142	2	.046
Physical discomfort for back posture (> 60 deg.) duration	135.234	5.835	2	.049
Physical discomfort for floor or surface vibration	130.809	1.410	2	.494
Physical discomfort for hand tool vibration	141.135	11.736	2	.003
Body mass index (BMI)	130.911	1.511	2	.470

3.5.1.3. Significant predictors to predict upper back MSD

Table 3.13 Manual dexterity, static strength, dynamic strength, trunk strength, flexibility, body equilibrium, arm hand steadiness, physical discomfort for 6 to 10 kg of lifting, physical discomfort for 16 to 20 kg of lifting, physical discomfort for lifting from knuckle to chest, physical discomfort for lifting from chest to shoulder, physical discomfort for back posture (20 to 60 degrees) repetition, physical discomfort for back posture (more than 60 degrees) repetition, physical discomfort for back posture (20 to 60 degrees) duration, physical discomfort for back posture (more than 60 degrees) duration, and physical discomfort for hand tool vibration are the significant predictors to predict the lower back musculoskeletal problems/ disorders. Exposure to physical discomfort due to repeated back flexion and extension (moderate i.e. 20 to 60 degrees to extreme i.e. more than 60 degrees) had a significant main effect on work related lower back MSD. Similarly, holding the back posture to a certain extent (moderate i.e. 20 to 60 degrees to extreme i.e. more than 60 degrees) also had a significant main effect on work related lower back MSD. As back posture had a significant main effect on lower back MSD, ability to safely use of trunk to support lifting lowering task significantly predict lower back MSD, $\chi^2(2) = 7.362, p < .01$.

Table 3.13 Likelihood ratio test for ascertain the significance of predictors to predict upper back MSDs

Effect	*Model Fitting Criteria*	*Likelihood Ratio Tests*		
	-2 Log Likelihood of Reduced Model	***Chi-Square***	***df***	***Sig.***
Intercept	164.506	25.206	2	.009
Manual dexterity	150.905	11.405	2	.003
Static strength	145.940	16.441	2	.007
Dynamic strength	142.537	23.238	2	.003
Trunk strength	135.861	7.262	2	.001
Flexibility	129.688	6.388	2	.047
Body equilibrium	130.203	6.403	2	.030
Stamina	134.662	5.363	2	.073
Arm hand steadiness	136.124	6.424	2	.036
Finger dexterity	135.036	5.637	2	.061
Multi limb coordination	134.011	4.611	2	.111
Physical discomfort for < 5 kg of lifting	130.971	1.572	2	.459
Physical discomfort for 6 to 10 kg of lifting	136.345	6.915	2	.021
Physical discomfort for 11 to 15 kg of lifting	132.126	2.766	2	.258
Physical discomfort for 16 to 20 kg of lifting	138.046	8.647	2	.012
Physical discomfort for lifting from floor to knuckle	131.578	2.158	2	.334

Effect	*Model Fitting Criteria*	*Likelihood Ratio Tests*		
	-2 Log Likelihood of Reduced Model	***Chi-Square***	***df***	***Sig.***
Physical discomfort for lifting from knuckle to chest	135.988	6.538	2	.036
Physical discomfort for lifting from chest to shoulder	145.714	6.344	2	.042
Physical discomfort for lifting above shoulder	139.442	.013	2	.970
Physical discomfort for back posture (< 20 deg.) repetition	144.784	5.324	2	.067
Physical discomfort for back posture (20 to 60 deg.) repetition	120.116	10.726	2	.008
Physical discomfort for back posture (> 60 deg.) repetition	152.155	12.716	2	.001
Physical discomfort for back posture (< 20 deg.) duration	142.128	2.719	2	.259
Physical discomfort for back posture (20 to 60 deg.) duration	125.542	6.132	2	.048
Physical discomfort for back posture (> 60 deg.) duration	115.234	5.845	2	.049
Physical discomfort for floor or surface vibration	120.809	1.450	2	.493
Physical discomfort for hand tool vibration	131.135	11.756	2	.002
Body mass index (BMI)	120.911	1.521	2	.510

3.5.1.4. Effect size of the predictors on acute lower back MSDs

Table 3.14 presents all explanatory variables for acute work related lower back musculoskeletal problems/ disorders in metal fitter and machinists of manufacturing industries. Variables that are associated with outcome and showed positive significant association are as follows: static strength i.e. ability to perform manual handling task such as lifting and carrying objects, physical discomfort for 16 to 20 kg of lifting, and physical discomfort for back posture (more than 60 degrees) duration. Working with the extent of lifting from knuckle to chest is a protective factor for acute lower back MSD. Variables that are associated with the outcome and showed no significant association are as follows: trunk strength i.e. ability to safely use trunk to support the manual handling tasks, body equilibrium i.e. ability to keep or regain body balance or stay upright during manual handling tasks, Stamina i.e. ability to exert physically without getting winded or out of breath, multi limb coordination – i.e. ability to coordinate limbs (for example, two arms, two legs, or one leg and one arm) while performing manual handling tasks, physical discomfort for less than 5 kg of lifting, physical discomfort for 6 to 10 kg of lifting, physical discomfort for lifting from floor to knuckle, physical discomfort for lifting above shoulder, and physical discomfort for back posture repetition. In order to quantify the effect of physical discomfort, those lifting form knuckle to chest, as opposed to lifting floor to knuckle, chest to shoulder, and above shoulder, can acted as the reference group in further analysis.

Static strength: The static strength of metal fitter and machinists significantly predicted whether they got acute work related musculoskeletal problems/ disorders or no musculoskeletal problems/ disorders, $b = 2.286, Wald\ \chi^2(1) = 4.330, p <$

.05. Odds of getting acute musculoskeletal problems/ disorder (rather than no musculoskeletal problems/ disorder) is 9.833.

Table 3.14 Occurances of MSD (sometimes (acute) vs. nil) lower back

	B	***Std. Error***	***Wald***	***df***	***Sig.***	***Exp(B)***	***95% Confidence Interval for Exp(B)***	
							Lower Bound	***Upper Bound***
Intercept	.601	7.220	.007	1	.934			
Manual dexterity	-3.769	1.439	6.857	1	.009	.023	.001	.388
Static strength	2.286	1.098	4.330	1	.037	9.833	1.142	84.662
Dynamic strength	-1.616	.714	5.115	1	.024	.199	.049	.806
Trunk strength	.921	.835	1.217	1	.270	2.512	.489	12.907
Flexibility	-.123	.733	.028	1	.867	.885	.210	3.718
Body equilibrium	.076	.565	.018	1	.893	1.079	.357	3.267
Stamina	1.389	.861	2.605	1	.107	4.011	.742	21.673
Arm hand steadiness	-.462	.735	.395	1	.530	.630	.149	2.661
Finger dexterity	-.202	.981	.042	1	.837	.817	.119	5.595
Multi limb coordination	.290	1.070	.073	1	.786	1.336	.164	10.889
Physical discomfort for < 5 kg of lifting	1.268	1.832	.479	1	.489	3.553	.098	128.754
Physical discomfort for 6 to 10 kg of lifting	2.637	1.517	3.020	1	.082	13.973	.714	273.455
Physical discomfort for 11 to 15 kg of lifting	-1.278	1.380	.858	1	.354	.279	.019	4.167
Physical discomfort for 16 to 20 kg of lifting	3.903	1.600	5.952	1	.015	49.531	2.154	1139.024
Physical discomfort for lifting from floor to knuckle	2.770	2.101	1.738	1	.187	15.955	.260	980.058
Physical discomfort for lifting from knuckle to chest	-3.220	1.602	4.041	1	.044	.040	.002	.922
Physical discomfort for lifting from chest to shoulder	-2.464	1.413	3.041	1	.081	.085	.005	1.357

	B	*Std. Error*	*Wald*	*df*	*Sig.*	*Exp(B)*	*95% Confidence Interval for Exp(B)*	
							Lower Bound	*Upper Bound*
Physical discomfort for lifting above shoulder	.199	1.083	.034	1	.854	1.220	.146	10.190
Physical discomfort for back posture (< 20 deg.) repetition	2.056	1.462	1.979	1	.159	7.818	.446	137.169
Physical discomfort for back posture (20 to 60 deg.) repetition	-1.018	1.182	.741	1	.389	.361	.036	3.667
Physical discomfort for back posture (> 60 deg.) repetition	-.010	.749	.000	1	.990	.990	.228	4.297
Physical discomfort for back posture (< 20 deg.) duration	-1.071	1.089	.968	1	.325	.343	.041	2.894
Physical discomfort for back posture (20 to 60 deg.) duration	-2.338	1.441	2.632	1	.105	.097	.006	1.626
Physical discomfort for back posture (> 60 deg.) duration	1.833	.873	4.407	1	.036	6.254	1.129	34.626
Physical discomfort for floor or surface vibration	-.494	1.201	.169	1	.681	.610	.058	6.430
Physical discomfort for hand tool vibration	-1.004	.674	2.217	1	.137	.366	.098	1.374
Body mass index (BMI)	-.004	.111	.001	1	.971	.996	.802	1.237

Physical discomfort for 16 to 20 kg of lifting: physical discomfort of metal fitter and machinists in lifting 16 to 20 kg significantly predicted whether they got acute work related musculoskeletal problems/ disorders or no musculoskeletal problems/ disorders, $b = 3.903, Wald\ \chi^2(1) = 5.952, p < .05$. As the physical discomfort (based on perception) of metal fitter and machinists in lifting 16 to 20 kg changes from nil to slight, slight to moderate, moderate to high, and high to very high, the change in the odds of having work related acute lower back MSD compared to not having acute lower back MSD is 49.53.

Physical discomfort for back posture (more than 60 degrees) duration: physical discomfort of metal fitter and machinists for holding back posture (more than 60 degrees) for a certain period of time significantly predicted whether they got acute work related musculoskeletal problems/ disorders or no musculoskeletal problems/ disorders, $b = 1.833, Wald\ \chi^2(1) = 4.407, p < .05$. As this variable increases, so as the lifting/ lowering tasks require more physical discomfort due to holding back posture in a position of more than 60 degrees flexion, the change in the odds of getting acute lower back MSD (rather than no MSD) is 6.254.

Stamina: The stamina of metal fitter and machinists not significantly predicted whether they got acute work related musculoskeletal problems/ disorders or no musculoskeletal problems/ disorders, $b = 1.389, Wald\ \chi^2(1) = 2.605, p > .05$. Although this predictor is not significant, the odds ratio is comparable to the odds ratio for physical discomfort of back posture (more than 60 degrees) duration (which was significant).

Physical discomfort for 6 to 10 kg of lifting: Physical discomfort of metal fitter and machinists in lifting 6 to 10 kg not significantly predicted whether they got acute work related musculoskeletal problems/ disorders or no musculoskeletal problems/ disorders, $b = 2.637, Wald\ \chi^2(1) = 3.020, p > .05$. Although this predictor is not significant, the odds ratio is comparable to the odds ratio for stamina (which was significant).

Physical discomfort for lifting from floor to knuckle: Physical discomfort of metal fitter and machinists for lifting from floor to knuckle did not significantly predicted whether they got acute work related musculoskeletal problems/ disorders or no musculoskeletal problems/ disorders, $b = 2.770, Wald\ \chi^2(1) = 1.738, p > 05.$ Although this predictor is not significant, the odds ratio is comparable to the odds ratio for stamina (which was significant).

Physical discomfort for back posture (< 20 deg.) repetition: Physical discomfort of metal fitter and machinists for repeating the back posture (less than 20 degrees) did not significantly predicted whether they got acute work related musculoskeletal problems/ disorders or no musculoskeletal problems/ disorders, $b = 2.056, Wald\ \chi^2(1) = 1.979, p >$ .05. Although this predictor is not significant, the odds ratio is comparable to the odds ratio for static strength (which was significant).

3.5.1.5. Effect size of the predictors on chronic lower back problems/ disorders

Table 3.15 presents all explanatory variables for chronic work related lower back musculoskeletal problems/ disorders in metal fitter and machinists of manufacturing industries. Variables that are associated with outcome and showed positive significant association are as follows: static strength i.e. ability to perform manual handling task such as lifting and carrying objects, stamina i.e. ability to exert physically without getting winded or out of breath, physical discomfort for 6 to 10 kg of lifting, physical discomfort for 16 to 20 kg of lifting, and physical discomfort for back posture (more than 60 degrees) repetition. Working with the extent of lifting from chest to shoulder is a protective factor for chronic lower back MSD. In order to quantify the effect of physical discomfort, those lifting form chest to shoulder, as opposed to lifting floor to knuckle, knuckle to chest, and above shoulder, can acted as the reference group in further analysis.

Table 3.15 Occurance of MSD (regular (chronic) vs. nil) lower back

	B	***Std. Error***	***Wald***	***df***	***Sig.***	***Exp(B)***	***95% Confidence Interval for Exp(B)***	
							Lower Bound	***Upper Bound***
Intercept	-28.750	10.041	8.199	1	.004	-	-	-
Manual dexterity	-4.605	1.605	8.231	1	.004	.010	.000	.232
Static strength	4.934	1.453	11.523	1	.001	138.868	8.045	2397.191
Dynamic strength	-4.147	1.033	16.110	1	.000	.016	.002	.120
Trunk strength	-.591	1.054	.314	1	.575	.554	.070	4.368
Flexibility	.200	.897	.050	1	.824	1.221	.211	7.078
Body equilibrium	.486	.698	.485	1	.486	1.626	.414	6.391
Stamina	2.169	1.003	4.674	1	.031	8.748	1.225	62.494
Arm hand steadiness	.927	.866	1.147	1	.284	2.528	.463	13.802
Finger dexterity	1.414	1.162	1.482	1	.223	4.114	.422	40.105
Multi limb coordination	-.843	1.083	.605	1	.437	.430	.052	3.597
Physical discomfort for < 5 kg of lifting	.012	2.036	.000	1	.995	1.012	.019	54.679
Physical discomfort for 6 to 10 kg of lifting	4.124	1.724	5.723	1	.017	61.806	2.107	1813.105
Physical discomfort for 11 to 15 kg of lifting	-.018	1.573	.000	1	.991	.982	.045	21.416
Physical discomfort for 16 to 20 kg of lifting	4.383	1.694	6.693	1	.010	80.074	2.893	2216.171
Physical discomfort for lifting from floor to knuckle	2.858	2.159	1.752	1	.186	17.425	.253	1199.535
Physical discomfort for lifting from knuckle to chest	-1.545	1.738	.790	1	.374	.213	.007	6.434

	B	*Std. Error*	*Wald*	*df*	*Sig.*	*Exp(B)*	*95% Confidence Interval for Exp(B)*	
							Lower Bound	*Upper Bound*
Physical discomfort for lifting from chest to shoulder	-3.875	1.648	5.529	1	.019	.021	.001	.525
Physical discomfort for lifting above shoulder	.274	1.445	.036	1	.850	1.315	.077	22.341
Physical discomfort for back posture (< 20 deg.) repetition	-.725	1.663	.190	1	.663	.484	.019	12.616
Physical discomfort for back posture (20 to 60 deg.) repetition	2.587	1.386	3.485	1	.062	13.296	.879	201.115
Physical discomfort for back posture (> 60 deg.) repetition	2.925	1.232	5.640	1	.018	18.637	1.667	208.367
Physical discomfort for back posture (< 20 deg.) duration	.604	1.376	.193	1	.661	1.830	.123	27.156
Physical discomfort for back posture (20 to 60 deg.) duration	-3.909	1.701	5.282	1	.022	.020	.001	.562
Physical discomfort for back posture (> 60 deg.) duration	.894	1.109	.650	1	.420	2.445	.278	21.485
Physical discomfort for floor or surface vibration	.617	1.402	.194	1	.660	1.854	.119	28.935
Physical discomfort for hand tool vibration	-2.521	.867	8.457	1	.004	.080	.015	.440
Body mass index (BMI)	.102	.133	.586	1	.444	1.107	.853	1.436

Static strength: The static strength of metal fitter and machinists significantly predicted whether they got chronic work related musculoskeletal problems/ disorders or no musculoskeletal problems/ disorders, $b = 4.934, Wald\ \chi^2(1) =$

$11.523, p < .05$. Odds of getting chronic musculoskeletal problems/ disorder (rather than no musculoskeletal problems/ disorder) is 138.868.

Stamina: The stamina of metal fitter and machinists significantly predicted whether they got chronic work related musculoskeletal problems/ disorders or no musculoskeletal problems/ disorders, $b = 2.169, Wald\ \chi^2(1) = 4.674, p < .05$. Odds of getting chronic musculoskeletal problems/ disorder (rather than no musculoskeletal problems/ disorder) is 8.748. Metal fitter and machinists are more likely to have chronic work related lower back musculoskeletal problems/ disorders than not to get musculoskeletal problems/ disorders if they do not have very good ability to exert physically without getting winded or out of breath.

Physical discomfort for 6 to 10 kg of lifting: Physical discomfort of metal fitter and machinists in lifting 6 to 10 kg significantly predicted whether they got chronic work related musculoskeletal problems/ disorders or no musculoskeletal problems/ disorders, $b = 4.124, Wald\ \chi^2(1) = 5.723, p < .05$. As the physical discomfort (based on perception) of metal fitter and machinists in lifting 6 to 10 kg changes from nil to slight, slight to moderate, moderate to high, and high to very high, the change in the odds of having work related chronic lower back MSD compared to not having chronic lower back MSD is 61.806.

Physical discomfort for 16 to 20 kg of lifting: Physical discomfort of metal fitter and machinists in lifting 16 to 20 kg significantly predicted whether they got chronic work related musculoskeletal problems/ disorders or no musculoskeletal problems/ disorders, $b = 4.383, Wald\ \chi^2(1) = 6.693, p < .05$. As the physical discomfort (based on perception) of metal fitter and machinists in lifting 16 to 20 kg changes from nil to slight, slight to moderate, moderate to high, and high to very high, the change in the odds of having work related chronic lower back MSD compared to not having chronic lower back MSD is 80.074.

Physical discomfort for back posture (more than 60 degrees) repetition: Physical discomfort of metal fitter and machinists for repeating back posture (more than 60 degrees) during lifting/ lowering significantly predicted whether they got chronic work related musculoskeletal problems/ disorders or no musculoskeletal problems/ disorders, $b = 2.925, Wald\ \chi^2(1) = 5.640, p < .05$. As this variable increases, so as the lifting/ lowering tasks require more physical discomfort due to holding back posture in a position of more than 60 degrees bending, the change in the odds of getting chronic lower back MSD (rather than no MSD) is 18.637.

Physical discomfort for lifting from floor to knuckle: Physical discomfort of metal fitter and machinists for lifting from floor to knuckle did not significantly predicted whether they got chronic work related musculoskeletal problems/ disorders or no musculoskeletal problems/ disorders, $b = 2.858, Wald\ \chi^2(1) = 1.752, p > 05$. Although this predictor is not significant, the odds ratio is comparable to the physical discomfort for back posture (more than 60 degrees) repetition (which was significant).

Physical discomfort for back posture (20 to 60 deg.) repetition: Physical discomfort of metal fitter and machinists for repeating the back posture (20 to 60 degrees) did not significantly predicted whether they got chronic work related musculoskeletal problems/ disorders or no musculoskeletal problems/ disorders, $b = 2.587, Wald\ \chi^2(1) = 3.485, p > .05$. Although this predictor is not significant, the odds ratio is comparable to the odds ratio for stamina (which was significant).

3.5.1.6. Model fitting summary

Table 3.16 represents that 129.400 (all age group), 12.791 (age less than 40 years), 31.068 (age between 40 and 60 years), and .000 (age over 60 years) unexplained variability of metal fitter and machinists work related lower back MSD is in the data; therefore; the difference or change, 342.626-129.400 = 213.226 (all age group), 66.482-12.791 = 53.691 (age less than 40 years), 104.609-31.068 = 73.541 (age between 40 and 60 years), and 106.636-.000 = 106.636 (age over 60 years), in log likelihood indicates how much new variance has been explained by the model. The decrease in unexplained variance from the intercept only model to the final model are significant (<.05) according to chi-square test, which means that the final models explain the significant amount of variability. The Pearson and Deviance statistics are not significant, that means the predicted metal fitter and machinists' work related acute and chronic lower back MSD are not significantly different from the observed metal fitter and machinists' work related acute and chronic lower back MSD. There is a big difference between Pearson and Deviance statistics for all age groups. Therefore, dispersion parameter has been calculated.

$$\phi_{Pearson} = \frac{\lambda^2}{df} = \frac{309.578}{304} = 1.018$$

Neither of these is high, the value based on Pearson is greater than one but not close to 2, so does not give a cause of concern that the data are over dispersed. Strong associations and significant interactions between outcome variables (i.e. MSD problems in lower back) and predictor variables (such as physical abilities, physical discomfort for repeated lifting, physical discomfort for repeated lifting/ lowering to a particular extent of height, physical discomfort for repeated awkward back posture, holding awkward back posture, vibration from floor, and vibration from hand tools) have been observed. The R-square values indicate these are good models of predicting the probabilities for metal fitter and machinists' work related lower back MSD problems from lifting and lowering tasks.

Table 3.16 Model fitting summary for work related lower back MSD

Age groups (Years)	Model fitting criteria *(-2 Log Likelihood)*		Likelihood ratio tests			Goodness of fit		R-Square	
	Intercept only	Final	Chi-Square	df	Sig.	Pearson	Deviance	Cox and Snell	Nagelkerke
All	342.626	129.400	213.226	54	.000	.401	1.000	.692	.815
<40	66.482	12.791	53.691	38	.047	1.000	1.000	.597	.884
40 to 60	104.609	31.068	73.541	36	.000	1.000	1.000	.672	.845
>60	106.636	.000	106.636	54	.000	1.000	1.000	.851	1.000

3.5.2. Model for carpenters

3.5.2.1. Study population characteristics

A structured questionnaire survey of carpenters' perception on physical ability, lifting/ lowering task demand, postural demand, and work related back problems/ disorders was conducted. 155 responses came from carpentry and joinery trade personnel. Summary of the participants is mentioned in Table 3.17.

Table 3.17 Summary of participants

Category	*Sub-category*	*Total*
	Less than 40	55
Age (years)	40 to 59	51
	60 and above	49
	Less than or equal to 10	16
Experience (years)	11 to 20	106
	More than 20	33

3.5.2.2. Significant predictors into the model

Table 3.18 shows the results of the likelihood ratio tests of the predictors to predict lower back MSD. The level of significance ascertains that all the predictors (manual dexterity, static strength, dynamic strength, flexibility, body equilibrium, stamina, arm hand steadiness, finger dexterity, multi limb coordination, lifting repetition (6 to 10 kg), lifting repetition (16 to 20 kg), back posture (> 60 degrees) repetition, and physical discomfort of lifting from chest to shoulder) are significant into the model.

Table 3.18 Likelihood ratio tests of the predictors to predict lower back MSD

Effect	*Model Fitting Criteria*	*Likelihood Ratio Tests*		
	-2 Log Likelihood of Reduced Model	*Chi-Square*	*df*	*Sig.*
Intercept	25.210	.000	0	.
Manual dexterity	63.458	38.248	4	.000
Static strength	88.314	63.104	4	.000
Dynamic strength	80.691	55.480	4	.000
Flexibility	86.372	61.162	4	.000
Body equilibrium	62.458	37.248	4	.000
Stamina	70.860	45.650	4	.000
Arm hand steadiness	103.870	78.659	4	.000
Finger dexterity	71.718	46.508	4	.000
Multi limb coordination	60.880	35.670	4	.000
Lifting repetition (6 to 10 kg)	71.103	45.893	4	.000
Lifting repetition (16 to 20 kg)	12.494	6.352	4	.000
Back posture (> 60 degrees) repetition	76.531	51.321	4	.000
Physical discomfort of lifting from chest to shoulder	61.400	36.190	4	.000

Table 3.19 shows the results of the likelihood ratio tests of the predictors to predict upper back MSD. Some predictors are not significant into the model. Finger dexterity: ability to perform coordinated movements of the fingers of one or both hands, for example to grasp, manipulate or assemble small objects did not show a significant effect to predict upper back MSD, $\chi^2(4) = 4.655, p > .325$.

Table 3.19 Likelihood ratio tests of the predictors to predict upper back MSD

Effect	*Model Fitting Criteria*	*Likelihood Ratio Tests*		
	-2 Log Likelihood of Reduced Model	*Chi-Square*	*df*	*Sig.*
Intercept	72.885	.000	0	.
Manual dexterity	79.238	6.354	4	.174
Static strength	83.488	10.603	4	.031
Dynamic strength	81.995	9.110	4	.049
Flexibility	92.887	20.002	4	.000
Body equilibrium	82.206	9.321	4	.041
Stamina	82.097	9.212	4	.043
Arm hand steadiness	80.808	9.923	4	.039
Finger dexterity	77.540	4.655	4	.325
Multi limb coordination	76.336	3.451	4	.485
Lifting repetition (6 to 10 kg)	131.875	58.990	4	.000
Lifting repetition (16 to 20 kg)	78.452	5.567	4	.234
Back posture (> 60 degrees) repetition	79.126	6.241	4	.182
Physical discomfort of lifting from chest to shoulder	86.476	13.591	4	.009

Similarly, multi limb coordination: ability to coordinate limbs (for example, two arms, two legs, or one leg and one arm) while performing manual handling tasks had not significant effect into the model to predict upper back MSD. The variables (manual dexterity, lifting repetition (16 to 20 kg), and back posture (> 60 degrees) repetition) had significant effect to predict lower back MSD, but these are insignificant to predict upper back MSD.

3.5.2.3. *Effect size of the predictors on back MSD*

Effect size of the predictors on back MSD summarised in Table 3.20 and Table 3.21.

Manual dexterity: Table 3.20 and Table 3.21 demonstrate that the very good and good compared to very poor and poor manual dexterity significantly predicted acute lower back (b = -28.563, Wald χ^2 (1) = 4.154, p < .05) and upper back (b = -3.798, Wald χ^2 (1) = 1.846, p < .05) MSD or no MSD. The very good and good compared to very poor and poor manual dexterity did not significantly predict occurrences of chronic lower back (b = 10.284, Wald χ^2 (1) = .514, p > .05) and upper back (b = -10.379, Wald χ^2 (1) = 2.491, p > .05) MSD. Similarly, moderate compared to very poor and poor did not significantly predict upper and lower back acute and chronic MSD.

Static strength: Good and very good compared to poor and very poor static strength of the physical ability significantly predicted occurrences of acute lower back MSD or no MSD, b = -129.647, Wald χ^2 (1) = 11.037, p < .05, but insignificant to predict acute upper back MSD b = -4.007, Wald χ^2 (1) = 2.120, p > .05. Static strength did not significantly predict occurrences of chronic lower back and upper back MSD.

Dynamic strength: Dynamic strength of the physical ability significantly predicted occurrences of acute lower back MSD, b = 134.699, Wald χ^2 (1) = 11.948, p < .05. It also significantly predicted occurrences of chronic lower back MSD, b = 134.668, Wald χ^2 (1) = 11.837, $p < .05$, but did not significantly predict the upper back MSD, b = 3.120, Wald χ^2 (1) = .755, $p > .05$.

Flexibility: Flexibility; ability to bend, stretch, twist, or reach with body, arms, and/or legs significantly predicted chronic lower back MSD, b = -43.486, Wald χ^2 (1) = 4.945, $p < .05$, but did not significantly predict upper back MSD.

Body equilibrium: Body equilibrium significantly predicted chronic lower back MSD, b = -25.767, Wald χ^2 (1) = 3.868, $p < .05$, b = -49.926, Wald χ^2 (1) = 7.576, $p < .05$. Moderate to very good body equilibrium reduces the occurrences of chronic lower back MSD compare to those who had poor to very poor body equilibrium. But did not predict acute lower back MSD significantly.

Stamina: Stamina significantly predicted chronic lower back MSD, b = -29.860, Wald χ^2 (1) = 6.285, $p < .05$, b = -37.299, Wald χ^2 (1) = 4.521, $p < .05$, but insignificant to predict acute lower back MSD. Stamina insignificantly predict the occurrences of acute and chronic upper back MSD.

Arm hand steadiness: Arm hand steadiness significantly predicted acute and chronic lower back MSD, but insignificant in predicting upper back MSD. Moderate arm hand steadiness reduces the probability of occurrences of chronic lower back MSD significantly, b = -20.404, Wald χ^2 (1) = 4.158, $p < .05$, compared to poor and very poor arm hand steadiness.

Table 3.20 Parameter estimate for lower back

Occur of MSD lower back	*Sometimes (Acute) vs. no MSD*				*Regular (Chronic) vs. no MSD*			
	B	***Wald***	***df***	***Sig.***	***B***	***Wald***	***df***	***Sig.***
Intercept	-239.933	13.343	1	.000	-258.716	14.194	1	.000
*Manual dexterity=1**	-28.563	4.154	1	.042	10.284	.514	1	.473
*Manual dexterity=2**	18.051	1.077	1	.299	11.926	.506	1	.477
*Manual dexterity=3**	0^b	.	0	.	0^b	.	0	.
*Static strength=1**	-129.647	11.037	1	.001	-85.848	3.715	1	.054
*Static strength=2**	10.821	.344	1	.558	23.604	.979	1	.322
*Static strength=3**	0^b	.	0	.	0^b	.	0	.
*Dynamic strength=1**	-134.699	11.948	1	.001	-134.668	11.837	1	.001
*Dynamic strength=2**	5.248	1.615	1	.204	19.043	1.184	1	.277
*Dynamic strength=3**	0^b	.	0	.	0^b	.	0	.
*flexibility=1**	-8.373	.410	1	.522	-43.486	4.945	1	.026
*flexibility=2**	28.053	3.787	1	.052	-29.450	4.154	1	.042
*flexibility=3**	0^b	.	0	.	0^b	.	0	.
*Body equilibrium=1**	24.958	1.888	1	.169	-25.767	3.868	1	.049
*Body equilibrium=2**	4.053	.144	1	.704	-49.926	7.576	1	.006
*Body equilibrium=3**	0^b	.	0	.	0^b	.	0	.
*stamina=1**	2.467	.076	1	.783	-37.299	4.521	1	.033
*stamina=2**	-8.744	.818	1	.366	-29.860	6.285	1	.012
*stamina=3**	0^b	.	0	.	0^b	.	0	.
*Arm hand steadiness=1**	307.492	13.459	1	.000	271.690	14.392	1	.000
*Arm hand steadiness=2**	27.825	4.091	1	.043	-20.404	4.158	1	.041
*Arm hand steadiness=3**	0^b	.	0	.	0^b	.	0	.
*Finger dexterity=1**	-60.582	5.809	1	.016	22.576	2.698	1	.100
*Finger dexterity=2**	-45.097	6.288	1	.012	2.497	.061	1	.806
*Finger dexterity=3**	0^b	.	0	.	0^b	.	0	.
*Multi limb coordination=1**	-56.599	5.711	1	.017	-60.861	6.684	1	.010
*Multi limb coordination=2**	-34.463	4.700	1	.030	-35.209	5.158	1	.023
*Multi limb coordination=3**	0^b	.	0	.	0^b	.	0	.
*Repetition 6 to 10 kg=1**	-24.251	.266	1	.606	-47.290	1.407	1	.236

Occur of MSD lower back	*Sometimes (Acute) vs. no MSD*				*Regular (Chronic) vs. no MSD*			
	B	***Wald***	***df***	***Sig.***	***B***	***Wald***	***df***	***Sig.***
*Repetition 6 to 10 kg=2**	8.632	.025	1	.875	-26.822	.338	1	.561
*Repetition 6 to 10 kg=3**	0[b]	.	0	.	0[b]	.	0	.
*Repetition 16 to 20 kg=1**	124.534	8.303	1	.004	144.331	8.029	1	.005
*Repetition 16 to 20 kg=2**	125.154	8.270	1	.004	141.905	7.856	1	.005
*Repetition 16 to 20 kg=3**	0[b]	.	0	.	0[b]	.	0	.
*Back posture repetition more than 60 degrees=1**	-79.382	5.699	1	.017	-117.815	924.704	1	.000
*Back posture repetition more than 60 degrees=2**	-77.758	5.491	1	.019	-107.928	889.602	1	.000
*Back posture repetition more than 60 degrees=3**	0[b]	.	0	.	0[b]	.	0	.
*Physical discomfort for lifting chest to shoulder=1**	-59.284	5.015	1	.025	23.795	1.335	1	.248
*Physical discomfort for lifting chest to shoulder=2**	-34.124	7.260	1	.007	5.024	.215	1	.643
*Physical discomfort for lifting chest to shoulder=3**	0[b]	.	0	.	0[b]	.	0	.

* 1 = good, 2 = moderate, and 3 = poor physical ability (manual dexterity, static strength, dynamic strength, flexibility, body equilibrium, body equilibrium, stamina, arm hand steadiness, finger dexterity, and multi limb coordination); 1 = low, 2 = moderate, and 3 = high repetition, back posture, and physical discomfort. [b] Reference category.

Finger dexterity: Finger dexterity had no significant effect in predicting chronic lower back, acute and chronic upper back MSD. Finger dexterity significantly predicted whether there is chance of occurrences of acute lower back MSD or no MSD, b = -45.097, Wald χ^2 (1) = 6.288, p < .05.

Multi limb coordination: multi limb coordination significantly predicted whether there was a chance of acute and chronic lower back MSD or no MSD, but did not significantly predicted whether there was acute/ chronic upper back MSD.

Repetition 6 to 10 kg of weight lifting/ lowering: The repetition of 6 to 10 kg of weight lifting/ lowering of task requirement significantly predicted whether there was a chance of getting acute and chronic upper back MSD or no MSD. Low (< 5 times per minute), and moderate (5 to 8 times per minute) repetition reduces the occurrences of upper and lower back acute and chronic MSD compared to high to very high (> 8 times per minute) repetition, $b = -11.132$, Wald χ^2 (1) = 15.751, $p < .05$. This item did not significantly predict lower back acute and chronic MSD.

Repetition 16 to 20 kg of weight lifting/ lowering: The repetition of 16 to 20 kg of weight lifting/ lowering of task requirement significantly predicted whether there was a chance of getting acute and chronic upper and lower back MSD or no MSD.

Back Posture repetition more than 60 degrees: The back posture (more than 60 degrees) repetition (low, moderate) requirement significantly predicted whether there was lower back acute and chronic MSD or no MSD.

Extent of lifting/ lowering: Physical discomfort to the extent (chest to shoulder) of lifting/ lowering significantly predict acute upper ($b = -6.895$, Wald χ^2 (1) = 5.917, $p < .05$,) and lower back ($b = 59.284$, Wald χ^2 (1) = 5.015, $p < .05$) MSD, but did not significantly predict chronic upper and lower back MSD.

Table 3.21 Parameter estimate for upper back

Occur of MSD upper back	***Sometimes (Acute) vs. no MSD***				***Regular (Chronic) vs. no MSD***			
	B	***Wald***	***df***	***Sig.***	***B***	***Wald***	***df***	***Sig.***
Intercept	30.132	11.887	1	.001	24.378	10.787	1	.001
*Manual dexterity=1**	-3.798	1.846	1	.174	-10.379	2.491	1	.115
*Manual dexterity=2**	-1.108	.199	1	.656	-12.405	2.158	1	.142
*Manual dexterity=3**	0^b	.	0	.	0^b	.	0	.
*Static strength=1**	4.007	2.120	1	.145	7.163	1.586	1	.208
*Static strength=2**	-.617	.065	1	.799	9.098	1.851	1	.174
*Static strength=3**	0^b	.	0	.	0^b	.	0	.
*Dynamic strength=1**	3.120	.755	1	.385	6.728	1.713	1	.191
*Dynamic strength=2**	3.441	2.941	1	.086	-2.418	.162	1	.687
*Dynamic strength=3**	0^b	.	0	.	0^b	.	0	.
*flexibility=1**	-4.104	.925	1	.336	11.646	1.174	1	.279
*flexibility=2**	-1.880	.576	1	.448	-4.022	2.043	1	.153
*flexibility=3**	0^b	.	0	.	0^b	.	0	.
*Body equilibrium=1**	-4.979	1.997	1	.158	-7.477	2.555	1	.110
*Body equilibrium=2**	-4.927	3.154	1	.076	-3.742	1.527	1	.217
*Body equilibrium=3**	0^b	.	0	.	0^b	.	0	.
*stamina=1**	.245	.007	1	.935	-5.476	1.986	1	.159
*stamina=2**	.346	.018	1	.894	-5.917	2.337	1	.126
*stamina=3**	0^b	.	0	.	0^b	.	0	.
*Arm hand steadiness=1**	-2.880	1.767	1	.184	3.366	.672	1	.412
*Arm hand steadiness=2**	1.163	.276	1	.599	4.268	2.036	1	.154
*Arm hand steadiness=3**	0^b	.	0	.	0^b	.	0	.
*Finger dexterity=1**	1.417	.204	1	.652	-.705	.023	1	.879
*Finger dexterity=2**	3.206	2.740	1	.098	-.368	.022	1	.881
*Finger dexterity=3**	0^b	.	0	.	0^b	.	0	.
*Multi limb coordination=1**	18.874	.000	1	.998	17.251	.000	1	.998
*Multi limb coordination=2**	.052	.001	1	.978	-2.487	.993	1	.319
*Multi limb coordination=3**	0^b	.	0	.	0^b	.	0	.

Occur of MSD upper back	***Sometimes (Acute) vs. no MSD***				***Regular (Chronic) vs. no MSD***			
	B	***Wald***	***df***	***Sig.***	***B***	***Wald***	***df***	***Sig.***
*Repetition 6 to 10 kg=1**	-11.132	15.751	1	.000	-8.163	5.748	1	.017
*Repetition 6 to 10 kg=2**	-4.684	6.881	1	.009	-13.193	3.192	1	.074
*Repetition 6 to 10 kg=3**	0[b]	.	0	.	0[b]	.	0	.
*Repetition 16 to 20 kg=1**	-20.367	13.215	1	.000	-16.467	25.056	1	.000
*Repetition 16 to 20 kg=2**	-16.765	11.901	1	.001	-14.288	20.321	1	.000
*Repetition 16 to 20 kg=3**	0[b]	.	0	.	0[b]	.	0	.
*Back posture repetition more than 60 degrees=1**	-1.322	.092	1	.761	-3.079	.235	1	.628
*Back posture repetition more than 60 degrees=2**	.418	.009	1	.923	-6.627	.763	1	.382
*Back posture repetition more than 60 degrees=3**	0[b]	.	0	.	0[b]	.	0	.
*Physical discomfort for lifting chest to shoulder=1**	-6.895	5.917	1	.015	-2.234	.181	1	.670
*Physical discomfort for lifting chest to shoulder=2**	-1.617	.335	1	.563	4.214	.411	1	.522
*Physical discomfort for lifting chest to shoulder=3**	0[b]	.	0	.	0[b]	.	0	.

* 1 = good, 2 = moderate, and 3 = poor physical ability (manual dexterity, static strength, dynamic strength, flexibility, body equilibrium, body equilibrium, stamina, arm hand steadiness, finger dexterity, and multi limb coordination); 1 = low, 2 = moderate, and 3 = high repetition, back posture, and physical discomfort. [b] Reference category.

3.5.2.4. Model fitting summary

The change from intercept model, model to predict upper and lower back work related MSD for all age group and individual age group, to final model is significant (< .05), which means that final model explains a significant amount of original variability. Pearson and Deviance statistics are not significant that means predicted upper and lower back MSDs are not significantly different from the observe upper and lower back MSDs. Cox and Snell's R^2 and Nagelkerke R^2 value indicates that there is strong association between lower and upper back work related acute/ chronic musculoskeletal disorder and included predictor variables (physical abilities, lifting/ lowering task requirements, and postural requirements) in this model.

Table 3.22 Model fitting summary for all age groups

MSD	Model fitting criteria *(-2 Log Likelihood)*		Likelihood ratio tests			R-Square	
	Intercept only	Final	Chi-Square	df	Sig.	Cox and Snell	Nagelkerke
Lower Back	266.554	25.210	241.344	52	.000	.789	.935
Upper Back	281.249	72.885	208.364	52	.000	.739	.865

Table 3.23 Model fitting summary for age <40 years

MSD	Model fitting criteria *(-2 Log Likelihood)*		Likelihood ratio tests			R-Square	
	Intercept only	Final	Chi-Square	df	Sig.	Cox and Snell	Nagelkerke
Lower Back	46.066	3.472	42.595	6	.000	.539	.880
Upper Back	51.152	1.850	49.303	6	.000	.592	.936

Table 3.24 Model fitting summary for age between 40 and 60 years

MSD	Model fitting criteria *(-2 Log Likelihood)*		Likelihood ratio tests			R-Square	
	Intercept only	Final	Chi-Square	df	Sig.	Cox and Snell	Nagelkerke
Lower Back	69.248	20.557	48.691	32	.030	.615	.760
Upper Back	81.357	5.443	75.914	32	.000	.774	.922

Table 3.25 Model fitting summary for age >60 years

MSD	Model fitting criteria *(-2 Log Likelihood)*		Likelihood ratio tests			R-Square	
	Intercept only	Final	Chi-Square	df	Sig.	Cox and Snell	Nagelkerke
Lower Back	101.789	.000	101.789	52	.000	.875	1.000
Upper Back	89.060	1.386	87.673	52	.001	.833	.989

3.5.3. Model for bricklayers

3.5.3.1. Study population characteristics

After discarding all incomplete/ irrelevant participations, the total number of valid responses from bricklayers is 107. Table 3.26 shows the age and experience details of the participants in this cross sectional research.

Table 3.26 Summary of participants

Category	Sub-category	Total
Age (years)	Less than 40	30
	40 to 59	38
	60 and above	39
Experience (years)	Less than or equal to 10	14
	11 to 20	73
	More than 20	20

3.5.3.2. Weight or coefficient values of the predictors

The model intercepts and coefficient values of predictors of the multinomial logistic regression modelling are consolidated in Table 3.27 to Table 3.31. The parameters with negative coefficients decrease the likelihood of that response category (i.e., acute/ chronic back MSD problems) and likewise, the parameters with positive coefficients increase the likelihood of that response category.

Table 3.27 Model intercept (b_{0k}) values for musculoskeletal problem/ disorder (k)

MSD (k)	***Acute****	***Chronic****
1 Upper Back	-33.13	-17.29
2 Low Back	-23.16	45.32

* No MSD problem is the reference benchmark

Table 3.28 Coefficient (b_{mk}) values of BMI for each musculoskeletal problem/ disorder (k)

MSD (k)	***Acute****	***Chronic****
1 Upper Back	.30	.08
2 Lower Back	-.47	-.44

* No MSD problem is the reference benchmark

Table 3.29 Coefficient (b_{ak}) values of predictor variables related to physical abilities

A	**Upper back**		**Lower back**	
	Acute $X_{ia} = \{1,2,3,4,5^c\}$	*Chronic* $X_{ia} = \{1,2,3,4,5^c\}$	*Acute* $X_{ia} = \{1,2,3,4,5^c\}$	*Chronic* $X_{ia} = \{1,2,3,4,5^c\}$
1	-49.77,-16.49,-19.80,-33.25,0_c	170.82,39.88,129.34,7.92,0_c	-156.05,-154.08,-13.10,-82.68,0_c	146.36,-212.95,81.80,50.54,0_c
2	43.38,60.64,17.40,0_c	2.71,27.77,77.00,0_c	-70.52,-83.81,-227.017,0_c	-249.87,-325.87,-172.74,0_c
3	-43.89,-9.04,-11.04,-14.31,0_c	7.10,45.90,-27.23,-8.39,0_c	209.05,-45.29,-107.88,-81.83,0_c	208.37,69.52,117.57,-31.04,0_c
4	-9.98,20.02,9.21,-18.82,0_c	101.45,76.70,47.98,46.01,0_c	-41.89,-89.45,5.40,50.354,0_c	173.71,216.43,88.80,104.63,0_c
5	-14.80,32.74,.25,17.51,0_c	-76.68,-26.77,13.89,37.39,0_c	70.27,-3.52,9.26,-24.05,0_c	-33.00,-35.40,-2.40,48.24,0_c
6	4.29,-4.33,-34.73,-15.37,0_c	20.75,-52.33,-87.91,-35.45,0_c	-17.92,-2.27,10.77,-11.27,0_c	80.89,58.45,68.38,-28.18,0_c
7	-44.77,-64.00,-22.49,-39.12,0_c	-59.06,-46.58,2.52,.69,0_c	49.52,16.55,-35.97,25.14,0_c	27.99,-62.69,-68.14,-57.89,0_c
8	157.26,5.66,23.61,-1.75,0_c	-78.84,-4.99,-75.03,-64.12,0_c	-4.49,-49.74,-11.45,36.38,0_c	-19.32,-42.79,-20.42,48.35,0_c
9	-31.06,44.24,1.72,0_c	12.91,27.15,46.90,0_c	187.91,140.66,185.55,0_c	102.76,66.21,132.77,0_c
10	-52.44,-22.35,-31.97,-7.617,0_c	150.55,16.33,9.18,25.99,0_c	-680.85,7.93,-68.922,-80.39,0_c	-391.93,-57.39,-33.40,-90.99,0_c

[c] This is set as the reference benchmark

[1, 2, 3, … 10] Number of predictor variables related to physical abilities.

Table 3.30 Coefficient (b_{fk}) values of predictors related to frequency of lifting/ lowering requirements

F	Upper back		Lower back	
	Acute	*Chronic*	*Acute*	*Chronic*
	$X_{if} = \{1, 2, 3, 4^c\}$	$X_{if} = \{1, 2, 3, 4^c\}$	$X_{if} = \{1, 2, 3, 4^c\}$	$X_{if} = \{1, 2, 3, 4^c\}$
1	-31.27,-28.74,23.47,0c	6.80,-37.55,82.28,0c	-241.85,-152.56,-339.94,0c	-354.06,-151.30,83.59,0c
2	36.88,17.08,0c	-33.97,-9.59,0c	426.67,408.22,454.63,0c	1441.13,1389.77,1368.17,0c
3	17.08,3.81,-147.67,0c	-59.62,-87.21,-40.80,0c	-5.09,-67.92,45.55,0c	-141.89,-181.65,505.79,0c
4	7.24,9.44,11.06,0c	107.94,110.70,166.80,0c	13.82,-110.94,77.37,0c	-275.05,-365.91,-74.07,0c

[c] This is set as the reference benchmark

Table 3.31 Coefficient (b_{ft}) values of predictors of back posture repetitions in lifting/ lowering tasks

T	Upper back		Lower back	
	Acute	*Chronic*	*Acute*	*Chronic*
	$X_{it} = \{1, 2, 3, 4^c\}$	$X_{it} = \{1, 2, 3, 4^c\}$	$X_{it} = \{1, 2, 3, 4^c\}$	$X_{it} = \{1, 2, 3, 4^c\}$
1	49.26,22.13,1.28,0c	142.49,167.98,105.75,0c	-72.41,-164.28,16.02,0c	324.37,-109.65,5.25,0c
2	-81.89,-40.44,22.93,0c	-373.10,-347.37,-380.89,0c	-839.57,-837.44,-786.36,0c	-852.31,-970.90,-772.85,0c
3	24.88,49.45,69.97,0c	-35.84,-33.70,-69.16,0c	-256.21,-253.09,-359.15,0c	-210.40,-265.24,-217.43,0c

[c] This is set as the reference benchmark

The model fitting summaries are consolidated in Table 3.32 (all age groups) Table 3.33 (less than 40 years' age group), Table 3.34 (40 to 59 years' age group) and Table 3.35 (old age workers above 60 years of age). The decrease in unexplained variance of work related acute/ chronic MSD problems in upper back or lower back, i.e. from the baseline model to the final model has been tested by using chi-square test. These changes (decrease) are significant, which means that final model explains a significant amount of the variability (in other words, it is a better fit than the original model). The goodness of fit values of the models have been verified by the estimates of Person's and Deviance's measures (i.e. Pearson's chi-square statistic/ degrees of freedom and Deviance's likelihood ratio chi-square statistic/ degrees of freedom respectively). Also, Cox and Snell's R-Square (R^2_{cs}) and Nagelkerke R-Square (R^2_n) have been used to verify the predictive capabilities of the multinomial logistic regression models. The Cox and Snell's R-Squared is based on the log-likelihood of the model (LLnew) and the log-likelihood of the original model (LLbaseline), i.e. for the sample size "n":

$$\mathrm{R}^2_{\mathrm{cs}} = 1 - e^{[-\frac{2}{n}(LL_{new} - LL_{baseline})]}$$

Similarly, the Nagelkerke R-Square (R^2_n) is computed by:

$$R^2_n = \frac{\mathrm{R}^2_{\mathrm{cs}}}{1 - e^{[\frac{2(LL_{baseline}}{n}]}}$$

Table 3.32 Model fitting summary for all age groups

MSD	Model fitting criteria *(-2 Log Likelihood)*		Likelihood ratio tests			Goodness of fit		R-Square	
	Intercept only	Final	Chi-Square	df	Sig.	Person	Deviance	Cox and Snell	Nagelkerke
Lower Back	396.49	34.13	362.36	120	.00	1.00	1.00	.82	.97
Upper Back	429.02	29.19	399.82	118	.00	1.00	1.00	.86	.98

Table 3.33 Model fitting summary for age <40 years

MSD	Model fitting criteria *(-2 Log Likelihood)*		Likelihood ratio tests			Goodness of fit		R-Square	
	Intercept only	Final	Chi-Square	df	Sig.	Person	Deviance	Cox and Snell	Nagelkerke
Lower Back	109.99	8.08	101.92	38	.00	1.00	1.00	.77	.97
Upper Back	109.91	.00	109.91	36	.00	1.00	1.00	.80	1.00

Table 3.34 Model fitting summary for age between 40 and 60 years

MSD	Model fitting criteria *(-2 Log Likelihood)*		Likelihood ratio tests			Goodness of fit		R-Square	
	Intercept only	Final	Chi-Square	df	Sig.	Person	Deviance	Cox and Snell	Nagelkerke
Lower Back	121.29	34.76	86.54	30	.00	1.00	1.00	.68	.85
Upper Back	107.49	22.72	84.77	30	.00	1.00	1.00	.67	.89

Table 3.35 Model fitting summary for age >60 years

MSD	Model fitting criteria *(-2 Log Likelihood)*		Likelihood ratio tests			Goodness of fit		R-Square	
	Intercept only	Final	Chi-Square	df	Sig.	Person	Deviance	Cox and Snell	Nagelkerke
Lower Back	120.06	.00	120.06	110	.24	1.00	1.00	.85	1.00
Upper Back	123.06	.00	123.06	104	.10	1.00	1.00	.87	1.00

Strong associations and significant interactions between outcome variables (i.e. MSD problems in upper back, and lower back) and predictor variables (such as BMI, physical abilities, load, frequency, back posture and repetition requirements for routine lifting lowering MH tasks) have been noted. The model fitting summaries indicate these are good models of predicting the probabilities for work related lower or upper back MSD problems of bricklayers, e.g. the R-square values for the 'more than 60 years' cohort is 0.85 (Cox and Snell) and 1.00 (Nagelkerke).

Predicting probabilities for work related MSD problems will be useful for enhancing occupational health and safety and mitigate risks from lifting and lowering related bricklaying tasks. The findings are limited to the cross-sectional research that modelled data of 107 bricklayers in Australia. As the nature of MH tasks and MSD risks are potentially relevant in most regions, the model framework and outcomes can be widely useful. As such the current model framework does not include: (i) environment factors such as heat and vibration, (ii) psychological factors, (iii) other root causes for MSD problems e.g. race and anthropometry, genetic and pharmacodynamics. Suitably integrating biomechanical modelling, incorporating other parameters (e.g. vibrations) and longitudinal studies with medical observations will be valuable for firmer generalisations and practical ergonomic applications.

3.6. Chapter conclusion

3.6.1. Metal fitter and machinists

- Working with the extent of lifting from knuckle to shoulder is a protective factor for both acute and chronic lower back MSD
- Metal fitter and machinists are more likely to get acute MSD than not to get MSD if they have lower (very good to very poor) static strength.
- Metal fitter and machinists are more likely to have work related acute lower back musculoskeletal problems/ disorders than not to get musculoskeletal problems/ disorders they do 16 to 20 kg of lifting with physical discomfort.
- Metal fitter and machinists are more likely to have work related acute lower back musculoskeletal problems/ disorders than not to get musculoskeletal problems/ disorders if they hold their back more than 60 degrees of bending position.
- Metal fitter and machinists are more likely to have chronic work related lower back musculoskeletal problems/ disorders than not to get musculoskeletal problems/ disorders if they do not have very good ability to perform manual handling task such as lifting and carrying objects.
- Metal fitter and machinists are more likely to have chronic work related lower back musculoskeletal problems/ disorders than not to get musculoskeletal problems/ disorders if they do not have very good ability to exert physically without being winded or out of breath.
- Metal fitter and machinists are more likely to have work related chronic lower back musculoskeletal problems/ disorders than not to get

musculoskeletal problems/ disorders if they do 6 to 10 kg of lifting with physical discomfort.

- Metal fitter and machinists are more likely to have work related chronic lower back musculoskeletal problems/ disorders than not to get musculoskeletal problems/ disorders if they do 16 to 20 kg of lifting with physical discomfort.
- Metal fitter and machinists are more likely to have work related chronic lower back musculoskeletal problems/ disorders than not to get musculoskeletal problems/ disorders if they bend (more than 60 degrees) their back repeatedly.
- Although some predictors are not significant, the odds ratio is approximately the same as for the significant predictors. So the effect size of significant and non-significant predictors is comparable.

3.6.2. carpenters

- Body equilibrium can reduce the occurrences of upper back MSD.
- According to likelihood ratio test, Multinomial logistic regression model significantly predicts lower back ($\chi^2(25.210) = 241.344$, $p < .05$), and upper back ($\chi^2(72.885) = 208.364$, $p < .05$) work related MSD problems/ disorders for all age groups.

3.6.3. Bricklayers

A multinomial logistic regression framework has been developed for predicting the probabilities potential MSD occurrences such as acute low back, chronic low back, acute upper back, and chronic upper back problems from lifting and lowering tasks. Predictor variables considered in the logistic regression modelling include: body mass index (BMI), ten physical abilities (i.e. manual dexterity, static strength, dynamic strength, trunk strength, flexibility, body equilibrium, stamina, arm-hand steadiness, finger dexterity, multi-limb coordination), loads and extent lifted, postures as well as durations and repetitions of lifting in daily job routines. The model fit summaries including R-Square values indicate good predictability outcomes throughout different age groups. Physical abilities are moderating variables that may increase or reduce the effect of independent variable (predictors) toward dependent variable (MSD).

4. QUANTIFYING LUMBAR LOADS

4.1. Chapter introduction

This chapter presents a regression based assessment model to quantify lumbar joint contact force and torques in lifting/ lowering related manual handling jobs. Appendix I, Figure A.18 shows lumber joints. A set of experimental procedure to have ground reaction force (weight of the body and external load applied onto the body), trunk angle (flexion and extension of the trunk during lifting and lowering), lifting height (extent of lifting from floor), lumbar joints (l1-l2, l2-l3, l3-l4, l4-l5, l5-p) contact force, and lumbar joint torque is presented in this chapter. This chapter also presents experimental quantification of trunk/ back strength and benchmarking this strength to integrate into trunk/ back musculoskeletal safety of lifting/ lowering related manual handling jobs.

4.2. Concept development

Concept 1: It has been found that trunk/ back strength is required for physical ability in the workplace (Rantanen et al. 1998; Foldvari et al. 2000; Rantanen et al. 2001; Tiedemann, Sherrington and Lord 2005; Fiser et al. 2010) and any deficiency of it reduces workability (Verbrugge and Jette 1994; Fried and Guralnik 1997; Dempsey 1998; Fried et al. 2004; Montero-Odasso et al. 2011). Reduced trunk/ back strength can create fatigue during manual handling tasks (Avlund, Rantanen and Schroll 2007; Shin and Kim 2007; Vestergaard et al. 2009). Any deficiency of it creates MSD risks in the workplace e.g. disorder and disability (Guralnik et al. 2000; Kemmlert and Lundholm 2001), dependency (Guralnik et al. 1994; Penninx et al. 2000; Rogers and Wiatrowksi 2005), and mortality (Guralnik et al. 1994; Studenski et al. 2011). This research measures trunk strength and integrated into trunk musculoskeletal safety of lifting lowering MH tasks.

Concept 2: Quantifying lumbar joint contact force and torque in lifting lowering task is required, since reduced lumbar joint contact force and torque is a risk factor for musculoskeletal problems/ disorders. (Marras et al. 2009; Dinesh Samuel 2012; Gallagher and Marras 2012). Existing measurement methods allow measurements of the worker's risk exposure and musculoskeletal activity while the tasks are being executed. In measurement methods, sensors are attached to the respondents' body for measuring exposure in different task of the job (Pontonnier et al. 2014). Electronic goniometer records continuously joint movements when undertaking the task. Continuous data were recorded using lumbar motion monitor (LMM) in three dimensions and later on computer software were used analysing acceleration and velocity of the body. Another technique has been developed where optical markers attached to the workers' anatomical segment of the body. Scanning unit tracks the position of these markers, which is acceleration and velocity of different body segments. Electromyography (EMG) measure muscle tension, evaluate local muscle fatigue (Bae and Armstrong 2011). Some examples of measurement method is given below in Table 4.1. Measurement methods provide comparatively accurate data (David 2005; Hu et al. 2011). Last few decades, there are many methods established to quantify lumbar joint contact force (Bruno, Bouxsein and Anderson 2015).The current measurement methods are too complicated to implement (Arjmand et al. 2011). During measurement, equipment attachment with the body of the subjects create discomfort and that might change the work behaviour, high initial investment is required, highly trained personnel are required to operate the machine, and complicated process. Hence, this research developed an assessment model for quantifying lumbar joint contact force and lumbar joint torque values from specific lifting/ lowering MH tasks. Model developed from personal attributes such as weight, lifting/ lowering task related input variables such as weight of the load and extent of lifting, and postural requirements (angle of back bending). This model will help to assess lumbar joint contact force and torque requirement to design the lifting/ lowering task which will reduce low back musculoskeletal problems/ disorders in the workplace.

Table 4.1 Direct methods to assess WMSDs risks

Techniques	**Main features**	**function**	**Reference**
Electronic goniometry	Records joint posture	Measure angular displacement of upper extremity posture	(Radwin and Lin 1993)
Inclinometers	Record movement in two dimension	Upper limbs, back, and head posture and movement were measured	(Hansson et al. 2001)
Body posture scanning system	Optical markers on body segments	Acceleration and velocities of the body parts were measured	(Bernmark and Wiktorin 2002)
Electromyography	Recording of muscles activities	Muscle force and tension were estimated	(Wells et al. 1997; Jia, Kim and Nussbaum 2011)
Force measurement	Assess force of the fingers	Determination of finger force exposures	(Johnson et al. 2000)
Cyber Glove	22 motion sensors attached into the gloves	Finger, hand, and wrist potion along with grip force were measured	(Freivalds et al. 2000)

4.3. Data collection procedure

This research synergistically employed a contemporary hybrid approach including motion captures, postural analyses, biomechanical modelling and direct measurement method as well as field observations. Since, biomechanical models for the human body are extensively required in understanding and reducing WMSDs risk at the place of work, and biochemical models describe complex musculoskeletal structures for the human body, and biochemical models play a critical role in estimating internal forces, which may not be determined using observational technique, this research adopted biomechanical models, which offer a quantitative evaluation for lumbar musculoskeletal loads in occupational activities, thus helping in the identification of harmful loading situations on lumber.

4.3.1. Motion capture and VR simulations

Body kinetics and kinematics are the need of quantification of the physical exposure (Garg and Kapellusch 2009). Recent advances in measurement systems, such as 3D motion capture systems, facilitate monitoring of body kinematics. Motion captured systems have demonstrated as a tool to assess joint kinematics (Favre et al. 2008; Kim and Nussbaum 2013). Performers' motion was captured in a virtual reality laboratory (Whitman et al. 2004). 22 infrared cameras of OptiTrack motion capturing system were used for capturing motion (kinematic data) during lifting/ lowering MH tasks. This is a marker based motion capturing procedure. Reflective markers were attached to the performers' joints (see Figure 4.1) to track the motion in a dark room with multiple infrared cameras. 30 reflective markers (20 mm in diameter) were attached at the anatomical joint of the upper and lower limbs of the body. A Helen Heyes style marker placement was adopted in placing the marker.

Four marker placed around head, two on right and left front head and two on right and left back head. One marker placed on c7 vertebrae, and another three on T10 vertebrae, clavicle notch, and Xiphoid process on the sternum. Ten markers on left and right side of acromion on the shoulder, elbow, hand wrist bar at the thumb end, wrist bar at the little finger end, and base of middle finger on hand. Four placed on spine (left and right anterior and posterior superior iliac spine. Eight markers placed on left and right lateral epicondyle of knee, lateral, calcaneus, and second metatarsal head. To analyse the recorded movement (kinetics and kinematics of the body), recorded *.c3d motion file was collected.

Figure 4.1 Marker position in motion capture

4.3.2. Ground reaction force measurement

Ground reaction force data was collected using a force plate on which the performer moves during their lifting lowering MH tasks. Since the foot forces change (increase, stabilize, and decrease) under real conditions, the ground reaction force is the value of the bodyweight and external load imposed on the body.

4.3.3. Bio-mechanical modelling

Since, application of biomechanics is recommended to prevent WMSDs (Arjmand and Shirazi-Adl 2005; Garg and Kapellusch 2009; Arjmand et al. 2010), the recorded motion and ground reaction force were applied to establish the biomechanical model, and to estimate the joint contact force and torque of the lumbar joint during lifting and lowering MH tasks. This lumbar joint contact force and torque of the body segments is the summation of the static and dynamic inertial effect of the body segments (Salvendy 2012). Inverse dynamic equation solver, body of biomechanics (BoB), was used for analysing ground reaction force, position, velocity, and acceleration of the performer during lifting/ lowering MH tasks. Sample output of the body of biomechanics is presented in the Figure 4.2.

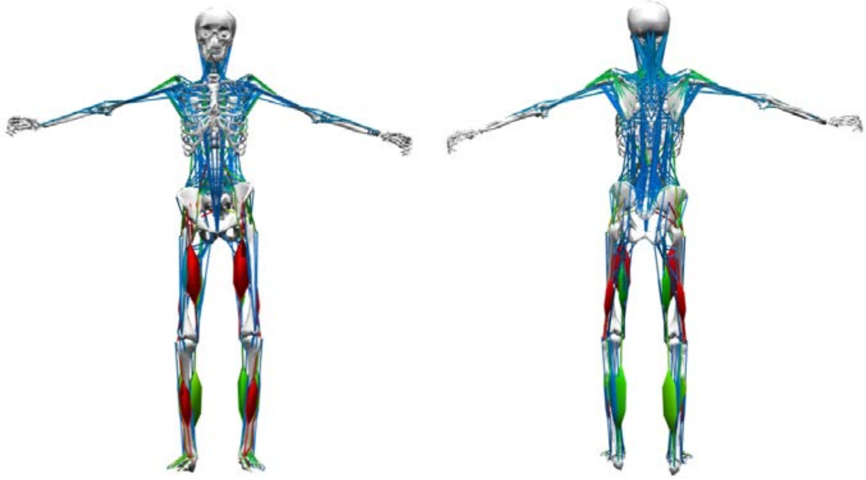


Figure 4.2 Body of biomechanics

Biomechanical models were also applied to assess vertical height of the load position, and back postural (bending) angle during workers lifting/ lowering tasks. Process to make biomechanical model was according to the figure 4.3.

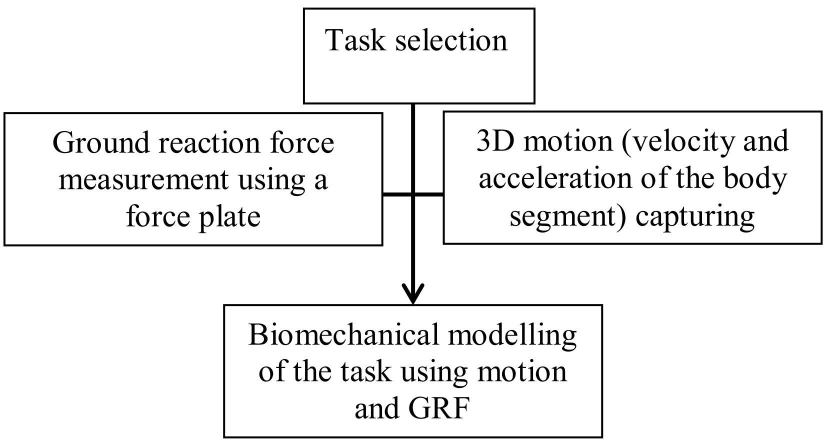


Figure 4.3 Methods of making biomechanical modelling

4.3.4. Isokinetic trunk/ back strength measurement

Torque at trunk/ back joint during trunk/ back flexion and extension are parameters of trunk/ back strength, trunk/ back strength has been implicated as a component for maintaining physical ability (Hoogendoorn et al. 2000a; Seynnes et al. 2005). The measurement of isokinetic trunk/ back strength was taken into interest. An isokinetic trunk/ back strength test is a test where the speed of the movement (trunk flexion and extension) is held constant and the resistance (load) is accommodating to the range of movement of the trunk. To determine maximum trunk/ back strength throughout the range-of-motion isokinetic testing was considered. The main advantage was that maximal load bearing capacity of the trunk throughout the whole range of motion was obtained, which helps to create a benchmark to integrate into trunk musculoskeletal safety of lifting/ lowering manual handling tasks.

4.3.4.1. Experimental design

Subjects reported to the specified laboratory of this university, for a familiarization and a testing session that were separated by 15 minutes. During the familiarization session subjects introduced themselves and practiced performing trunk joint muscle flexion and extension testing. After 15 minutes of familiarization, subjects were asked for the test, the test was taken approximately 30 minutes. Total time (from arrival to the end of test) was 1 hour. Subjects were tested to perform trunk joint muscle flexion and extension on a Humac Norm dynamometer (Computer Sports Medicine, Inc. 101 Tosca Drive Stoughton, MA. 02072 United States of America). Trunk angle was at 0° for both flexion and extension with the axis of rotation. On the dynamometer, leg position was on non-slip support. The chest and thigh cuff helped to secure supports to stabilize body position in different posture throughout the testing. Figure 4.4 shows the trunk/ back strength measurement for whole range of motion of the performer. In build, automated computer generated data were taken to analyse.

Figure 4.4 Trunk strength measurement in a laboratory settings

All isokinetic trunk joint torque measurements were conducted by the same experimenter and equipment to avoid inter-tester variability. The maximal strength of the trunk extensor and flexor was measured using an isokinetic dynamometer (Cybex NORM, Humac, CA, USA) which allowed recording of instantaneous isokinetic torque. Trunk/ back flexion and extension velocity influences pick torque capacity of individuals (Arjmand et al. 2010). Table 4.2 shows the flexion and extension speed/ velocity during testing.

Table 4.2 Flexion-extension speed of isokinetic testing

Mode	*Speed settings*	*Termination*	*Set Rest*
Isokinetic (Flexion/Extension)	30-30 deg/sec	4 Repetition	10 Sec
Isokinetic (Flexion/Extension)	60-60 deg/sec	4 Repetition	10 Sec
Isokinetic (Flexion/Extension)	90-90 deg/sec	4 Repetition	10 Sec
Isokinetic (Flexion/Extension)	120-120 deg/sec	4 Repetition	10 Sec

4.4. Data analysis and modelling

In this study, the predictor variables are (i) ground reaction force, which is the total of performer's weight and lifting lowering load imposed on their body (ii) trunk angle, and (iii) vertical distance of the load from ground level. Predictor variables are continuous. The outcome variables (i.e. lumbar (lower back) joint contact force and torque) are also continuous. Hence, linear regression analysis was used to assess lower back musculoskeletal load component (spinal load- lumbar joint contact force and torque) from specific person attributes (weight), routine job requirements of lifting and lowering MH tasks (weight of the load), and postural requirement (trunk angle) of the task. The number of observations was 40. For checking association of predictor variables with outcome variables, Pearson coefficient values were calculated with 95% confidence interval and significant level $p<.05$.

4.4.1. Models for quantifying lumbar loads

This research developed a regression model for quantifying lumbar joint contact force, and lumbar joint torque.

$$Y_{ik} = b_0 + b_{grf}x_{grf} + b_{ta}x_{ta} + b_{vd}x_{vd}$$

Where,

Y Quantity of lumbar load

i Reference identifier for a person

k Lumber load index, $k \in 1{,}2;$

$1 \in Lumber\ joint\ contact\ force, and\ 2 \in Lumber\ joint\ torque$

b_0 Model intercept for assessing lumbar load for each k

b_{grf} Coefficient or weight attached to the predictor variables related to ground reaction force (GRF) for each k

x_{grf} Input of predictor variables related to ground reaction force (GRF) for person, i and lifting/ lowering load imposed on him.

b_{ta} Coefficient or weight attached to the predictor variables related to the back angle for each k

x_{ta} Input of predictor variables related to the back angle for i

b_{vd} Coefficient or weight attached to the predictor variables related to the vertical distance of the load for each k

x_{vd} Input of predictor variables related to the vertical distance of the load for i

4.5. Benchmarking trunk strength

Table 4.3 and Table 4.4 presents trunk/ back strength in terms of trunk/ back joint torque in Newton-meter (N-m) with respect to back bending and velocity of back bending. The highest torque recorded for the lowest bending angle of the back. The more the veocity of back bending during lifitng lowering the less the trunk/ back strength is.

Table 4.3 Trunk/ back strength (joint torque in N-m) with respect to back bending

Trunk angle (deg.)	Trunk torque during lowering					lifting torque during lifting				
	Min	Ave	Max	Median	Std. dev	Min	Ave	Max	Median	Std. dev
20	102	124.4	206	114	30.93	61	90	137	87	29.66
40	125	150.3	227	142.5	30.58	69	117	170	116	31.10
60	124	167.9	247	163.5	31.59	87	140.1	225	133.50	41.82
80	65	145.8	242	149	50.42	30	114.2	213	112.5	48.89

Table 4.4 Trunk/ back strength (joint torque in N-m) with respect to trunk angle and velocity of back forward bending during lifting and lowering

Trunk angle (deg.)	Reps.	Lifting/ lowering Velocity (deg./ sec)	lowering torque			lifting torque		
			Min	Ave	Max	Min	Ave	Max
20	4	30/30	102	124.4	206	61	90	137
		60/60	101	119.3	153	57	84	129
		90/90	95	109.7	137	51	77	117
		120/120	80	93.6	117	43	71	103
40	4	30/30	125	150.3	227	69	117	170
		60/60	119	141.7	211	65	119	161
		90/90	111	133.4	190	63	117	149
		120/120	103	124.5	157	59	106	137
60	4	30/30	124	167.9	247	87	140.1	225
		60/60	121	151.3	231	81	131.3	211
		90/90	117	135.7	219	75	119.9	203
		120/120	109	131.1	202	71	103.5	190
80	4	30/30	65	145.8	242	30	114.2	213
		60/60	61	124.4	221	29	101.9	189
		90/90	57	99.3	201	27	90.3	171
		120/120	55	93.3	180	26	88.5	163

4.6. Predicting lumbar joint contact force and torque from carpentry tasks

4.6.1. Task selection

There are many labour intensive trades in the construction and manufacturing industries. Carpentry is one of them, where carpenters face frequent exposure in lifting lowering MH tasks, such as forceful exertion and inappropriate posture. Hence, they are under risk of musculoskeletal disorder. Once they get musculoskeletal problem, their income goes down since they keep them off work. It affects to the industry as well, a lot of financial loss happen to the industry because of sickness absenteeism, ill-health lay off, and productivity loss (Weimer 1995). Field visit revealed that floor deck making requires significant lifting lowering task of the carpenters. The nature of the task requires carpenters to reach and bend to grab the load and lift/ lower. This exposes them to risk from load and awkward bending postures.

4.6.2. Task description

After receiving the work order, the carpenters check the drawings to determine the floor type to be decked in that day. Workers walk to the component storage area where they reach to select and grab the appropriate components for the floor decking. The components include plywood, and wooden bar. This cycle continues until all required components have been brought to the working area. Once this activity has been completed, the carpenters assemble the components according to the given specifications. The components are then nailed (using hammer or nail gun) to form the frame of the floor. Workers proceed to nail the components according to the design specifications. The carpenter then walks to the storage to lift the board, lift and carries it to the work station, and lowers it in place on top of the framed components. Workers align the sheathing on top of the components and secure them in place by nailing according to the layout. This cycle continues in the same sequence until all sections are covered and nailed. The floor deck is then moved to place. In actual cases, the daily tasks involve the floor decking of different floor panel models; however, for simplicity, the decking process of only one floor is assessed in this research.

4.6.3. Activities assessed

Ergonomic studies and interventions designed based on the tasks or activities which are seen as being the most stressful or hazardous. Based on the task description, three main activities had been identified as posing the greatest risk of ergonomic injury to the workers, and are selected for assessment due to the force, and awkward posture requirements. These include: (a) lifting activities, (b) nailing activities using nail gun, (c) nailing activities manually using hammer.

(a) Lifting Activities

Lifting components (plywood-boards or timber frame). This involves the following:

- Walking to the load area (component storage) without external load
- Reaching to touch the component
- Lifting the component from the stack
- Lowering the load onto the work area

(b) Nailing activities

- Nailing using hammer and nail gun of plywood-board and joints in awkward posture (back bending) by carpenter

Activities are assessed based on the posture adopted during the activities, the ground reaction force (body weight, and weight handled), and trunk angle during activities.

4.6.4. Basis and type of analysis performed

The types and bases of assessments executed are as follows:

- Ergonomic analysis based on an application of the dynamic biomechanical models
- Joint contact forces, and torques due to body segments and external loads generated around the lumbar joint were estimated.
- Assessment model developed to estimate lumbar Joint contact forces, and torques
- The results provide a basis for recommending administrative and engineering controls for reduction of the lower back MSD.

4.6.5. Assumptions

- Activities are assessed based on work being performed in three (3) dimensional plane
- Workers are assumed to right-handed.
- Inverse kinematic approach has been employed to account for force and torque under given postures and loads. Net torque has been estimated using biomechanical model developed for each respective scenario.

4.6.6. Trial setup

On-site field observation was conducted. Interview was taken with on-site supervisor of the carpenters about the task performed by the carpenters, nature of lifting and lowering activities of the task. To make a proper set-up in the laboratory, on-site carpentry task was filmed. The participant utilised recorded videos as the basis for performing the activity within the laboratory system. The following tasks are identified based on the description of the supervisor and video recordings

(i) nailing using nail gun and using hammer

(ii) lifting particle board and

The floor decking components and equipment are presented in Table 4.5

Table 4.5 Weight of components and equipments were used during task trial

Item	Total weight (kg)
1. Plywood board	9.3
2. Nailing gun	3.27

4.6.7. Data collection

By following the procedure described in section 4.3 motion was captured of the mentioned carpenters activities, ground reaction force which is the effect of body weight and external load was measured simultaneously during motion capture. Biomechanical model was developed using GRF and motion of the performer to get lumbar joint contact force, lumbar joint torque, trunk posture, and vertical height of the load.

4.6.7.1. Lumber joint contact force and torque during board (plywood) lifting

The board was lifted holding the top edge of the board and then it was lifted holding from vertical side of the board, same as carpenters do in their workplace. The size of the board is 1198mmX1200mm and weight is 9.3 kg. Figure 4.5 shows the board lifting and subsequent biomechanical model posture.

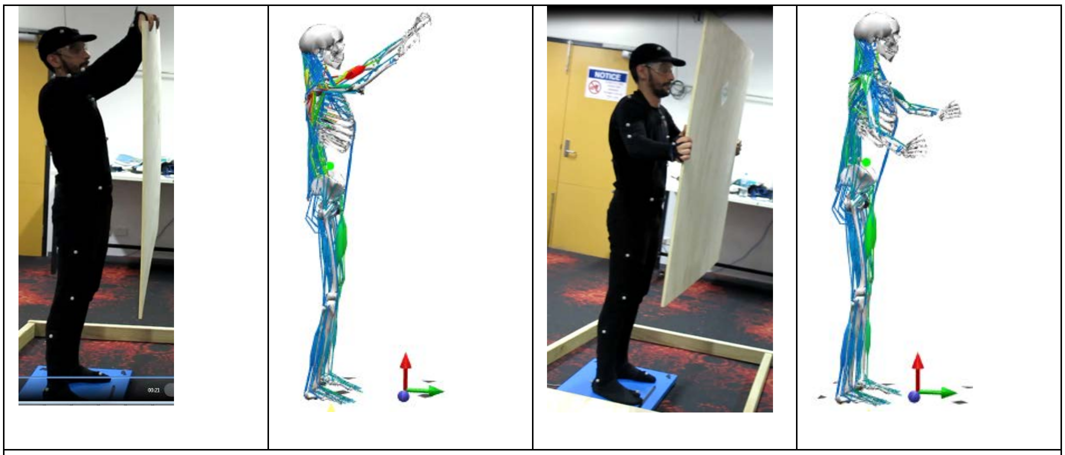


Figure 4.5 Motion capture, ground reaction force measurement and subsequent biomechanical model during plywood board lifting lowering task of the carpenters

Ground reaction forces of these tasks are given in the Appendix F, Figure A.3. Figure 4.6 and Figure 4.7 below shows lumbar joint (L1-L2, L2-L3, L3-L4, L4-L5, L5-Pelvis (detail picture in Appendix I, Figure A.18) contact force and torque due to board lifting.

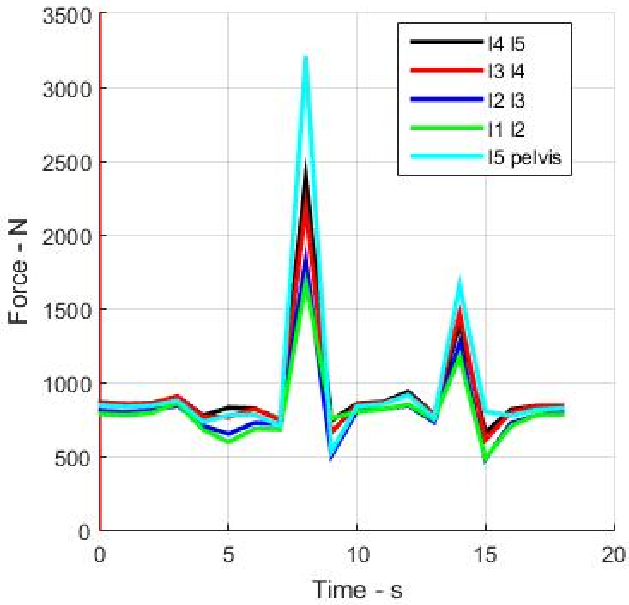


Figure 4.6 lumbar joint contact force during board lifting

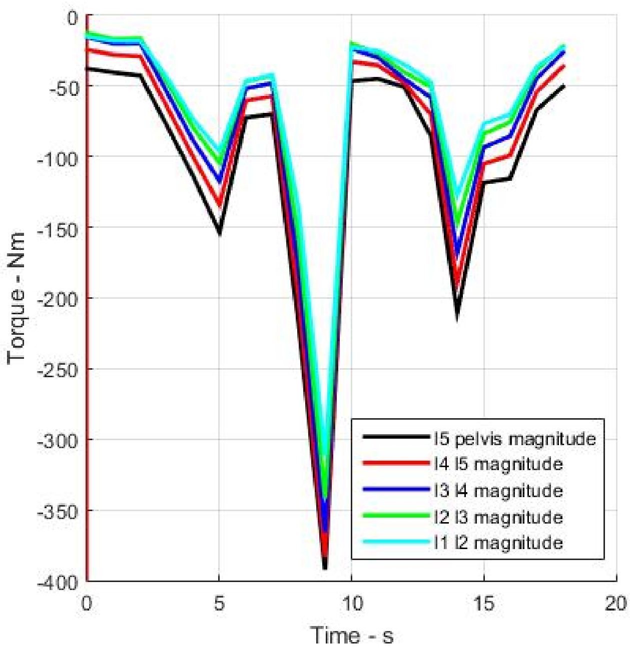


Figure 4.7 lumbar jont torque during board lifting

4.6.7.2. Lumber joint contact force and torque during nailing with nail gun

5.27 kg nail gun was lifted and placed in a position where nailing was necessary. A sample picture of nailing and corresponding biomechanical posture is shown is Figure 4.8.

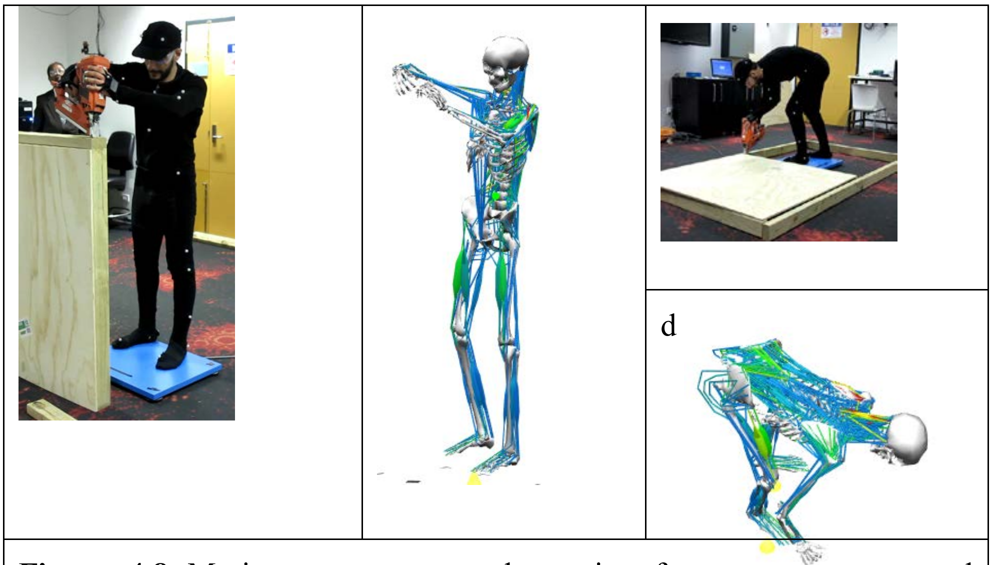


Figure 4.8 Motion capture, ground reaction force measurement and subsequent biomechanical model when carpenters nailing with nail gun

Ground reaction forces of these tasks are given in the Appendix F, Figure A.4. Figure 4.9 and Figure 4.10 shows lumbar joint (L1-L2, L2-L3, L3-L4, L4-L5, L5-Pelvis) contact force and torque due to nailing with nail gun.

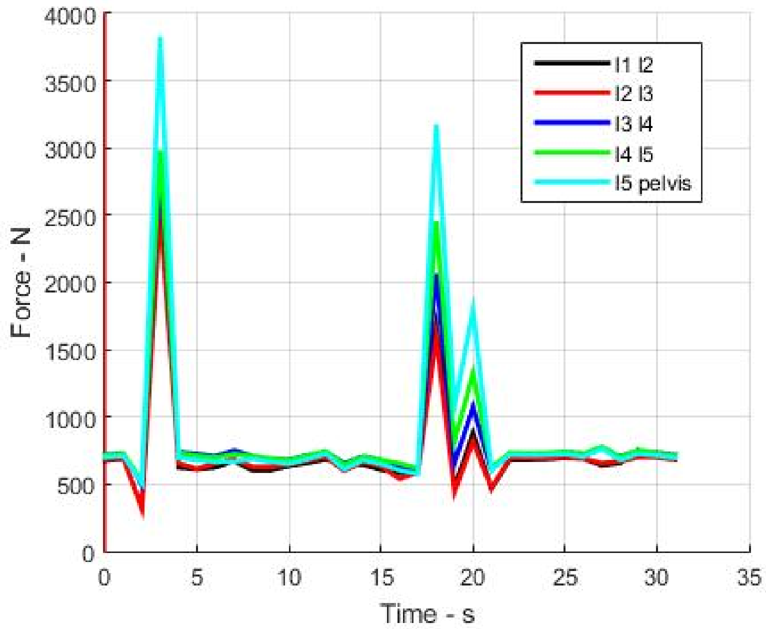


Figure 4.9 lumbar joint contact force during nailing with nail gun

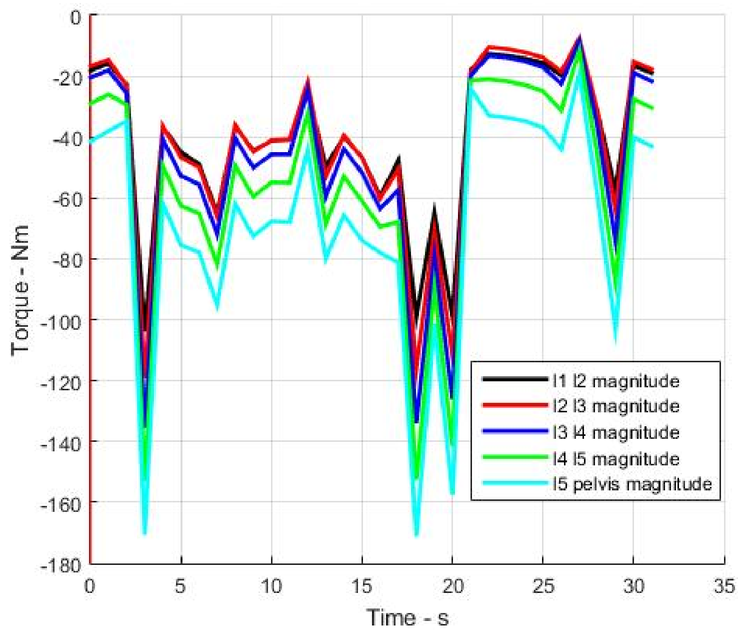


Figure 4.10 lumbar joint torque during nailing with nail gun

4.6.7.3. Lumber joint contact force and torque during nailing with hammer

Awkward posture in nailing task using hammer was noticed during field visit, the same task was performed in the laboratory condition to investigate the lumbar joint torque developed from motion and ground reaction force.

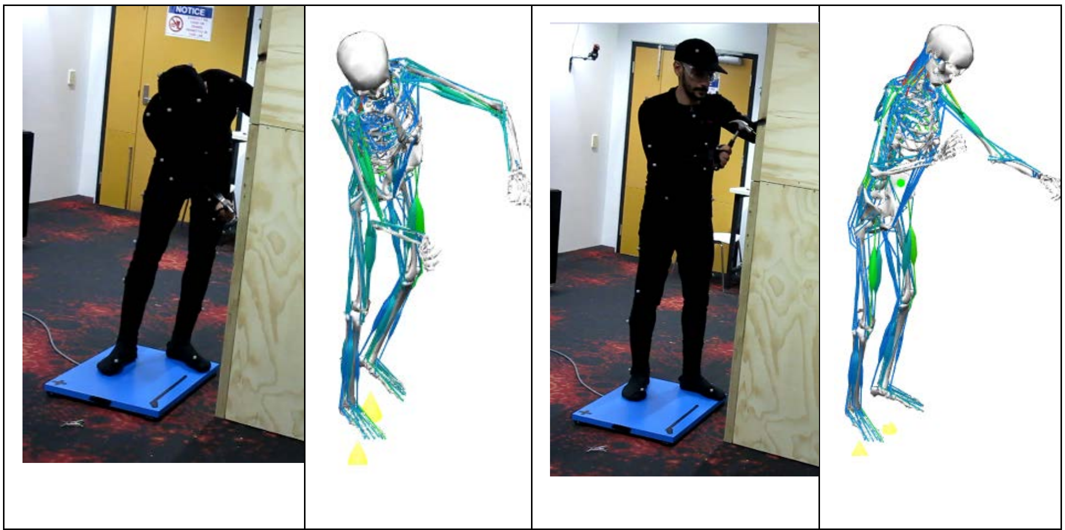


Figure 4.11 Motion capture, ground reaction force measurement and subsequent biomechanical model when carpenters nailing with a hammer

Ground reaction forces of these tasks are given in the Appendix F, Figure A.5. Figure 4.12 and Figure 4.13 shows lumbar joint (L1-L2, L2-L3, L3-L4, L4-L5, L5-Pelvis) contact force and torque due to nailing with hammer.

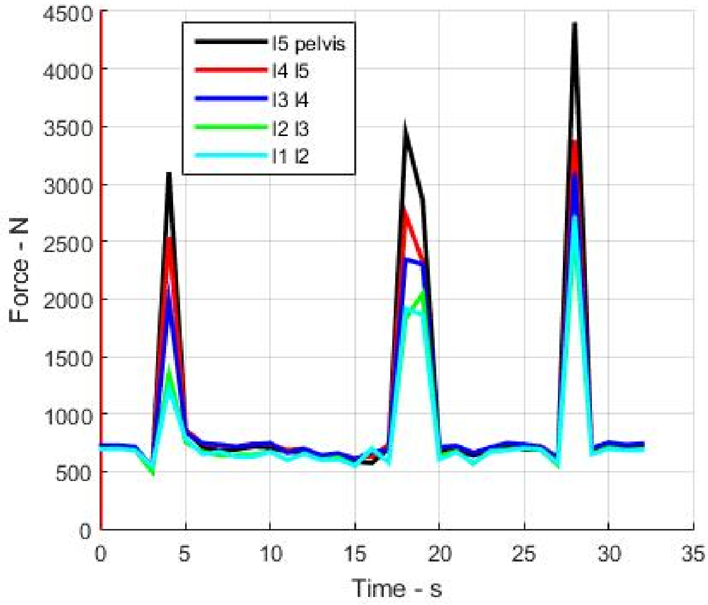


Figure 4.12 lumbar joint contact force during nailing using nail gun

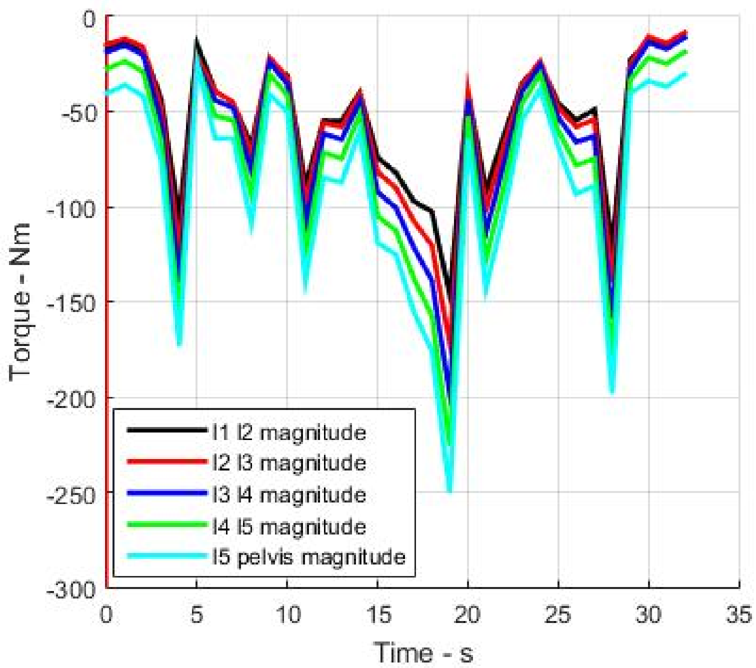


Figure 4.13 lumbar joint torque during nailing using nail gun

4.6.8. Model fitting summary

Table 4.6 shows lumbar joint contact force assessment model fitting summary. R-square value showed that how much of lumbar joint contact force and torque variability can be explained by ground reaction force, trunk angle, and vertical distance of the object. For example, R-square value .355 indicated that 35.5% of the joint contact force can be explained by ground reaction force, trunk angle, and vertical distance of the object. The last column of the table indicated that whether lumbar joint contact force and torque significantly assessed or not. Significant value .001 indicated that ground reaction force, trunk angle, and vertical distance of the object significantly (<.01) assessed lumbar joint contact force.

Data (in table 4.6, 4.7, and 4.8) can be used to quantify lumber load using the equation mentioned in section 4.4.1By predicting lumber joint torque requirement in task, lumber joint torque can be compared with the benchmark mentioned in section 4.5, and task can be classified as level of risk involved in the task with respect to lumber load

Table 4.6 Model fitting summary of the assessemnt model to assess lumbar joint contact force, and lumbar joint torque of carpenters MH tasks

Lifting/ lowering task	***Risk factors***	***Model***	***R square***	***Sig***
Board lifting	*Joint contact force*	L1-L2	.355	.001
		L2-L3	.243	.017
		L3-L4	.399	.002
		L4-L5	.430	.023
		L5-P	.439	.015
	Joint torque	L1-L2	.511	.012
		L2-L3	.500	.028
		L3-L4	.492	.045
		L4-L5	.490	.056
		L5-P	.491	.012
Nailing with gun lifting	*Joint contact force*	L1-L2	.511	.023
		L2-L3	.505	.039
		L3-L4	.543	.013
		L4-L5	.559	.027
		L5-P	.614	.014
	Joint torque	L1-L2	.652	.000
		L2-L3	.665	.000
		L3-L4	.659	.001
		L4-L5	.639	.003
		L5-P	.609	.004
Nailing with hammer lifting	*Joint contact force*	L1-L2	.844	.008
		L2-L3	.854	.009
		L3-L4	.842	.009
		L4-L5	.856	.008
		L5-P	.852	.002
	Joint torque	L1-L2	.749	.005
		L2-L3	.764	.006
		L3-L4	.765	.004
		L4-L5	.757	.007
		L5-P	.745	.000

4.6.9. Results and discussions

Table 4.7 shows coefficients of the assessment model to assess lumbar joint (L1-L2, L2-L3, L3-L4, L4-L5, L5-P) contact force during carpenters' selected MH tasks.

Ground reaction force coefficient value, $b_{grf} = 4.66$, indicated that ground reaction force increased by one unit, l1-l2 lumbar joint contact force increased by 4.66 unit. Both unit measured in Newton (N), hence, for every 1 N ground reaction force increased an extra lumbar joint contact force increased by 4.66 N.

Trunk angle coefficient value, $b_{ta} = 3.30$, indicated that trunk angle increased by one unit, l1-l2 lumbar joint contact force increased by 3.30 unit. Trunk angle measured in degrees (^{0}). Joint contact force measured in Newton (N). Hence, 1^0 trunk angle increased an extra lumbar joint contact force increased by 3.30 N.

Vertical distance of the object handled coefficient value, $b_{vd} = 1.60$, indicated that vertical distance of the object handled increased by one unit, l1-l2 lumbar joint contact force increased by 1.60 unit. Vertical distance of the object handled measured in meter (m). Joint contact force measured in Newton (N). Hence, 1 m vertical distance of the object increased an extra lumbar joint contact force increased by 1.60 N.

Table 4.7 Coefficients of the assessment model to assess lumbar joint contact force from carpenter MH tasks

Lifting/ lowering tasks	*Regression coefficient*	*L1-L2*	*L2-L3*	*L3-L4*	*L4-L5*	*L5-P*
Board lifting	b_0*	84.46	89.03	83.68	84.86	86.12
	b_{grf}*	4.66	3.84	7.12	9.56	14.30
	b_{ta}*	3.30	6.72	4.41	12.34	17.79
	b_{vd}*	1.60	2.46	3.23	2.73	4.12
Nailing with gun	b_0*	60.23	71.76	78.41	60.98	67.85
	b_{grf}*	1.48	1.37	2.28	2.13	3.01
	b_{ta}*	1.63	1.56	1.05	1.79	2.15
	b_{vd}*	1.49	1.94	2.61	2.91	3.65
Nailing with hammer	b_0*	59.66	51.86	61.01	74.79	60.35
	b_{grf}*	1.54	1.71	2.14	2.38	3.03
	b_{ta}*	2.14	2.44	2.36	3.34	3.54
	b_{vd}*	1.97	3.49	2.71	2.03	3.72

*b_0 is model intercept, b_{grf} is coefficient of ground reaction force, b_{ta} is trunk angle, b_{vd} is vertical distance of the object.

Table 4.8 shows coefficients of the assessment model to assess lumbar joint (L1-L2, L2-L3, L3-L4, L4-L5, L5-P) torque during carpenters MH tasks.

Ground reaction force coefficient value, $b_{grf} = 1.42$, indicated that ground reaction force increased by one unit, l1-l2 lumbar joint torque increased by 1.42 unit. Ground reaction force increased in Newton (N). Lumbar joint torque increased in Newton-meter (N-m) hence, for every 1 N ground reaction force increased an extra lumbar joint torque increased by 1.42 N-m. This interpretation is true only if the effects of trunk angle and vertical distance of the object are held constant.

Trunk angle coefficient value, b_{ta} = .91, indicated that trunk angle increased by one unit, l1-l2 lumbar joint torque increased by .91 unit. Trunk angle measured in degrees (^{0}). Joint torque measured in Newton-meter (N-m). Hence, 1^0 trunk angle increased an extra lumbar joint torque increased by .91 N. This interpretation is true only if the effects of ground reaction force and vertical distance of the object are held constant.

Vertical distance of the object handled coefficient value, b_{vd} = 1.24, indicated that vertical distance of the object handled increased by one unit, l1-l2 lumbar joint torque increased by 1.24 unit. Vertical distance of the object handled measured in meter (m). Joint torque measured in Newton-meter (N-m). Hence, 1 m vertical distance of the object increased an extra lumbar joint torque increased by 1.24 N. This interpretation is true only if the effects of ground reaction force and trunk angle are held constant.

Table 4.8 Coefficients of the assessment model to assess lumbar joint torque from carpenter MH tasks

Lifting/ lowering tasks	***Regression coefficient***	***L1-L2***	***L2-L3***	***L3-L4***	***L4-L5***	***L5-P***
Board lifting	$b_0{}^*$	36.23	32.17	43.03	45.436	58.30
	$b_{grf}{}^*$	1.42	1.57	1.67	1.71	1.70
	$b_{ta}{}^*$	.91	1.94	2.61	2.90	2.79
	$b_{vd}{}^*$	1.24	1.86	2.65	2.82	3.77
Nailing with gun	$b_0{}^*$	47.98	48.95	44.63	35.66	21.33
	$b_{grf}{}^*$	.01	.01	.02	.03	.02
	$b_{ta}{}^*$	1.16	2.63	3.80	4.65	5.11
	$b_{vd}{}^*$	1.70	2.33	4.59	3.48	4.89
Nailing with hammer	$b_0{}^*$	34.23	47.02	52.68	50.06	40.00
	$b_{grf}{}^*$	.195	.21	.22	.23	.24
	$b_{ta}{}^*$	1.54	3.81	5.54	6.73	7.42
	$b_{vd}{}^*$	1.05	1.07	1.66	1.00	1.95

$^*b_0$ is model intercept, b_{grf} is coefficient of ground reaction force, b_{ta} is trunk angle, b_{vd} is vertical distance of the object.

4.7. Predicting lumbar joint contact force and torque from bricklayers' lifting/ lowering tasks

4.7.1. Task selection

Construction trade workers, bricklayer's include supervisor bricklayer, bricklayer, and apprentice bricklayer (Australian Bureau of Statistics 2013). The following lifting lowering MH tasks are the main MH tasks of bricklayers.

- manually loading and unloading bricks and blocks on pallets (the brick, stone and building blocks vary in size and weight; typical concrete blocks used include 140mm X 400mm X 200mm weighing 11 kg each and 200mm X 400mm X 200mm weighing 13-15 kg each)
- cement and mortar mixes are handled in 20 kg quantities/bags between ground and chest height
- laying bricks individually by hand in the mortar, laying approximately 150 blocks per day (therefore can manually handle up to 2-3 tonnes of blocks)

4.7.2. Activities assessed

- Activity 1: Lifting and working above shoulder height, forward bending and twisting during lifting brick (3.5 kg)
- Activity 2: Block (10 kg) lifting between floor and chest level and
- Activity 3: Cement bag (20 kg) lifting between ground and chest level

4.7.3. Data collection

By following the procedure described in section 4.3 motion was captured of the mentioned bricklayers activities, ground reaction force which is the effect of body weight and external load was measured simultaneously during motion capture.

Biomechanical model was developed using GRF and motion of the performer to get lumbar joint contact force, lumbar joint torque, trunk posture, and vertical height of the load.

4.7.3.1. Field observation and motion capture

Field observations in some construction site revealed a list of bricklayers' tasks and the object particulars. Furthermore, basic visual observations indicate certain cases/ circumstances of postural discomforts. Figure 4.11 to Figure 4.18 some snapshot of field observations and developed biomechanical models.

	
Figure 4.14 Field observation of brick laying task forward bending and lifting	**Figure 4.15** Biomechanical model of the observed forward bending and lifting task

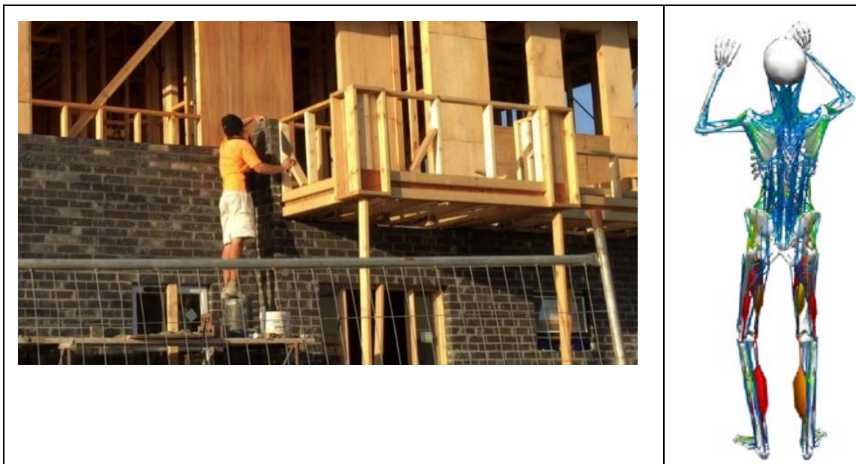


Figure 4.16 (a) Brick laying activities in above shoulder height (b) Biomechanical model of brick laying activities in above shoulder height

Figure 4.17 Field observation of brick laying task forward bending and twisting

Figure 4.18 Biomechanical model of the observed task

4.7.3.2. Lumber joint contact force and torque during activity 1

Pick lumbar joint contact forces and lumbar joint torques are the consequences of awkward posture and load of the brick. Figure 4.19 and Figure 4.20 show lumbar joint contact force and lumbar joint torque during this Activity 1. In this activities relatively low joint contact force found as the load in this activity was smaller compared to other two activities.

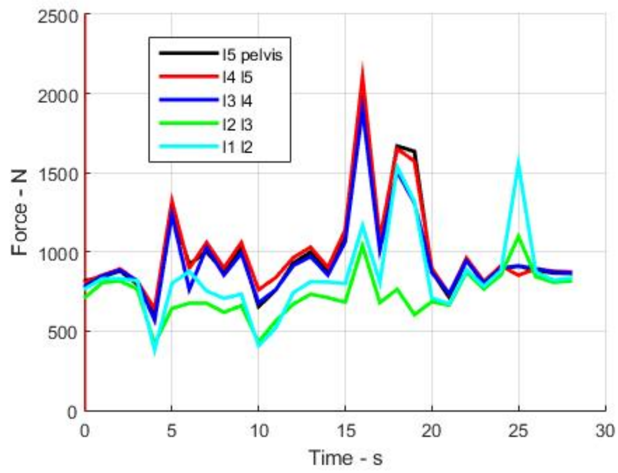


Figure 4.19 lumbar joint contact force during activity 1

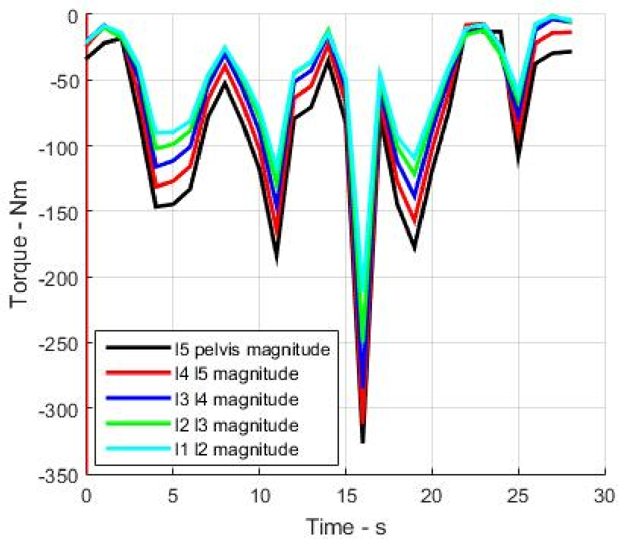


Figure 4.20 lumbar joint torque during activity 1

4.7.3.3. Lumber joint contact force and torque during activity 2

Figure 4.21 to Figure 4.22 presents lumbar joint contact force and lumbar joint torque during activity 2. In this activity performer lift a block (10 kg) between floor and chest level. lumbar joint contact force in this case is much higher compared to the activity 1.

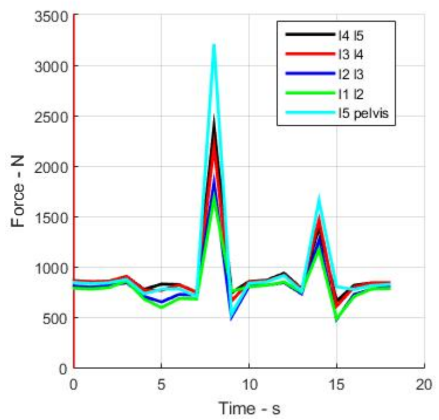


Figure 4.21 lumbar joint contact force during activity 2

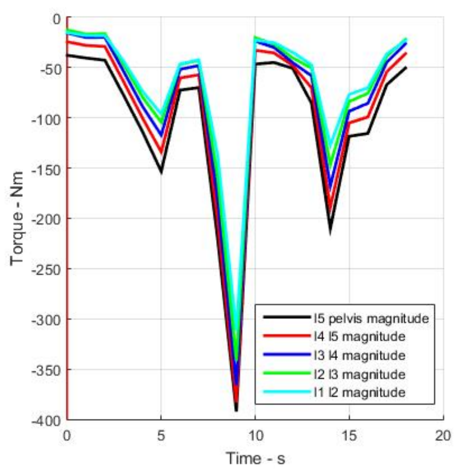


Figure 4.22 lumbar joint torque during activity 2

4.7.3.4. Lumber joint contact force and torque during activity 3

Figure 4.23 and Figure 4.24 presents lumbar joint contact force and lumbar joint torque during activity 3. In this activity performer lift a cement bag (20 kg) between floor and chest level. lumbar joint contact force in between l5 and pelvis was 4400 N, which is the highest joint contact force compared to the other joints such as l1-l2, l2-l3, l3-l4, and l4-l5.

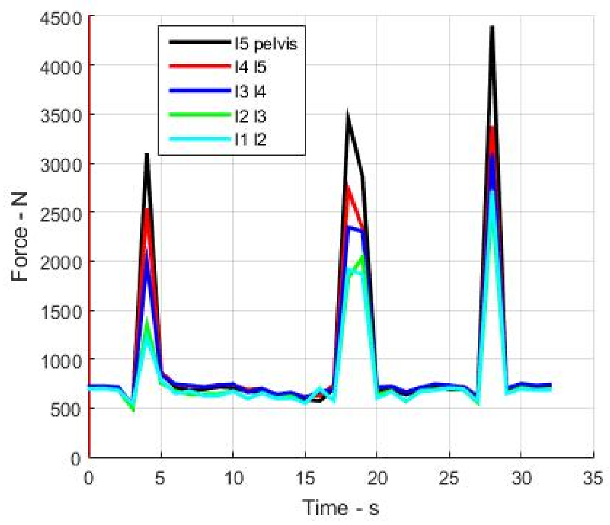


Figure 4.23 lumbar joint contact force during activity 3

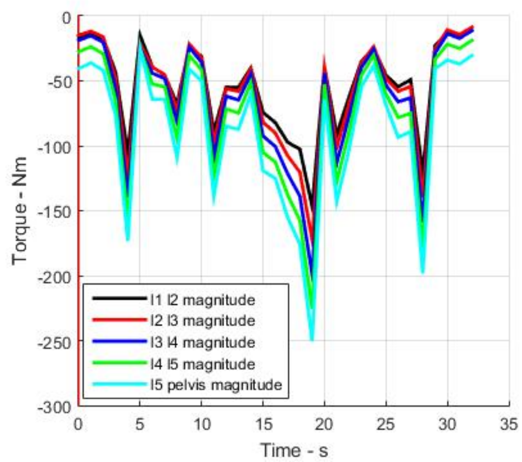


Figure 4.24 lumbar joint torque during activity 3

4.7.4. Model fitting summary

Table 4.9 shows lumbar joint contact force assessment model fitting summary. R-square value showed that how much of lumbar joint contact force and torque variability can be explained by ground reaction force, trunk angle, and vertical distance of the object. For example, R-square value .364 indicated that 36.4% of the joint contact force can be explained by ground reaction force, trunk angle, and vertical distance of the object. The last column of the table indicated that whether lumbar joint contact force and torque significantly assessed or not. Significant value .009 indicated that ground reaction force, trunk angle, and vertical distance of the object significantly (<.01) assessed lumbar joint contact force.

Table 4.9 Model fitting summary of the assessemnt model to assess lumbar joint contact force, and lumbar joint torque

Lifting/ lowering task	*Risk factors*	*Model*	*R square*	*Sig.*
Activity 1	Joint contact force	L1-L2	.364	.009
		L2-L3	.260	.053
		L3-L4	.528	.000
		L4-L5	.596	.000
		L5-P	.604	.000
	Joint torque	L1-L2	.983	.000
		L2-L3	.964	.000
		L3-L4	.969	.000
		L4-L5	.983	.000
		L5-P	.989	.000
Activity 2	Joint contact force	L1-L2	.225	.064
		L2-L3	.109	.351
		L3-L4	.409	.002
		L4-L5	.481	.000
		L5-P	.488	.000
	Joint torque	L1-L2	.640	.000
		L2-L3	.619	.000
		L3-L4	.637	.000
		L4-L5	.674	.000
		L5-P	.717	.000
Activity 3	Joint contact force	L1-L2	.836	.000
		L2-L3	.848	.000
		L3-L4	.839	.000
		L4-L5	.850	.000
		L5-P	.846	.000
	Joint torque	L1-L2	.730	.000
		L2-L3	.748	.000
		L3-L4	.751	.000
		L4-L5	.739	.000
		L5-P	.725	.000

4.7.5. Results and discussions

Table 4.10 shows coefficients of the assessment model to assess lumbar joint (L1-L2, L2-L3, L3-L4, L4-L5, L5-P) contact force during activity 1, 2, and 3.

Ground reaction force coefficient value, b_{grf} = 1.25, indicated that ground reaction force increased by one unit, l1-l2 lumbar joint contact force increased by 1.25 unit. Both unit measured in Newton (N), hence, for every 1 N ground reaction force increased an extra lumbar joint contact force increased by 1.25 N.

Trunk angle coefficient value, b_{ta} = 1.56, indicated that trunk angle increased by one unit, l1-l2 lumbar joint contact force increased by 1.56 unit. Trunk angle measured in degrees (^{0}). Joint contact force measured in Newton (N). Hence, 1^0 trunk angle increased an extra lumbar joint contact force increased by 1.56 N.

Vertical distance of the object handled coefficient value, b_{vd} = 1.59, indicated that vertical distance of the object handled increased by one unit, l1-l2 lumbar joint contact force increased by 1.59 unit. Vertical distance of the object handled measured in meter (m). Joint contact force measured in Newton (N). Hence, 1 m vertical distance of the object increased an extra lumbar joint contact force increased by 1.59 N.

Table 4.10 Coefficients of the assessment model to assess lumbar joint contact force from bricklayers MH tasks activity 1, 2, and 3

Lifting/ lowering tasks	***Regression coefficient***	***L1-L2***	***L2-L3***	***L3-L4***	***L4-L5***	***L5-P***
Activity 1	b_0^*	.03	.48	.14	.82	.52
	b_{grf}^*	1.25	1.47	1.87	2.107	2.16
	b_{ta}^*	1.56	2.77	5.92	8.17	8.63
	b_{vd}^*	1.59	2.39	3.21	3.58	4.12
Activity 2	b_0^*	.32	.44	.02	.76	.84
	b_{grf}^*	1.61	.28	.95	1.06	1.03
	b_{ta}^*	2.65	.97	4.49	6.54	6.89
	b_{vd}^*	4.35	1.85	7.68	8.58	8.82
Activity 3	b_0^*	.44	.64	.83	.39	.11
	b_{grf}^*	1.32	1.49	1.89	2.12	2.67
	b_{ta}^*	2.13	1.21	2.55	2.70	3.64
	b_{vd}^*	1.89	1.94	2.10	2.12	3.35

*b_0 is model intercept, b_{grf} is coefficient of ground reaction force, b_{ta} is trunk angle, b_{vd} is vertical distance of the object.

Table 4.11 shows coefficients of the assessment model to assess lumbar joint (L1-L2, L2-L3, L3-L4, L4-L5, L5-P) torque during bricklayers MH task activity 1, 2, and 3. Ground reaction force coefficient value, b_{grf} = .01, indicated that ground reaction force increased by one unit, l1-l2 lumbar joint torque increased by .01 unit. Ground reaction force increased in Newton (N). Lumbar joint torque increased in Newton-meter (N-m) hence, for every 1 N ground reaction force increased an extra lumbar joint torque increased by .01 N-m. This interpretation is true only if the effects of trunk angle and vertical distance of the object are held constant.

Trunk angle coefficient value, b_{ta} = 1.16, indicated that trunk angle increased by one unit, l1-l2 lumbar joint torque increased by 1.16 unit. Trunk angle measured in degrees (^{0}). Joint torque measured in Newton-meter (N-m). Hence, 1^0 trunk angle increased an extra lumbar joint torque increased by 1.16 N. This interpretation is true only if the effects of ground reaction force and vertical distance of the object are held constant.

Vertical distance of the object handled coefficient value, b_{vd} = 1.53, indicated that vertical distance of the object handled increased by one unit, l1-l2 lumbar joint torque increased by 1.53 unit. Vertical distance of the object handled measured in meter (m). Joint torque measured in Newton-meter (N-m). Hence, 1 m vertical distance of the object increased an extra lumbar joint torque increased by 1.53 N. This interpretation is true only if the effects of ground reaction force and trunk angle are held constant.

Table 4.11 Coefficients of the assessment model to assess lumbar joint torque from bricklayers MH task activity 1, 2, and 3

Lifting/ lowering tasks	***Regression Coefficient***	***L1-L2***	***L2-L3***	***L3-L4***	***L4-L5***	***L5-P***
Activity 1	${b_0}^*$	2.57	1.99	7.40	4.03	5.04
	${b_{grf}}^*$	.01	.02	.03	.02	.01
	${b_{ta}}^*$	1.16	1.33	1.52	1.70	1.80
	${b_{vd}}^*$	1.53	3.18	3.71	6.46	9.58
Activity 2	${b_0}^*$	6.74	7.77	2.82	8.58	3.08
	${b_{grf}}^*$	.137	.16	.167	.172	.18
	${b_{ta}}^*$	.936	1.06	1.22	1.39	1.50
	${b_{vd}}^*$	6.06	2.15	5.69	3.92	8.90
Activity 3	${b_0}^*$	1.34	2.11	5.87	1.84	1.19
	${b_{grf}}^*$	.18	.19	.21	.24	.20
	${b_{ta}}^*$	.93	1.09	1.47	2.79	4.39
	${b_{vd}}^*$	3.78	1.91	2.65	3.24	4.65

$^*b_0$ is model intercept, b_{grf} is coefficient of ground reaction force, b_{ta} is trunk angle, b_{vd} is vertical distance of the object.

4.8. Predicting lumbar joint contact force and torque from metal fitter and machinists' lifting/ lowering Tasks

4.8.1. Task selection

According to Australian Standard Classification of Occupations, metal fitter and machinists include fitter (general), fitter and turner, fitter-welder, metal machinist (first class) occupations (Australian Bureau of Statistics 2013). Metal fitter and machinist's manual handling (lifting and lowering) tasks include (i) setting guides, stops and other controls on machining tools, setting up prescribed cutting or shaping tools or dies in machines or presses (ii) forming metal stock or castings to fine tolerances using machining tools to press, cut, grind, plane, bore or drill metal (iii) fitting fabricated metal parts into products and assembling metal parts and sub-assemblies to produce machinery and equipment (iv) preparing pattern mechanisms to control the operation of machines (Australian Bureau of Statistics 1997; Safe Work Australia 2012; Australian Government Department of Industry Innovation and Science 2014). The likelihood of injury from metal fitter and machinists would increase depending on the posture assumed while performing MH tasks. Neck, lower back, ankle, and wrist are the common location of injury due to exerting excessive force.

Prominent mechanism of musculoskeletal injury in metal fitter and machinists are:

(i) repetitive or sustained application of force while lifting, carrying, or putting down objects, such as finished fabricated metal products are transported from the manufacturing site to loading bay.

(ii) repetitive or sustained awkward posture, such as packing stillage are often used for transporting product. Many have high solid sides that require the employee to fully bend.

(iii) repetitive or sustained movement.

(iv) application of high force (lifting more than 20 kg) when transporting of materials on the shop floor.

(v) die handling, which includes a range of tasks, such as setting, moving and maintaining dies that are often very heavy. As such, die handling may be performed while in awkward postures and for long periods, increasing the risk of MSD.

(vi) exposure to mechanical vibration such as, excessive vibration while grinding, exerting force while in an awkward posture during grinding (Work Safe Victoria 2007). Consequently, musculoskeletal problems/ disorder happen in this occupation such as back pain, muscle/tendon sprains/ strains, disc displacement (Work Safe Victoria 2007).

4.8.2. Key tasks and MSD risks in structural steel welding works

Ergonomic risks of metal fitter and machinists MSDs can arise from workplace elements (conditions) and actions, or a combination of both, which might yield significant physical stresses and adverse impacts. Examples include metal fitter and machinists' forceful exertions, awkward postures, repetitive exertions, and environmental factors. In metal fitter and machinists trade works, common tasks are: (i) cutting marked-out metal sections and shapes using hand tools, flame cutting torches or metal cutting machines; (ii) shaping and bending metal sections and pipes using hand and machine tools or by heating and hammering; (iii) joining metal sections; and (iv) cleaning and smoothing welds by filing, chiselling and grinding.

4.8.3. Data collection

By following the procedure described in section 4.3 motion was captured of the mentioned metal fitter and machinists tasks, ground reaction force which is the effect of body weight and external load was measured simultaneously during motion capture. Biomechanical model was developed using GRF and motion of the performer to get lumbar joint contact force, lumbar joint torque, trunk posture, and vertical height of the load.

4.8.3.1. Field observation and motion capture

Field observations in some structural steel welding facilities revealed a list of tasks and the object particulars. Furthermore, basic visual observations indicate certain cases/ circumstances of postural discomforts. A series of brainstorming discussions and expert consultations revealed specific details regarding ergonomic risks of metal fitter and machinists. This research covered key ergonomic risks in the task of ‘joining metal sections’, especially related to lower back related WMSDs.

Figures 1 to 3 portray observations and details of activity 1 to 3 respectively. Activity 1 in the welding working cycle is basically slight bending for positioning the welding devices, gas cylinder. From the field observation of workplace, it has been noted that moving gas cylinder is one of the risky tasks for the structural steel welding trade persons, i.e. with respect to posture and task requirements. In this research, the weight of welding gas cylinders is 37.2 kg, which is manually lifted and placed on the two wheeled trolley, mostly by a single person. According to ISO 11226:2000, trunk inclinations between 20 to 60 degrees should be with full trunk support and otherwise the holding duration should be controlled within limits. In this activity task requirements were trunk inclination (49^0) awkward posture holding time (6 minutes), 2 times per hour is the frequency of this activity, and weight of the gas cylinder was 37.2 kg.

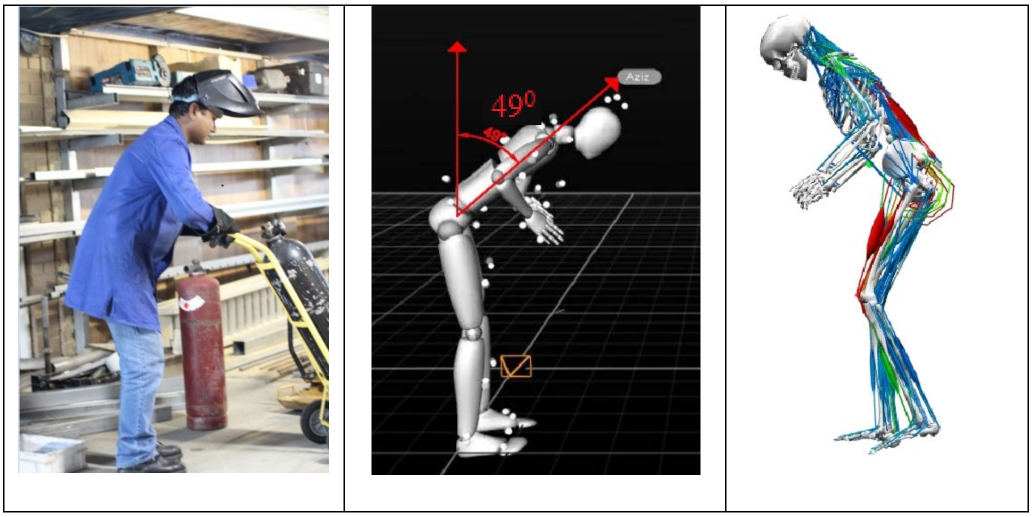


Figure 1. Activity 1 in actual and virtual environments

Activity 2 represents the welding cycle action of picking the welding gun and parent material, which is frequent bending and reaching, e.g. around 35 times per hour and repetitive in a workday (i.e. 8 hours shift) to accomplish welding task requirements. In these actions, welders often bend their back severely and mostly without any support. Picking loads for this purpose varies from 1 to 15 kg. Every time, the welding trade person has to bend and grab the work piece or welding gun and aim to hit the welding spot. Ergonomically awkward postures have been detected in these operations, especially higher WMSD risks (e.g. back pain). Task requirements were 90^0 trunk angle, holding 90^0 forward back bending position for 30 seconds, frequency of doing this activity almost 35 times per hour, and weight of the load 5 kg (average).

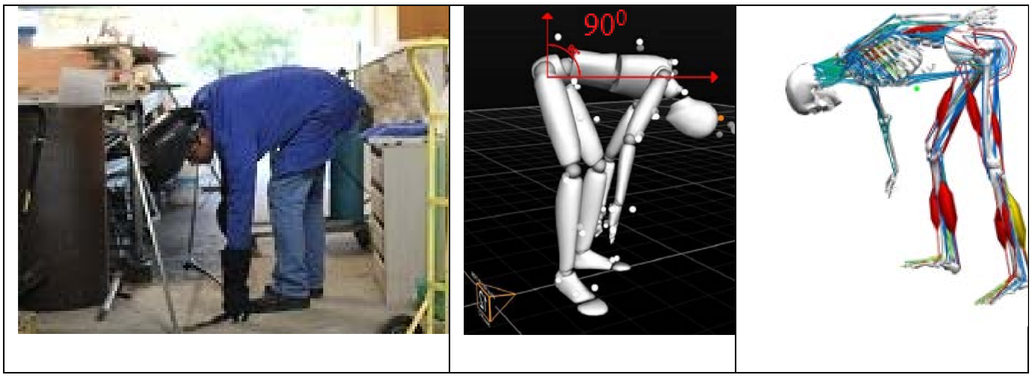


Figure 2. Activity 2 in actual and virtual environments

Activity 3 is the reaching and forward bending pose common in the structural steel and welding trade. Welders often grab welding guns and target to hit inclined work pieces by bending and reaching their back. This posture is mostly repetitive in daily routines of the trade, i.e. 35 to 40 times per minute. In many cases, this position has to be held for 1 minute for welding purpose followed by approximately 15 seconds of rest. Task requirements were 64^0 trunk angle, holding 64^0 forward back bending position for 1 min, frequency of doing this activity almost 40 times per hour, and weight of the load 1.2 kg (average).

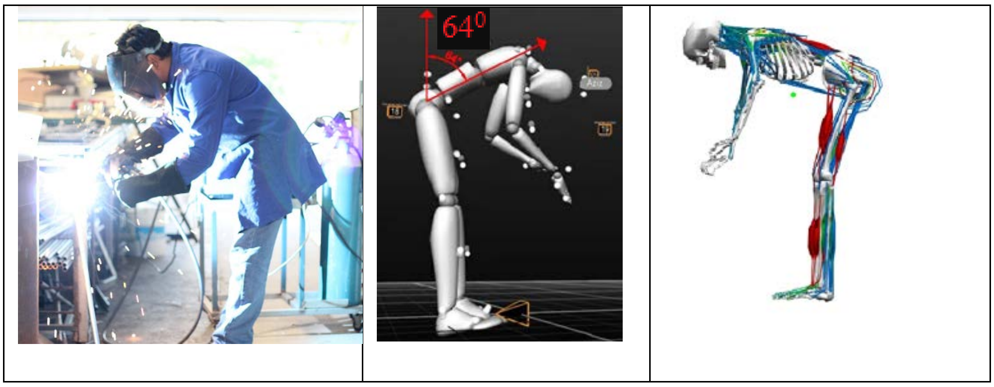


Figure 4. Activity 3 in actual and virtual environments

4.8.3.2. Lumber joint contact force and torque during metal fitter and machinists' activity 1

Pick lumbar joint contact forces and lumbar joint torques are the consequences of awkward posture and load of the gas cylinder during loading and unloading of the trolley. Figure 4.25 and Figure 4.26 show lumbar joint contact force and lumbar joint torque during this Activity 1. In this activities relatively low joint contact force found as the load in this activity was smaller compared to other two activities.

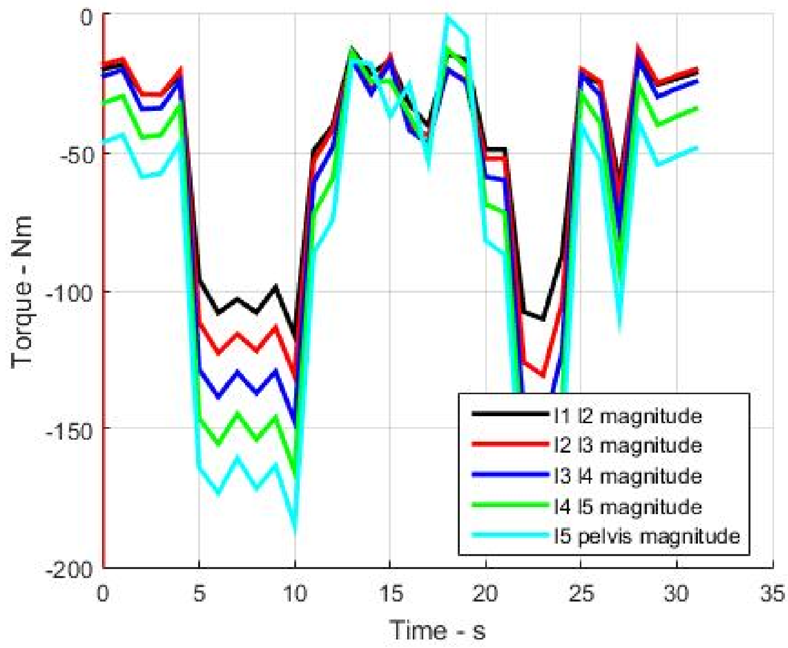


Figure 4.25 lumbar joint contact force during activity 1 (loading and unloading gas bottles by the metal ftter and machinists)

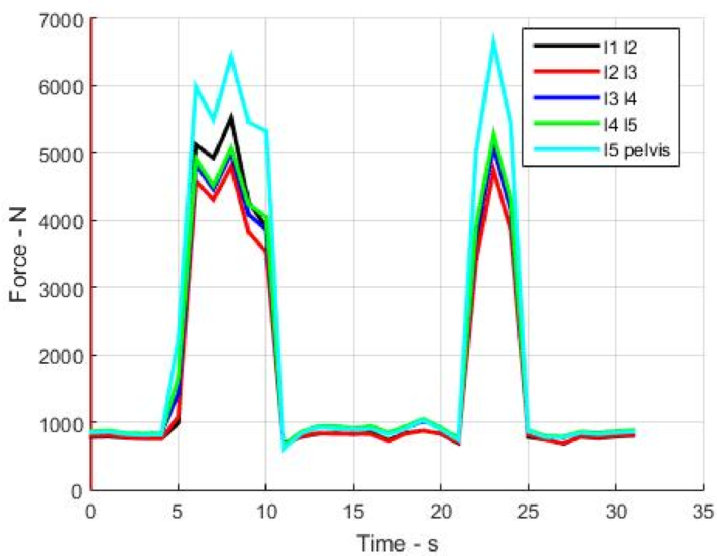


Figure 4.26 lumbar joint torque during activity 1 (loading and unloading gas bottles by the metal ftter and machinists)

4.8.3.3. Lumber joint contact force and torque during metal fitter and machinists' activity 2

Pick lumbar joint contact forces and lumbar joint torques are the consequences of trunk flexion and extension during the task. Figure 4.27 and Figure 4.28 show lumbar joint contact force and lumbar joint torque during Activity 2. Because of bending and twisting L2-l3 joint contact fore was higher compared to the others.

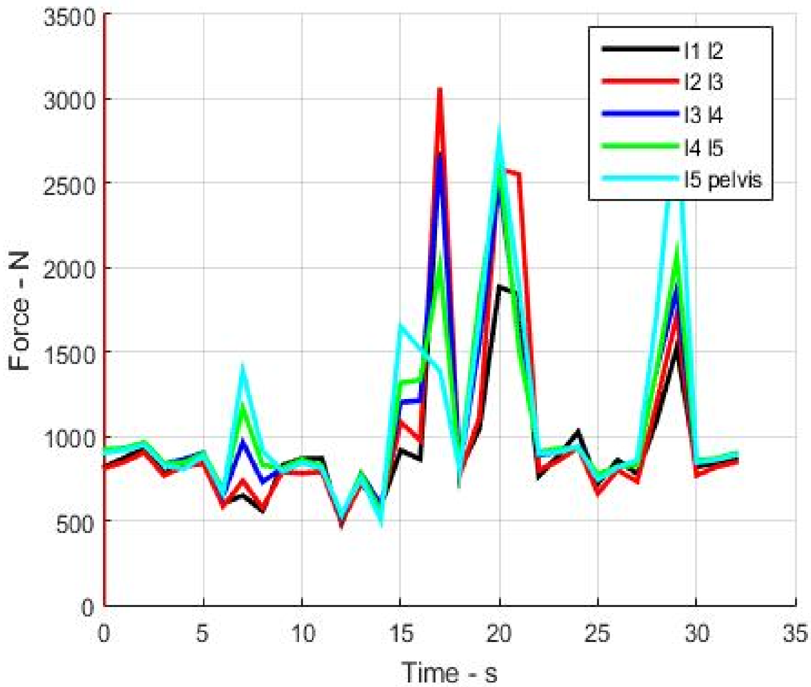


Figure 4.27 lumbar joint contact force of metal fitter and machinists during activity 2 (picking up the welding gun and parent material)

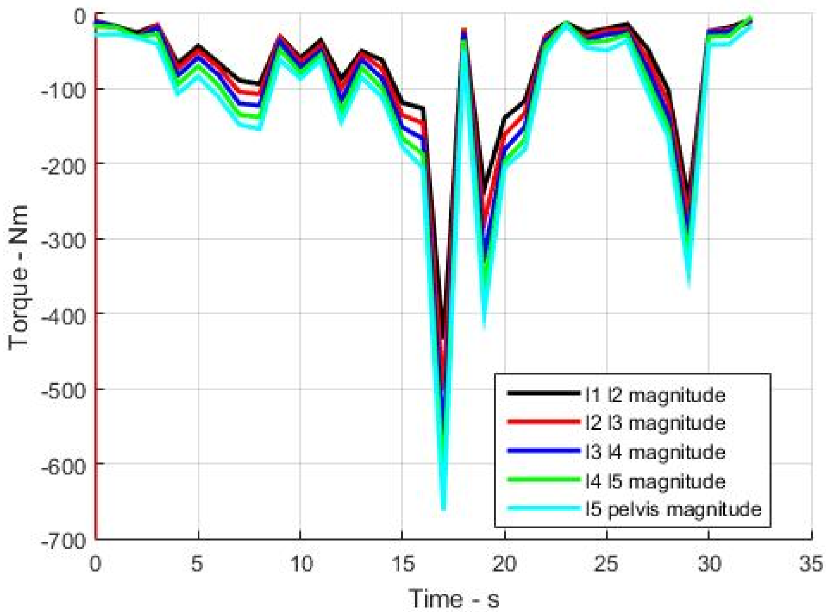


Figure 4.28 lumbar joint torque of metal fitter and machinists during activity 2 (picking up the welding gun and parent material.)

4.8.3.4. Lumber joint contact force and torque during metal fitter and machinists' activity 3

Figure 4.29 and Figure 4.30 show lumbar joint contact force and lumbar joint torque during Activity 3. Pick lumbar joint contact forces and lumbar joint torques are the consequences of trunk flexion and the ground reaction force during the task, ground reaction force is the summation of the load imposed on the body and the body weight.

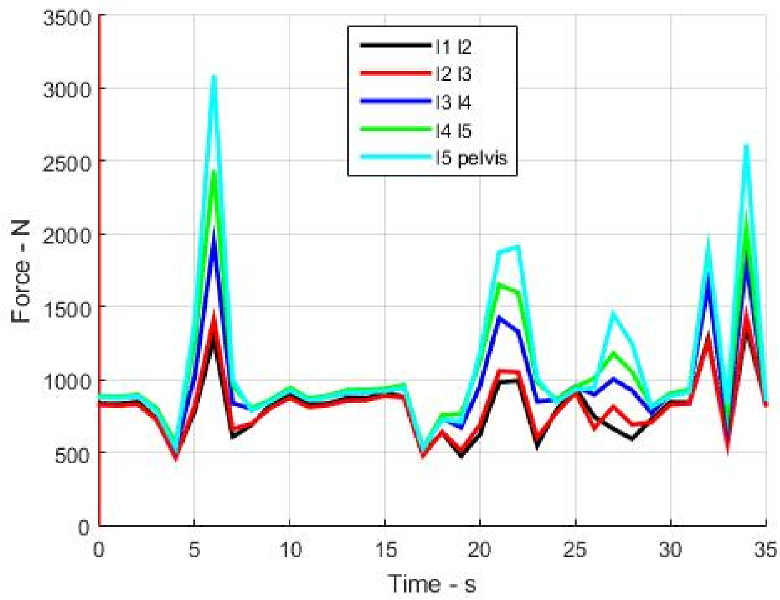


Figure 4.29 lumbar joint contact force during activity 3 (welding in reaching and forward bending pose)

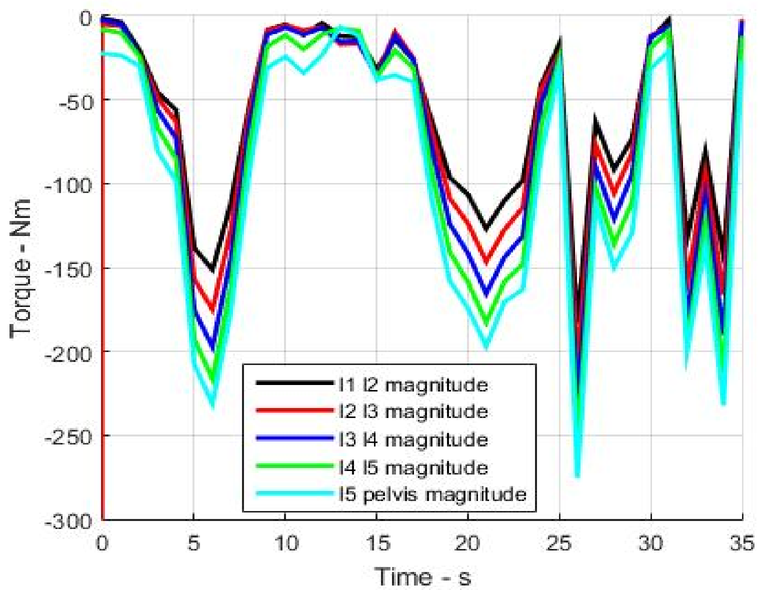


Figure 4.30 lumbar joint torque during activity 3 (welding in reaching and forward bending pose)

4.8.4. Model fitting summary

Table 4.12 shows lumbar joint contact force assessment model fitting summary. R-square value showed that how much of lumbar joint contact force and torque variability can be explained by ground reaction force, trunk angle, and vertical distance of the object. For example, R-square value .770 indicated that 77.0% of the joint contact force can be explained by ground reaction force, trunk angle, and vertical distance of the object. The last column of the table indicated that whether lumbar joint contact force and torque significantly assessed or not. Significant value .000 indicated that ground reaction force, trunk angle, and vertical distance of the object significantly (<.01) assessed lumbar joint contact force.

Table 4.12 Model fitting summary of the assessemnt model to assess lumbar joint contact force, and lumbar joint torque

Lifting/ lowering task	***Risk factors***	***Model***	***R square***	***Sig***
Activity 1	Joint contact force	L1-L2	.770	.000
		L2-L3	.777	.005
		L3-L4	.781	.003
		L4-L5	.787	.021
		L5-P	.802	.045
	Joint torque	L1-L2	.769	.000
		L2-L3	.750	.010
		L3-L4	.766	.032
		L4-L5	.802	.047
		L5-P	.836	.000
Activity 2	Joint contact force	L1-L2	.646	.001
		L2-L3	.605	.002
		L3-L4	.584	.004
		L4-L5	.548	.007
		L5-P	.581	.004
	Joint torque	L1-L2	.794	.000
		L2-L3	.806	.000
		L3-L4	.807	.000
		L4-L5	.796	.000
		L5-P	.781	.000
Activity 3	Joint contact force	L1-L2	.468	.001
		L2-L3	.368	.011
		L3-L4	.621	.000
		L4-L5	.672	.000
		L5-P	.689	.000
	Joint torque	L1-L2	.984	.000
		L2-L3	.967	.000
		L3-L4	.972	.000
		L4-L5	.986	.000
		L5-P	.990	.000

4.8.5. Results and discussions

Table 4.13 shows coefficients of the assessment model to assess lumbar joint (L1-L2, L2-L3, L3-L4, L4-L5, L5-P) contact force during activity 1, 2, and 3 of metal fitter and machinists.

Ground reaction force coefficient value, $b_{grf} = 1.65$, indicated that ground reaction force increased by one unit, l1-l2 lumbar joint contact force increased by 1.65 unit. Both unit measured in Newton (N), hence, for every 1 N ground reaction force increased an extra lumbar joint contact force increased by 1.65 N.

Trunk angle coefficient value, $b_{ta} = 1.12$, indicated that trunk angle increased by one unit, l1-l2 lumbar joint contact force increased by 1.12 unit. Trunk angle measured in degrees (^{0}). Joint contact force measured in Newton (N). Hence, 1^0 trunk angle increased an extra lumbar joint contact force increased by 1.12 N.

Vertical distance of the object handled coefficient value, $b_{vd} = 1.15$, indicated that vertical distance of the object handled increased by one unit, l1-l2 lumbar joint contact force increased by 1.15 unit. Vertical distance of the object handled measured in meter (m). Joint contact force measured in Newton (N). Hence, 1 m vertical distance of the object increased an extra lumbar joint contact force increased by 1.15 N.

Table 4.13 Coefficients of the assessment model to assess lumbar joint (L1-L2, L2-L3, L3-L4, L4-L5, L5-P) contact force during activity 1, 2, and 3 of metal fitter and machinists

Lifting/ lowering tasks	***Regression coefficient***	***L1-L2***	***L2-L3***	***L3-L4***	***L4-L5***	***L5-P***
Activity 1	b_0*	82.57	29.28	97.97	80.94	60.19
	b_{grf}*	1.65	2.70	2.93	3.22	4.27
	b_{ta}*	1.12	1.005	1.15	1.19	1.71
	b_{vd}*	1.15	2.77	4.59	5.27	4.17
Activity 2	b_0*	71.80	62.57	56.95	24.84	13.10
	b_{grf}*	1.29	1.99	2.83	2.88	3.725
	b_{ta}*	1.14	9.29	1.04	1.16	1.23
	b_{vd}*	2.45	1.46	1.10	1.02	4.66
Activity 3	b_0*	75.44	54.48	56.60	66.92	75.45
	b_{grf}*	3.37	2.01	3.52	4.08	4.09
	b_{ta}*	4.75	2.82	7.08	9.62	9.98
	b_{vd}*	1.65	1.89	2.75	4.59	5.91

*b_0 is model intercept, b_{grf} is coefficient of ground reaction force, b_{ta} is trunk angle, b_{vd} is vertical distance of the object.

Table 4.14 shows coefficients of the assessment model to assess lumbar joint (L1-L2, L2-L3, L3-L4, L4-L5, L5-P) torque during metal fitter and machinists MH task activity 1, 2, and 3.

Ground reaction force coefficient value, b_{grf} = 1.08 indicated that ground reaction force increased by one unit, l1-l2 lumbar joint torque increased by 1.08 unit. Ground reaction force increased in Newton (N). Lumbar joint torque increased in Newton-meter (N-m) hence, for every 1 N ground reaction force increased an extra lumbar joint torque increased by 1.08 N-m. This interpretation is true only if the effects of trunk angle and vertical distance of the object are held constant.

Trunk angle coefficient value, b_{ta} = 1.25 indicated that trunk angle increased by one unit, l1-l2 lumbar joint torque increased by 1.25 unit. Trunk angle measured in degrees (^{0}). Joint torque measured in Newton-meter (N-m). Hence, 1^0 trunk angle increased an extra lumbar joint torque increased by 1.16 N. This interpretation is true only if the effects of ground reaction force and vertical distance of the object are held constant.

Vertical distance of the object handled coefficient value, b_{vd} = 6.65, indicated that vertical distance of the object handled increased by one unit, l1-l2 lumbar joint torque increased by 6.65 unit. Vertical distance of the object handled measured in meter (m). Joint torque measured in Newton-meter (N-m). Hence, 1 m vertical distance of the object increased an extra lumbar joint torque increased by 6.65 N. This interpretation is true only if the effects of ground reaction force and trunk angle are held constant.

Table 4.14 Coefficients of the assessment model to assess lumbar joint (L1-L2, L2-L3, L3-L4, L4-L5, L5-P) torque during activity 1, 2, and 3 of metal fitter and machinists

Lifting/ lowering tasks	*Regression coefficient*	*L1-L2*	*L2-L3*	*L3-L4*	*L4-L5*	*L5-P*
Activity 1	$b_0{}^*$	44.21	22.75	37.87	88.06	161.10
	$b_{grf}{}^*$	1.08	1.13	2.14	2.09	3.02
	$b_{ta}{}^*$	1.25	2.36	2.50	3.94	5.14
	$b_{vd}{}^*$	6.65	6.89	7.82	8.38	8.78
Activity 2	$b_0{}^*$	82.67	80.30	31.39	45.92	56.18
	$b_{grf}{}^*$	.02	.01	.02	.02	.03
	$b_{ta}{}^*$	7.24	7.16	7.33	7.67	8.05
	$b_{vd}{}^*$	8.68	8.43	9.26	9.87	10.06
Activity 3	$b_0{}^*$	42.48	73.56	86.95	77.41	42.51
	$b_{grf}{}^*$	1.03	1.05	1.06	2.04	3.02
	$b_{ta}{}^*$	1.17	1.34	1.53	1.70	1.79
	$b_{vd}{}^*$	8.13	7.12	7.17	8.46	9.48

*b_0 is model intercept, b_{grf} is coefficient of ground reaction force, b_{ta} is trunk angle, b_{vd} is vertical distance of the object.

4.9. Chapter conclusion

- This research developed a simple assessment model for quantifying lumbar joint contact force and lumbar joint torque values from specific lifting/ lowering MH tasks. The required input data, ground reaction force, should be estimated accurately on a ground reaction force plate or using a similar GRF measuring equipment.
- The required input data, trunk angle and vertical height of the load/weight, should be measured accurately using 3-D motion capturing system.

- The proposed applicable equation is for quantifying lumbar joint contact force and lumbar joint torque values are applicable for the occupational tasks considered in this research associated with lifting and lowering, further research is required to generalize.
- Joint contact force was found to be unsafe for carpenters' unsafe task such as forward bending and nailing using nail gun, forward bending and twisting when nailing using hammer, since the joint contact force was beyond the tolerance (Waters et al. 1993).
- Joint contact force was found to be unsafe for bricklayers' unsafe task such as 20 kg block lifting from floor to chest level with trunk flexion and extension, since the joint contact force was beyond the tolerance (Waters et al. 1993).
- Joint contact force was found to be unsafe for metal fitter and machinists' unsafe task such as 37.5 kg gas bottle loading and unloading of trolley with awkward posture, since the joint contact force was beyond the tolerance (Waters et al. 1993).
- Lifting and twisting increase the lumbar joint contact force, Kim and Zhang (2016) found similar result in their research (Kim and Zhang 2016).
- The more the joint angle from the neutral position the greater the likelihood of injury. L1-L2, L2-L3, L3-L4, L4-L5, and L5-P lumbar joint contact force increased for the following factors (i) weight of the body (ii) postural stance and (iii) weight of the load.

5. ERGONOMIC RISK ASSESSMENT FRAMEWORK

5.1. Chapter introduction

This chapter presents a proposed ergonomic risk assessment framework for decision support to ensure musculoskeletal safety from lifting/ lowering MH tasks, also presents a review of current methods for ergonomic risk assessment.

5.2. Review of current methods for ergonomic risk assessment

Earlier research attempted to reduce work-related musculoskeletal disorders in various occupations. Several techniques for assessing WMSDs were formulated and grouped: 1) self-reports (for instance, questionnaires and interviews), 2) observational techniques, alongside 3) direct measurements (for instance, sensors) (David 2005). Employees' personal accounts may be utilised for collecting data regarding exposure to physical factors using questionnaires, interviews and diaries of workers (David 2005). Observational techniques focus on working motions and postures in occupational activities. Electric instrumental techniques that include accelerometer-based systems, electromagnetic system, sonic system, optical scanning system and the goniometric system –have been formulated for direct description of body postures (David 2005). Alwasel et al. (2011) used magneto-resistive sensors in measuring angles of body joints, and determined employees' exposure to poor postures during activities. Ray and Teizer (2012) proposed real-time assessment on employees' posture with a Kinect range camera to identify ergonomic tasks. Li and Lee (2011) came up with a computer-vision-oriented method to collect employees' motion video data, and located risky motions and postures to prevent WMSDs by returning the findings to the employees. However, the WMSDs are interactive internal response process for the human body towards physical stresses (for instance, vibration, exertion and posture) during occupational activities (Kumar 2001). Particularly, load, and level of exertion on tissues constitute essential factors in establishing WMSDs (Armstrong et al. 1996). Although the posture-based methods used previously for assessing WMSDs, such techniques are not ideal in the estimation of personal attributes such as physical abilities linked to WMSDs, which has been covered in this research.

5.2.1. Self-assessment methods

In these methods, data collected about physical exposure to manual handling risk factors. To collect data, written records, and interviews have been used for many years as methodology. Self-evaluation of recorded video clips of manual material handling tasks (Kadefors and Forsman 2000) and online questionnaire survey using Borg scale have been used as methods in this research for recent few years (Borg 1990; Krawczyk 1996; Dane et al. 2002; Stock et al. 2005). These methods deal with different variables such as, demographic, pain/ ache/ discomfort symptoms, and respondent's physical exposure. This method is easy to use in different types of jobs, and it is cost effective. Any number of respondents can be included in this method, and exposure to risk factors for a certain period of time can be analysed. Table 5.1 portrays data collection procedure, assumed scale, study population adopted in some self-assessment method based research. There are some drawbacks of using this method:

- Persons having neck pain mentioned higher exposure level compare to persons had no pain in a same job (Balogh et al. 2004). But, other investigator did not support this type of findings (Toomingas, Alfredsson and Kilbom 1997).

- Problems arise with self-reports from level of workers education and comprehension or question interpretation (Spielholz et al. 2001).
- The exposure level is unconvinced to quantify in this technique (Spielholz et al. 2001). There are other methods available to quantify the exposure level, however; validity and reliability of those methods are very poor to take as reference for ergonomic analysis (Li and Buckle 1999).

Table 5.1 Scale and data collection procedure assumed in previous research

Data collection procedure	**Assumed scale**	**Study population**	**Researchers**
Workers assess video recordings of their work to get ergonomic exposure	Using CR-10 scale, workers rate work related body discomfort	Workers on assembly of special cars (n = 7)	(Kadefors and Forsman 2000)
Risk factor was identified by analysing recorded physical workload	Dutch musculoskeletal questionnaire was used to identify higher risk factors	Metal, and shipbuilding workers (n = 1575)	(Hildebrandt et al. 2001)
Physical workload assessment of musculoskeletal disorder	Questionnaire for physical work demand and prevalence of musculoskeletal disorder	Forestry workers (n=2756)	(Viikari-Juntura et al. 1996)
Exposure prediction for shoulder and neck	Posture, and movement assessed using comprehensive questionnaire and MSD problem assessed using Nordic Questionnaire	General population (n = 14 556)	(Balogh et al. 2001)
Web based questionnaire was used to get ergonomic exposure	Job Requirements and Physical demands Survey were used to measure self-reported ergonomic exposure, and pain	Office workers (n = 92)	(Dane et al. 2002)

Data collection procedure	Assumed scale	Study population	Researchers
Force, frequency, posture of physical work demand was assessed	Visual analogue scale were used	Workers from service industry (n = 123)	(Pope et al. 1998)
Assessment of manual handling risk factors	Visual analogue scale were used	Tree-nursery workers (n = 71)	(Spielholz, Silverstein and Stuart 1999)

5.2.2. Observational methods

Many observational methods found in the literature, and these methods mentioned that observers assessed exposure to risk factors from a recording of the tasks. A set of methods is shown in Table 5.2.

Table 5.2 A list of observational methods for musculoskeletal risk assessment

Technique	Main features	Functions	Reference
OWAS	Working postures	Upper limbs, back, and lower limbs postural analysis	(Karhu, Kansi and Kuorinka 1977)
Checklist	Task frequency assessment for neck, back, and lower part of the body	Ergonomic risk (pain in different body regions) assessment in various time period	(Keyserling, Brouwer and Silverstein 1992b)
RULA	Scoring of muscle load, and body posture	Assessment of upper part of the body	(McAtamney and Corlett 1993)
LUBA	Perceived discomfort were measured for five range of motion of the body segments	Upper body discomfort assessment	(Kee and Karwowski 2001)
REBA	For assessment of musculoskeletal discomfort, force, and whole body posture have been categorised	Risk assessment for full body	(Hignett and McAtamney 2000; Bao et al. 2007)
NIOSH Lifting Equation	Represents lifting index which is ratio of actual load to recommended weight of lifting	Ergonomic risk assessment for lifting such as level of stress	(Waters et al. 1993; Motamedzade et al. 2011)
PLIBEL	Questions and checklist to assess musculoskeletal risk factors	Identified body regions which may have injury effect	(Kemmlert 1995)

Technique	Main features	Functions	Reference
The Strain Indes	Exertion time in a cycle, exertion intensity, level of efforts in every minute, wrist posture, and task duration per day were considered to make index of risk factors of work tasks.	Evaluation of upper limb disorder	(Steven Moore and Garg 1995)
OCRA	Measuring frequency of the task and posture of the body	Integrated evaluation of different risk factors such as, force, posture, repetitiveness, recovery time	(Occhipinti 1998; Shin and Kim 2007)
QEC	Obtain observers and workers response to find combined score of exposure	Back, shoulder/ arm, wrist/ hand, and neck exposure assessment	(Li and Buckle 1998; David et al. 2008)
Manual Handling Guidance	Checklists for task, equipment, environment and individual risk factors	Checklist for identifying risk factors for manual handling	(Manual Handling 1998)
FIOH Risk Factor Checklist	Checklist for force, body posture, and task frequency	Upper limb disorder assessment	(Ketola, Toivonen Iv and Viikari-Juntura 2001)
Upper Limb Disorder Guidance.	Checklist for assessing upper limb disorder for workplace hazards	Assessments of upper limb disorder risk factors	(David et al. 2008)
MAC	Identify dominating risk factors through a flow chart	Individuals manual handling risk assessment	(Monnington et al. 2003)

Different methods considered different factors. A portrait is given in Table 5.3 on what risk factor assessed by which method. OCRA and QEC use subjective data from workers to assess physical demands.

Table 5.3 Risk factors are assessed by different methods

	Checklist	***NIOSH***	***The Strain Index***	***OCRA***	***MH Guidance***	***LUBA***	***MAC***	***OWAS***	***RULA***	***PLIBEL***	***QEC***	***REBA***	***FIOSH Checklist***
Load/ force		√	√	√	√		√	√	√	√	√	√	√
Movement frequency		√	√	√	√		√		√		√	√	√
Recovery		√		√	√								
Vibration				√							√		
Posture	√	√	√	√	√	√	√	√	√	√	√	√	√
Duration		√	√	√	√						√		√
*Others**		√	√	√	√		√			√	√	√	√

* personal protective equipment, equipment used in the task, environmental factor, psychological factors, psychosocial factors, visual factors, and load coupling.

These methods are inexpensive compared to direct measurement methods. This is a practical method without causing any disruption of work. It is suitable for assessment of static or repetitive job, and more accurate postural information can be observed by using this method. However, the scoring systems are hypothetical as interactions between factors had not been counted. It is costly compared to self-assessment methods.

Recently, to assess body posture in different tasks of the job, observation techniques based on videos have been developed. Computer or video tape was used in this method to record data, then data were analysed using software. Body postures were recorded to analyse joint segments for example, 3-D motion capture used for recording range of movement, angular velocity and acceleration, then biomechanical model developed with the data of anthropometry, external load, and posture to calculate joint contact force and moment. Table 5.4 portraits some of the examples.

Table 5.4 Body posture assessment techniques

Technique	Main features	Function	Reference
Analysis of video	Analysis video of captured body posture	Trunk angular velocity and angle was measured	(Neumann et al. 2001b)
PEO,	Posture and activity analysis from computerised recording	Records all task during the job	(Fransson-Hall et al. 1995)
PATH		Assess jobs that are not repetitive	(Buchholz et al. 1996)
SIMI Motion	Capture movement in three dimension	Upper limbs movement assessment	(Li and Buckle 1999)
Biomechanical Model	Segmental analysis of capture movement in three dimension	Exposure estimation during performance of the task	(Chaffin, Andersson and Martin 1999)

This method involves substantial cost, require extensive technical support, and it is time consuming method.

5.3. Proposed ergonomic risk assessment framework

Ergonomics is the science of fitting workplace conditions and job demands to the capabilities of workers. MSD is a problem and ergonomics is a solution. The framework focuses on:

- Identifying musculoskeletal risk factors associated with lifting/ lowering
- Providing of a risk scoring/ rating system
- Proposing a MSD risks assessment framework for lifting/ lowering manual handling applicable to all age groups

5.3.1. Risk factors identification

Items such as individual particulars, task demand, postural demand, and environmental factors are considered in this MSD risk assessment framework.

A conceptual diagram is given below. Posture, repetition, and force characterize potential musculoskeletal disorder risk factors in manual handling tasks (Forcier et al. 2008; Vandergrift et al. 2012). Individual particulars such as physical abilities are related to the work related MSD. Task demand such as lifting repetition, and the extent of lifting is also connected to the MSD. Back, head/ neck, shoulder/ upper arm, wrist, and knee was identified as some risk regions due to their awkward position during the task. Environmental factor such as vibration has impact on MSD.

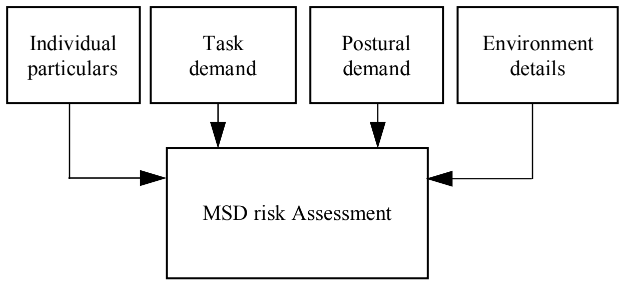


Figure 5.1 A conceptual model for MSD risk assessment

5.3.2. MSD risk breakdown structure

A hierarchical breakdown structure of MSD risk assessment criteria is given in Figure 5.2. Three main criteria are placed at the beginning of the structure, these are work content, work ability, and work environment. After the main criteria, sub-criteria are taken placed in the figure. For example, under the work ability criteria, sub-criteria such as manual dexterity, static strength, dynamic strength, trunk strength, flexibility, body equilibrium, stamina, arm-hand steadiness, finger dexterity, and multi-limb coordination are placed. Basically, these sub-criteria represent work abilities of a person. This last level in the hierarchy is the detail representation of the main criteria. The frequency of weight lifting/ lowering; the extent of lifting/ lowering repetition; frequency of working posture of back, neck, shoulder, wrist, and knee; and duration of working posture of back, neck, shoulder, wrist, and knee are the sub criteria of work content main criteria.

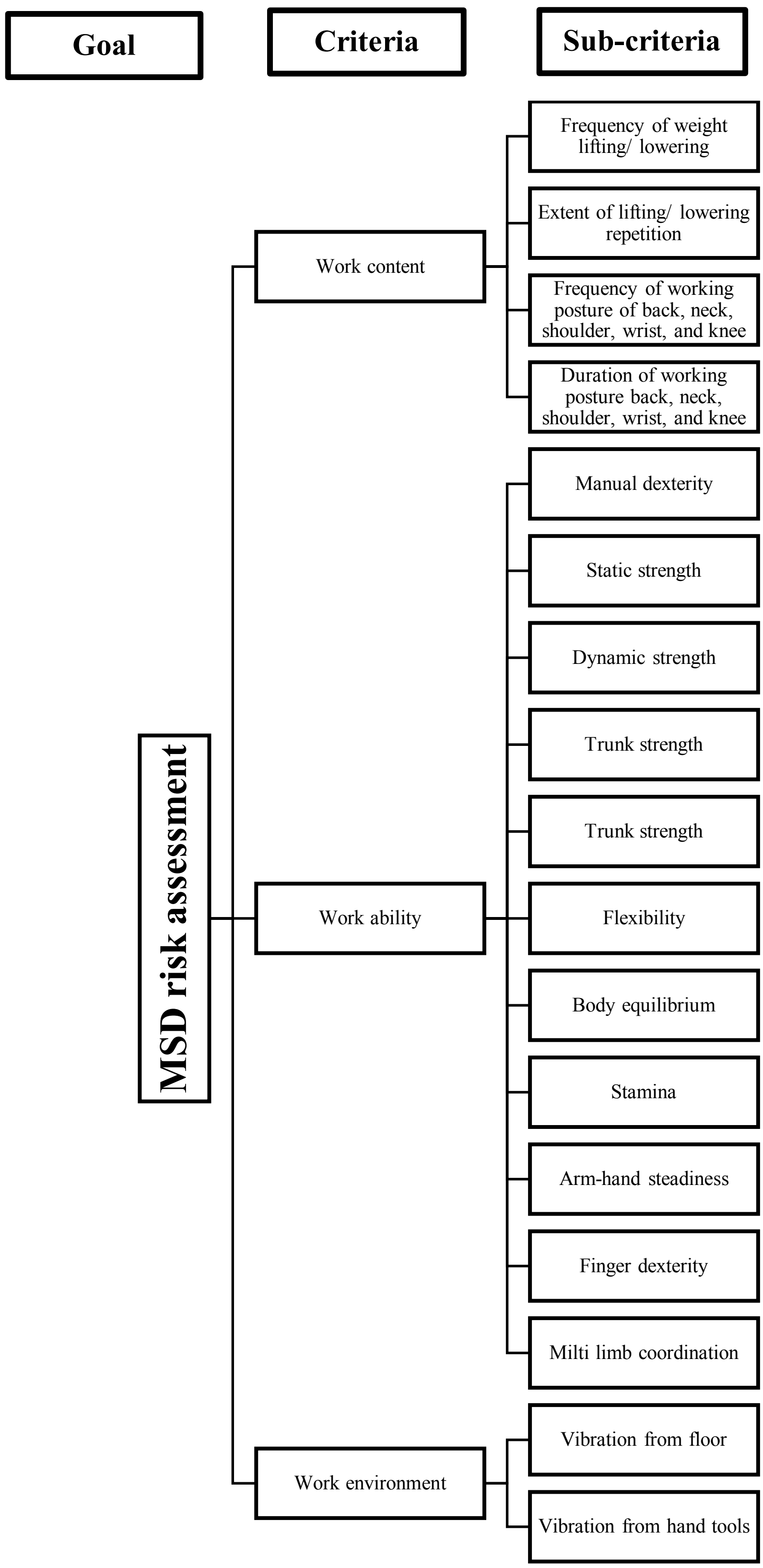


Figure 5.2 Hierarchical framework of the lifting/ lowering task criteria

5.3.3. Development of the ergonomic risk scoring system

Combined effect of the risk factors provides greater musculoskeletal risk compare to individual factor (Marras et al. 1995; Tayyari and Smith 1997; Ciriello et al. 2001) such as, only weigh of the load underestimate MSD, weight and repetition, and weight and extent of lifting can be combined. Simple weighted scoring is a popular system/ arrangement for multi-criteria based decision context. Along with the questionnaire that is described/ reported in chapter 3, respondents were asked to provide perception on their physical discomfort for every sub-criteria of work content and work environment. Sub-criteria of work content and work environment are given in figure 5.2. Regression analysis taken into consideration between sub-criteria and corresponding physical discomfort to find the coefficient, which is the weight attached to the sub-criteria or predictor variables. Coefficient/ weight attached to the predictor variables reported in Chapter 3 are linked to construct the proposed framework (risk rating and scoring system) in this chapter., which is shown in Table 5.5 and

Table **5.6**.

Table 5.5 Risk rating table

Sub criteria		***Risk factor A***				
		Risk Level 1	***Risk Level 2***	***Risk Level 3***	***Risk Level 4***	***Risk Level 5***
Sub criteria	*Risk Level 1*	1	2	3	4	5
	Risk Level 2	2	3	4	5	6
	Risk Level 3	3	4	5	6	7
	Risk Level 4	4	5	6	7	8
	Risk Level 5	5	6	7	8	9

*Weight attached to the predictor variables

Table 5.6 Risk scoring table

Sub criteria		***Wt.*** [*]	***Risk factor A***				
			Risk Level 1	***Risk Level 2***	***Risk Level 3***	***Risk Level 4***	***Risk Level 5***
Risk factor B	*Risk Level 1*	Wt_{l1}	1* Wt_{l1}	2* Wt_{l1}	3* Wt_{l1}	4* Wt_{l1}	5* Wt_{l1}
	Risk Level 2	Wt_{l2}	2* Wt_{l2}	3* Wt_{l2}	4* Wt_{l2}	5* Wt_{l2}	6* Wt_{l2}
	Risk Level 3	Wt_{l3}	3* Wt_{l3}	4* Wt_{l3}	5* Wt_{l3}	6* Wt_{l3}	7* Wt_{l3}
	Risk Level 4	Wt_{l4}	4* Wt_{l4}	5*Wt_{l4}	6* Wt_{l4}	7* Wt_{l4}	8* Wt_{l4}
	Risk Level 5	Wt_{l5}	5* Wt_{l5}	6* Wt_{l5}	7* Wt_{l5}	8* Wt_{l5}	9* Wt_{l5}

[*]Weight attached to the predictor variables

Risk scoring system was developed considering combined risk factors that contribute to MSDs, which can be seen from Table 5.7 to Table 5.33.

Table 5.7 Risk rating for the combined effect of weight and frequency of lifting/ lowering tasks

Weight lifted/ lowered	***Requirement for repeating of lifting/ lowering tasks***			
	Low [**]	***Moderate*** [**]	***High*** [**]	***Very High*** [**]
Less than 5 kg	1	2	3	4
6 to 10 kg	2	3	4	5
11 to 15 kg	3	4	5	6
16 to 20 kg	4	5	6	7

**Low, i.e. less than 5 times per minute; Moderate i.e. 5 to 8 times per minute; High i.e. 9 to 12 times per minute; Very High i.e. more than 12 times per minute

Table 5.8 Risk scoring for the combined effect of weight and frequency of lifting/ lowering tasks

Weight lifted/ lowered	*Wt.**	*Requirement for repeating of lifting/ lowering tasks*			
		*Low***	*Moderate***	*High***	*Very High***
Less than 5 kg	0.148	0.148	0.296	0.444	0.592
6 to 10 kg	0.183	0.366	0.549	0.732	0.915
11 to 15 kg	0.250	0.75	1	1.25	1.5
16 to 20 kg	0.263	1.052	1.315	1.578	1.841

*Weight attached to the predictor variables. **Low, i.e. less than 5 times per minute; Moderate i.e. 5 to 8 times per minute; High i.e. 9 to 12 times per minute; Very High i.e. more than 12 times per minute

Table 5.9 Risk rating for the combiled effect of height and weight of lifting/ lowering MH tasks

Height of lifting/ lowering	*Requirement for repeating of lifting/ lowering tasks*			
	*Low***	*Moderate***	*High***	*Very High***
Floor to knuckle	1	2	3	4
Knuckle to chest	2	3	4	5
Chest to shoulder	3	4	5	6
Above shoulder	4	5	6	7

**Low, i.e. less than 5 times per minute; Moderate i.e. 5 to 8 times per minute; High i.e. 9 to 12 times per minute; Very High i.e. more than 12 times per minute

Table 5.10 Risk scoring for the combiled effect of height and weight of lifting/ lowering MH tasks

Height of lifting/ lowering	*Wt.* *	***Requirement for repeating of lifting/ lowering tasks***			
		Low **	***Moderate*** **	***High*** **	***Very High*** **
Floor to knuckle	.156	0.156	0.312	0.468	0.624
Knuckle to chest	.258	0.516	0.774	1.032	1.29
Chest to shoulder	.321	0.963	1.284	1.605	1.926
Above shoulder	.740	2.96	3.7	4.44	5.18

*Weight attached to the predictor variables. **Low, i.e. less than 5 times per minute; Moderate i.e. 5 to 8 times per minute; High i.e. 9 to 12 times per minute; Very High i.e. more than 12 times per minute

Table 5.11 Risk rating for the combiled effect of forward back bending and repeating in lifting/ lowering MH tasks

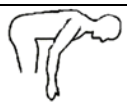
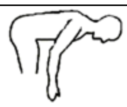
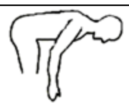
Back bending	***Representative figure***	***Requirement for repeating of lifting/ lowering tasks***			
		Low *	***Moderate*** *	***High*** *	***Very High*** *
Neutral **		1	2	3	4
Moderate **		2	3	4	5
Extreme **		3	4	5	6

Table 5.12 Risk scoring for the combiled effect of forward back bending and repeating in lifting/ lowering MH tasks

Back bending	***Figure***	***Requirement for repeating of lifting/ lowering tasks***				
		Wt.*	***Low****	***Moderate****	***High****	***Very High****
*Neutral***		.011	0.011	0.022	0.033	0.044
*Moderate***		.127	0.254	0.381	0.508	0.635
*Extreme***		.176	0.528	0.704	0.88	1.056

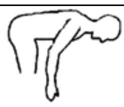
***Weight attached to the predictor variables; *Low, i.e. less than 5 times per minute; Moderate; i.e. 5 to 8 times per minute; High i.e. 9 to 12 times per minute; Very High i.e. more than 12 times per minute. **Neutral – i.e. almost no bending (less than 20 degrees); Moderate – i.e. moderately flexed (20 to 60 degrees); Extreme – i.e. extremely flexed (more than 60 degrees)

Table 5.13 Risk rating for the combiled effect of back bending and duration (minutes) in lifting/ lowering MH task

Back bending	***Figure***	***Posture duration***				
		<1	***1 to 2***	***2 to 3***	***3 to 4***	***>4***
*Neutral***		1	2	3	4	5
*Moderate***		2	3	4	5	6
*Extreme***		3	4	5	6	7

**Neutral – i.e. almost no bending (less than 20 degrees); Moderate – i.e. moderately flexed (20 to 60 degrees); Extreme – i.e. extremely flexed (more than 60 degrees)

Table 5.14 Risk scoring for the combiled effect of back bending and duration (minutes) in lifting/ lowering MH task

Back bending	*Figure*	***Posture duration***					
		Wt.*	***<1***	***1 to 2***	***2 to 3***	***3 to 4***	***>4***
*Neutral***		.145	0.145	0.29	0.435	0.58	0.725
*Moderate***		.161	0.322	0.483	0.644	0.805	0.966
*Extreme***		.240	0.72	0.96	1.2	1.44	1.68

*Weight attached to the predictor variables. **Neutral – i.e. almost no bending (less than 20 degrees); Moderate – i.e. moderately flexed (20 to 60 degrees); Extreme – i.e. extremely flexed (more than 60 degrees)

Table 5.15 WMSDs scoring scoring for the combiled effect of head inclination and repeation in lifting/ lowering MH tasks

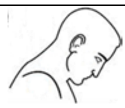
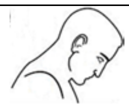
Head inclination	***Figure***	***Requirement for repeating of lifting/ lowering tasks***			
		Low*	***Moderate****	***High****	***Very High****
*Neutral***		1	2	3	4
*Moderate***		2	3	4	5
*Extreme***		3	4	5	6

Table 5.16 Risk scoring for the combiled effect of head inclination and repeation in lifting/ lowering MH tasks

Head inclination	***Figure***	***Requirement for repeating of lifting/ lowering tasks***				
		Wt.*	***Low****	***Moderate****	***High****	***Very High****
*Neutral***		.223	0.223	0.446	0.669	0.892
*Moderate***		.224	0.448	0.672	0.896	1.12
*Extreme***		.227	0.681	0.908	1.135	1.362

***Weight attached to the predictor variables. *Low, i.e. less than 5 times per minute; Moderate; i.e. 5 to 8 times per minute; High i.e. 9 to 12 times per minute; Very High i.e. more than 12 times per minute. **Neutral – i.e. almost no bending (less than 20 degrees); Moderate – i.e. moderately flexed (20 to 30 degrees); Extreme – i.e. extremely flexed (more than 30 degrees).

Table 5.17 Risk rating for the combiled effect of head inclination and duration (minutes) in lifting/ lowering MH tasks

Head inclination	***Figure***	***Posture duration in a lifting/ lowering task***				
		< 2	***2 to 4***	***4 to 6***	***6 to 8***	***> 8***
*Neutral***		1	2	3	4	5
*Moderate***		2	3	4	5	6
*Extreme***		3	4	5	6	7

**Neutral – i.e. almost no bending (less than 20 degrees); Moderate – i.e. moderately flexed (20 to 30 degrees); Extreme – i.e. extremely flexed (more than 30 degrees).

Table 5.18 Risk scoring for the combiled effect of head inclination and duration (minutes) in lifting/ lowering MH tasks

Head inclination	***Figure***	***Posture duration in a lifting/ lowering task***					
		Wt.*	***< 2***	***2 to 4***	***4 to 6***	***6 to 8***	***> 8***
*Neutral***		.076	0.076	0.152	0.228	0.304	0.38
*Moderate***		.119	0.238	0.357	0.476	0.595	0.714
*Extreme***		.120	0.36	0.48	0.6	0.72	0.84

*Weight attached to the predictor variables. **Neutral – i.e. almost no bending (less than 20 degrees); Moderate – i.e. moderately flexed (20 to 30 degrees); Extreme – i.e. extremely flexed (more than 30 degrees).

Table 5.19 Risk rating for upper arm/ shoulder elevation and repeatition in lifting/ lowering MH tasks

Upper arm/ shoulder elevation	***Figure***	***Requirement for repeating of lifting/ lowering tasks***			
		Low*	***Moderate****	***High****	***Very High****
*Neutral***		1	2	3	4
*Moderate***		2	3	4	5
*Extreme***		3	4	5	6

Table 5.20 Risk scoring for upper arm/ shoulder elevation and repeatition in lifting/ lowering MH tasks

Upper arm/ shoulder elevation	***Figure***	***Requirement for repeating of lifting/ lowering tasks***				
		Wt.*****	***Low******	***Moderate******	***High******	***Very High******
*Neutral***		.087	0.087	0.174	0.261	0.348
*Moderate***		.334	0.668	1.002	1.336	1.67
*Extreme***		.437	1.311	1.748	2.185	2.622

***Weight attached to the predictor variables. *Low, i.e. less than 5 times per minute; Moderate; i.e. 5 to 8 times per minute; High i.e. 9 to 12 times per minute; Very High i.e. more than 12 times per minute. **Neutral – i.e. almost no elevation (less than 20 degrees); Moderate – i.e. moderately elevated (20 to 60 degrees); Extreme – i.e. extremely elevated (more than 60 degrees)

Table 5.21 Risk rating for upper arm/ shoulder elevation level and posture duration in lifting/ lowering task

Upper arm/ shoulder elevation	***Figure***	***Posture duration (minutes)***				
		< 1	***1 to 2***	***2 to 3***	***3 to 4***	***> 4***
*Neutral***		1	2	3	4	5
*Moderate***		2	3	4	5	6
*Extreme***		3	4	5	6	7

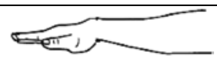
**Neutral – i.e. almost no elevation (less than 20 degrees); Moderate – i.e. moderately elevated (20 to 60 degrees); Extreme – i.e. extremely elevated (more than 60 degrees)

Table 5.22 Risk scoring for upper arm/ shoulder elevation level and posture duration in lifting/ lowering task

Upper arm/ shoulder elevation	***Figure***	***Posture duration (minutes)***					
		Wt.*	***< 1***	***1 to 2***	***2 to 3***	***3 to 4***	***> 4***
*Neutral***		.182	0.182	0.364	0.546	0.728	0.182
*Moderate***		.289	0.578	0.867	1.156	1.445	0.578
*Extreme***		.361	1.083	1.444	1.805	2.166	1.083

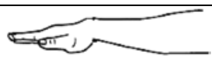
*Weight attached to the predictor variables. **Neutral – i.e. almost no elevation (less than 20 degrees); Moderate – i.e. moderately elevated (20 to 60 degrees); Extreme – i.e. extremely elevated (more than 60 degrees)

Table 5.23 Risk rating for wrist posture and repetition in lifting/ lowering MH tasks

Wrist posture	***Figure***	***Requirement for repeating of lifting/ lowering tasks***		
		Low**	***Moderate*****	***High*****
*Neutral***		1	2	3
*Moderate***		2	3	4
*Extreme***		3	4	5

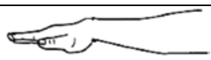
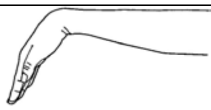
**Neutral – i.e. almost straight wrist position (less than 10 degrees); Moderate – i.e. moderately bent/ deviated wrist position (10 to 50 degrees); Extreme – i.e. extremely bent/ deviated wrist position (more than 50 degrees); ***Low i.e. less than 10 times per minute; Moderate i.e. 10 to 20 times per minute; High i.e. more than 20 times per minute

Table 5.24 Risk scoring for wrist posture and repetition in lifting/ lowering MH tasks

Wrist posture	***Figure***	***Requirement for repeating of lifting/ lowering tasks***			
		Wt.*	***Low******	***Moderate******	***High******
*Neutral***		.217	0.217	0.434	0.651
*Moderate***		.357	0.714	1.071	1.428
*Extreme***		.652	1.956	2.608	3.26

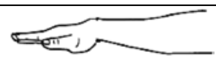
*Weight attached to the predictor variables. **Neutral – i.e. almost straight wrist position (less than 10 degrees); Moderate – i.e. moderately bent/ deviated wrist position (10 to 50 degrees); Extreme – i.e. extremely bent/ deviated wrist position (more than 50 degrees); ***Low i.e. less than 10 times per minute; Moderate i.e. 10 to 20 times per minute; High i.e. more than 20 times per minute

Table 5.25 Risk rating for wrist posture and duration in lifting/ lowering MH tasks

Wrist posture	***Figure***	***Posture duration (seconds)***		
		< 30	***30 to 60***	***> 60***
*Neutral***		1	2	3
*Moderate***		2	3	4
*Extreme***		3	4	5

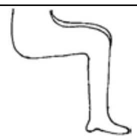
**Neutral – i.e. almost straight wrist position (less than 10 degrees); Moderate – i.e. moderately bent/ deviated wrist position (10 to 50 degrees); Extreme – i.e. extremely bent/ deviated wrist position (more than 50 degrees)

Table 5.26 Risk scoring for wrist posture and duration in lifting/ lowering MH tasks

Wrist posture	*Figure*	*Posture duration (seconds)*			
		Wt.*	***< 30***	***30 to 60***	***> 60***
*Neutral***		.338	0.338	0.676	1.014
*Moderate***		.367	0.734	1.101	1.468
*Extreme***		.580	1.74	2.32	2.9

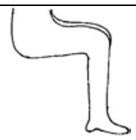
*Weight attached to the predictor variables. **Neutral – i.e. almost straight wrist position (less than 10 degrees); Moderate – i.e. moderately bent/ deviated wrist position (10 to 50 degrees); Extreme – i.e. extremely bent/ deviated wrist position (more than 50 degrees)

Table 5.27 Risk rating for knee posture and repetition of lifting/ lowering tasks

Knee posture	*Figure*	*Frequency per minute*		
		Low**	***Moderate*****	***High*****
*Neutral***		1	2	3
*Moderate***		2	3	4
*Extreme***		3	4	5

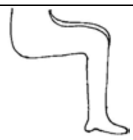
**Neutral – i.e. almost straight knee position (less than 10 degrees); Moderate – i.e. moderately bent/ deviated knee position (10 to 90 degrees); Extreme – i.e. extremely bent/ deviated knee position (more than 90 degrees). ***Low, i.e. less than 10 times per minute; Moderate i.e. 10 to 20 times per minute; High i.e. more than 20 times per minute

Table 5.28 Risk scoring for knee posture and repetition of lifting/ lowering tasks

Knee posture	***Representative figure***	***Frequency per minute***			
		Wt.*	***Low******	***Moderate******	***High******
*Neutral***		.073	0.073	0.146	0.219
*Moderate***		.411	0.822	1.233	1.644
*Extreme***		.638	1.914	2.552	3.19

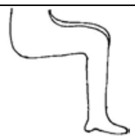
*Weight attached to the predictor variables. **Neutral – i.e. almost straight knee position (less than 10 degrees); Moderate – i.e. moderately bent/ deviated knee position (10 to 90 degrees); Extreme – i.e. extremely bent/ deviated knee position (more than 90 degrees). ***Low, i.e. less than 10 times per minute; Moderate i.e. 10 to 20 times per minute; High i.e. more than 20 times per minute

Table 5.29 Risk rating for knee posture and duration in lifting/ lowering MH task

Knee posture	***Figure***	***Posture duration (seconds)***		
		< 30	***30 to 60***	***> 60***
*Neutral***		1	2	3
*Moderate***		2	3	4
*Extreme***		3	4	5

**Neutral – i.e. almost straight knee position (less than 10 degrees); Moderate – i.e. moderately bent/ deviated knee position (10 to 90 degrees); Extreme – i.e. extremely bent/ deviated knee position (more than 90 degrees).

Table 5.30 Risk scoring for knee posture and duration in lifting/ lowering MH task

Knee posture	***Figure***	***Posture duration (second)***			
		Wt.*	***< 30***	***30 to 60***	***> 60***
*Neutral***		.069	0.069	0.138	0.207
*Moderate***		.290	0.58	0.87	1.16
*Extreme***		.449	1.347	1.796	2.245

*Weight attached to the predictor variables. **Neutral – i.e. almost straight knee position (less than 10 degrees); Moderate – i.e. moderately bent/ deviated knee position (10 to 90 degrees); Extreme – i.e. extremely bent/ deviated knee position (more than 90 degrees).

Table 5.31 Risk rating for vibration from floor and hand tools in lifting lowering MH tasks

Source of vibration	Exposure duration (hour)				
	< 1	1 to 2	2 to 3	3 to 4	> 4
1. Vibration from surface	1	2	3	4	5
2. Vibration from tools handled	1	2	3	4	5

Table 5.32 Risk scoring for vibration from floor and hand tools in lifting lowering MH tasks

Source of vibration	Wt.*	Exposure duration (hour)				
		< 1	1 to 2	2 to 3	3 to 4	> 4
1. Vibration from floor	.527	0.527	1.054	1.581	2.108	2.635
2. Vibration from tools handled	.517	1.034	1.551	2.068	2.585	3.102

*Weight attached to the predictor variables

Table 5.33 Risk scoring for physical ability

	Very good	*Good*	*Moderate*	*Poor*	*Very poor*
1. Your ability to use your hand and arm, for example to grasp, manipulate, or assemble objects.	1	2	3	4	5
2. Your ability to perform manual handling tasks such as lifting and carrying objects.	1	2	3	4	5
3. Your ability to perform the manual handling tasks repeatedly or continuously over time.	1	2	3	4	5
4. Your ability to safely use your trunk to support the manual handling tasks.	1	2	3	4	5
5. Your ability to bend, stretch, twist, or reach with your body, arms, and/or legs.	1	2	3	4	5
6. Your ability to keep or regain your body balance or stay upright during manual handling tasks.	1	2	3	4	5
7. Your ability to exert physically without getting winded or out of breath.	1	2	3	4	5
8. Your ability to keep your hand and arm steady while performing manual handing tasks.	1	2	3	4	5
9. Your ability to perform coordinated movements of the fingers of one or both hands, for example to grasp, manipulate or assemble small objects.	1	2	3	4	5
10. Your ability to coordinate your limbs (for example, two arms, two legs, or one leg and one arm) while performing manual handling tasks.	1	2	3	4	5

Table 5.34 Classification of the risk ratings

Framework items	Combination of risk factors	Risk ratings		
		Low	Medium	High
Weight lifted/ lowered	Weight Repetition	1-3	4-5	6-7
Height of lifting lowering	Height Repetition	1-3	4-5	6-7
Forward back bending	Bending level Repetition	1-2	3-4	5-6
Forward back bending	Bending level Duration	1-3	4-5	6-7
Neck posture	Inclining level Repetition	1-2	3-4	5-6
Neck posture	Inclining level Duration	1-3	4-5	6-7
Upper arm elevation	Elevation level Repetition	1-2	3-4	5-6
Upper arm elevation	Elevation level Duration	1-3	4-5	6-7
Wrists posture	Bending level Repetition	1-2	3	4-5
Wrist posture	Bending level Duration	1-2	3	4-5
Knee posture	Bending level Repetition	1-2	3	4-5
Knee posture	Bending level Duration	1-2	3	4-5
Surface vibration	Duration	1-3	4	5
Hand tool vibration	Duration	1-3	4	5
Physical ability		10-20	21-35	36-50
Total risk rating		24-55	70-92	107-133
Weighted total of the risk rating or risk score, R_s		13.268-31.742	31.742-62.886	62.886-84.079

Risk score, $R_s = \sum_n^N w_n * x_{in}$

Risk class, $R_c = \begin{cases} Low, i.e. 13.268 < Rs < 31.742 \\ Medium, i.e. 31.742 < R_s < 62.886 \\ High, i.e. 62.886 < R_s < 84.079 \end{cases}$

Where,

i	Reference identifier for a person
N	Total number of criteria
n	Indices for criteria with set $n = \{1, 2, 3, \dots, N\}$
R_s	Risk score for $i, n \in N$
R_c	Risk classification
w_n	Weight attached to the criteria for $n \in N$
x_{in}	Input of the criteria for $n \in N$ and $x_{if} = \{1, 2, 3, \dots, 9\}$

5.4. Use and benefits of the proposed model

This ergonomic risk assessment framework can be potentially useful to job design with respect to lifting/ lowering work with due consideration of worker's physical ability and the assessment of musculoskeletal disorders (MSDs) risks. With such contemporary framework, lifting/ lowering related manual handling work can be rationally designed/ redesigned for improved musculoskeletal safety and health outcomes – even for highly ergonomically risky and challenging trades. This model can also serve occupational health and safety practitioners to audit/ check and recommend regarding design the lifting/ lowering related manual handling work and advise for rehabilitation and return to the work programme. Moreover, manipulation in the lifting/ lowering related manual handling work demand by the industrial engineers might take place using this model considering the interrelationships of the model components.

5.5. Chapter conclusion

The proposed risk assessment framework will be useful for safely engaging aging workforce in physically demanding trade works in industries such as construction and manufacturing. To validate the proposed model one domain expert's opinion was taken. The expert confirmed that the proposed model has potential value in assessing musculoskeletal disorder risk of the workers involved in lifting/ lowering manual handling tasks. The expert stated that the proposed model is a reasonable reference and no such model exists in the current body of knowledge. The proposed model can be improved further for wider practical applications.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. Summary and conclusions

The life expectancy in Australia has been around 80 to 84 years (*Deaths, Australia* Australian Bureau of Statistics, 2014) and approximately 2.5 million people are still willing to work even after their retirement age. However, the physical abilities significantly decline with aging (Ketcham et al. 2002; Roper and Yeh 2007). Although the physical abilities are generally depleting with ageing, the physical demands of work in most jobs have not been changed (Ilmarinen 1997). Physical abilities of individuals have direct significance for health and safety in MH tasks (Ilmarinen, Tuomi and Seitsamo 2005). Existing risk assessment frameworks do not comprehensively integrate the physical requirements of “ageing” workforce, especially to minimise MH related MSDs.

In chapter 2, work related MSD risk factors have been benchmarked. Risk factors include personal attributes, task demands, and environmental demands. If personal attributes such as, physical abilities are lower than task demands, MSDs may take place. Aging workforce is particularly vulnerable, because of their reduced physical abilities.

Chapter 3 has demonstrated the relationships between (a) personal attributes, job demands, postural requirements, and work environment; and (b) work related MSDs. The age of the workers working in manufacturing and construction industries and engaged in manual handling tasks, mainly lifting/ lowering, significantly related with the work related occurrences of upper and lower back musculoskeletal disorders. Some of the significant relationships are (i) physical abilities significantly associated with the work related lower and upper back musculoskeletal disorder for the workers age more than 60 years, (ii) lifting lowering frequency and duration, frequency and duration of awkward posture are significantly correlated with lower and upper back MSDs, (iii) environmental factor such as, vibration has strong effect on lifting lowering MH tasks related MSDs.

In chapter 3, a suite of multinomial regression models for predicting probabilities of work related MSD occurrences from lifting/ lowering MH tasks has been included. Such prediction of probabilities for work related MSD problems will enhance occupational health and safety through improved selection of people as well as suitable job designs/ redesigns in occupations involving significant MH tasks of lifting and lowering. Three models for predicting the probabilities of potential back MSD occurrences have been presented for three trades (i) metal fitter and machinists' tasks (ii) carpenters' tasks and (iii) bricklayers' tasks. The odds of having metal fitter and machinists' work related acute and chronic lower back musculoskeletal problems/ disorders can be attributed to physical ability (static strength and stamina), frequency of lifting/ lowering task (6 to 10 kg, 16 to 20 kg), extent of repeating lifting/ lowering task (floor to knuckle), back posture (less than 20, 20 to 60, and more than 60 degrees) repetition, and Physical discomfort for back posture (more than 60 degrees) duration. Bricklaying work with the extent of lifting from knuckle to shoulder is a risk factor for both acute and chronic lower back MSDs. Carpenters are more likely to get acute MSDs than not to get MSDs if they have lower (very good to very poor) static strength.

In chapter 4, a biomechanical modelling and virtual reality (VR) simulations based assessment system for quantifying lumber joint contact force and lumber joint torque values from specific lifting/ lowering MH tasks has been developed. The system is suitable for providing quantitative assessment of spinal loads (lumber joint contact force, and lumber joint torque) from personal attributes, lifting/ lowering task related input variables such as weight of the load and extent of lifting, and postural requirements (angle of back bending). Significant variability of lumber joint contact force and joint torque can be attributed to the above mentioned predictors/ variables. Three trades were considered for assessing lumber joint contact force, and lumber joint torque (i) carpenters (ii) bricklayers (iii) metal fitter and machinists (welders). A benchmark of maximal strength of the trunk/ back extensor and flexor (equivalent to lifting and lowering) has been made using an isokinetic dynamometer which allowed recording of instantaneous isokinetic torque. Job matching based on strength criteria to be beneficial.

In chapter 5, an ergonomic risk assessment framework of lifting/ lowering MH tasks has been proposed in order to assess MSD risks. The developed framework facilitates the MSD risk analysis process which are suitable for wide range of age, industries and occupations. Framework provides a variety of information describing risk factors and its impact on musculoskeletal problems/ disorders. This framework includes a range of body part's MSD risk assessment and provides risk ratings and scores for the combined effect of the risk factors. This will identify severity and the source of risks, and provide more integrated information for lifting/ lowering task designing decision making.

This research has applied ergonomic principles. Models and framework developed in this research is of benefit to the researchers, academic body of knowledge, and design the job to make fit to the workers.

6.2. Recommendation for further research

This research focused on aging workforce and considered only physical factors. The psychological and psychosocial risk factors that might influence MSDs are not considered in this research. Future research might explore those factors and their influences on MSDs.

Muscle fatigue from challenging tasks could be prevented and mitigate with suitable recovery periods. Hence future research should include recovery time as a parameter in predictions or ergonomic risk assessment. Also, other factors such as light and temperature may be explored.

Based on this research an ergonomic risk assessment framework has been developed. Further study can be carried out to evaluate how well this proposed framework can access ergonomic risks in manufacturing and construction industry when workers perform lifting/ lowering related manual handling tasks. The proposed framework can be evaluated/ validated with respect to the existing musculoskeletal disorder (MSD) risk assessment tool such as,

- Ovako Working Posture Analysis System (OWAS)
- Quick Exposure Check (QEC)
- Upper Extremity Risk Assessment Tools

- Occupational Repetitive Actions (OCRA)
- Rapid Upper Limb Assessment (RULA)
- Revised Strain Index (SI)
- Revised NIOSH Lifting Equation(RNLE)

6.3. Limitations of the study

The following limitations of the study have been explicitly addressed in this chapter 6, section 6.3.

- This research did not consider combined effect of individual particulars such as, combined effect of medical condition, physical ability, and pharmacology.
- Lifting/ lowering object characteristics was not considered in this research.
- Weather condition such as temperature and humidity were not considered in this research.

It has been found that physical factors are mainly responsible for musculoskeletal disorders from lifting/ lowering manual handling tasks, hence the above mentioned factors were not considered.

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APPENDICES

Appendix A. Global trend of aging population

Populations are aging, which enables increasing number of elderly people in the society. In the twenty-first century, the issues of this increasing demographic trend have been intensified all over the world. In Australia, aging population is increasing. In this country life expectancy is around 81 to 85 years (Australian Bureau of Statistics 2014). It is forecasted that the percentage of the population (65 years or older) will have increased from 14% to 24% between 2010 and 2050. Number of population aged 60 and above in 2016 is 137,853. Projected population age 60 and above in 2045 is 207,920. Figure A.1 shows current and projected population in Australia.

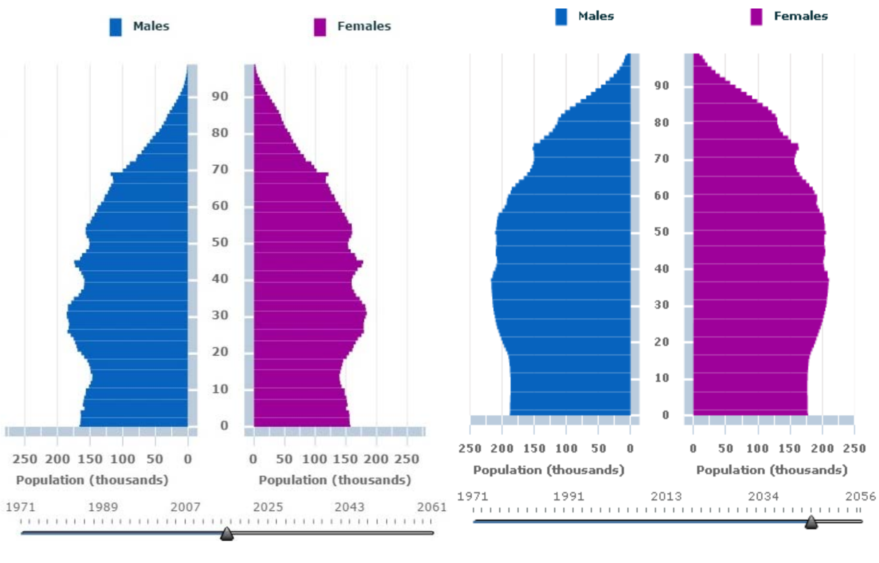

Figure A.1 Growing aged population in Australia

Figure A.2 shows growing aged population (age 60 – 79 years) over last 35 years' period from 1981 to 2015 in some developed countries (United Nations 2015). In the next 30 to 35 years, it is expected that in the developed countries, the life expectancy will be 83 years, and in the developing countries 75 years (United Nations 2015). Therefore, most of the countries of the world will face growing number of aging population. For example, in the European Union (EU), the demography in the labour force has been changing for last 40 years. In 1980, the proportion of 50-60 years old and 20-30 years old workers in EU was 26% for both of the age group. 30 years later in 2010, 30% of the worker's age was 50-60 years. On the other, only 15% of workers were in the age of 20-30 years. It is forecasted that in next 30 years 50-60 years old workers will be twice as many workers in the age group of 20-30 years in EU (United Nations 2015).In many areas and trades, more aged workforce is available compared to the younger. As this situation will continue, managing between work and aging is critical.

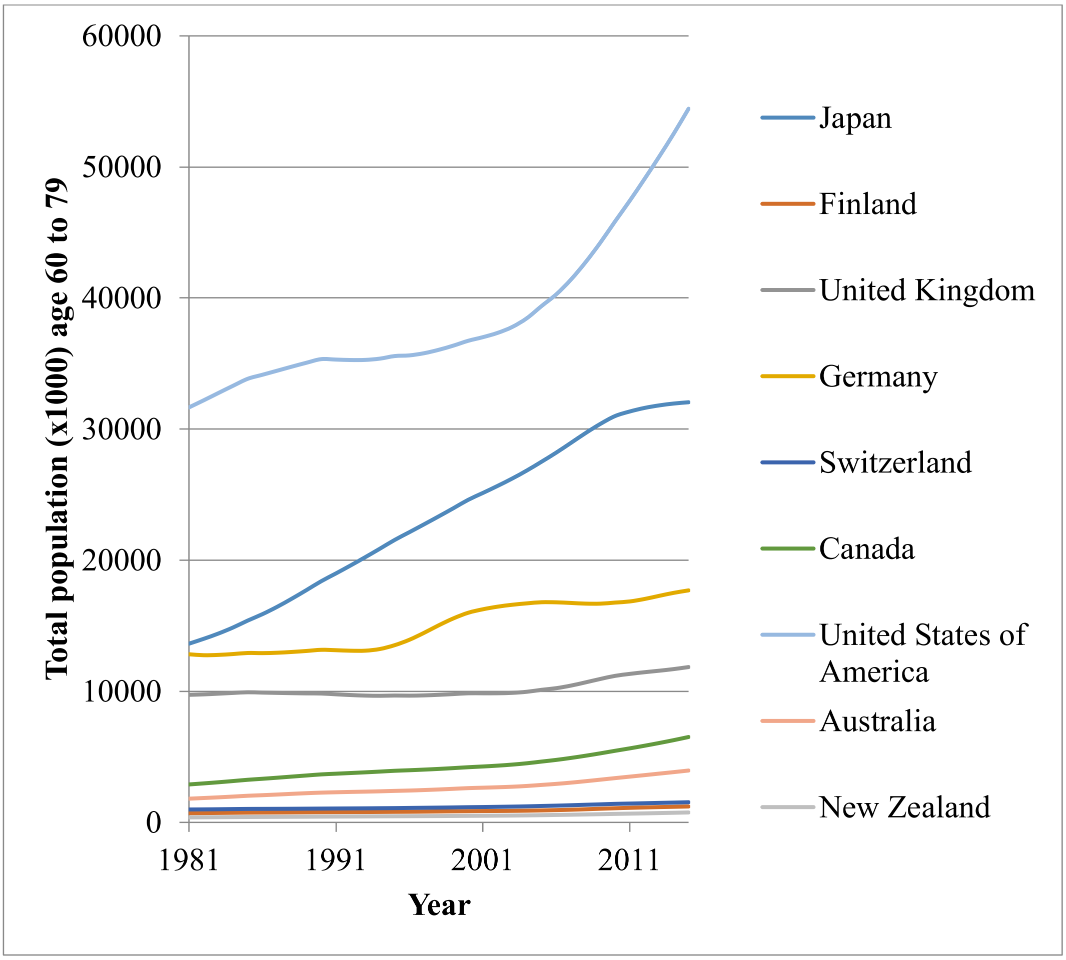

Figure A.2 Growing aged population (age 60 – 79 years) over last 35 years, data extracted from United Nations (2015)

Appendix B. Part of the questionnaire

Section A: Respondent Background

Please provide following details of yourself

1. Height __________cm

2. Weight __________kg

3. Age (years)

   ☐ Less than 40
   ☐ 40 to 59
   ☐ 60 and above

4. Gender

   ☐ Male

   ☐ Female

5. Race

   ☐ Oceanian
   ☐ North-West European
   ☐ Southern and Eastern European
   ☐ North African and Middle-Eastern
   ☐ South-East Asian
   ☐ North-East Asian
   ☐ Southern and Central Asian
   ☐ People of the Americas
   ☐ Sub-Saharan African

6. Current/ recent industry

   ☐ Manufacturing

   ☐ Construction

   ☐ Other ____________________

7. Current/ recent occupation

☐ Structural steel and welding tradesperson
☐ Bricklayer
☐ Metal fitter and machinist
☐ Carpentry and joinery tradesperson
☐ Plumber
☐ Wall and floor tiler/ stonemason
☐ Roof slater and tiler
☐ Plasterer
☐ Motor mechanic
☐ Other ____________________

8. Experience in this occupation _____years

Section B: Physical Ability for Manual Handling Tasks

Please provide your perceptions regarding following physical abilities for manual handling tasks in your current/ recent occupation

	Very poor	*Poor*	*Moderate*	*Good*	*Very good*
1. Your ability to use your hand and arm, for example to grasp, manipulate, or assemble objects.	☐	☐	☐	☐	☐
2. Your ability to perform manual handling tasks such as lifting and carrying objects.	☐	☐	☐	☐	☐
3. Your ability to perform the manual handling tasks repeatedly or continuously over time.	☐	☐	☐	☐	☐
4. Your ability to safely use your trunk to support the manual handling tasks.	☐	☐	☐	☐	☐
5. Your ability to bend, stretch, twist, or reach with your body, arms, and/or legs.	☐	☐	☐	☐	☐
6. Your ability to keep or regain your body balance or stay upright during manual handling tasks.	☐	☐	☐	☐	☐
7. Your ability to exert physically without getting winded or out of breath.	☐	☐	☐	☐	☐

8. Your ability to keep your hand and arm steady while performing manual handing tasks.	☐	☐	☐	☐	☐
9. Your ability to perform coordinated movements of the fingers of one or both hands, for example to grasp, manipulate or assemble small objects.	☐	☐	☐	☐	☐
10. Your ability to coordinate your limbs (for example, two arms, two legs, or one leg and one arm) while performing manual handling tasks.	☐	☐	☐	☐	☐

Section G: *Musculoskeletal disorder symptoms and conditions*

1. Please provide your responses regarding occurrence of any muscle and/ or bone related problems (i.e. musculoskeletal disorders) in recent 12 months

Body part	***Occurrence of musculoskeletal problems/ disorders***		
	Nil	***Sometimes (Acute)***	***Regular (Chronic)***
Neck	☐	☐	☐
Left shoulder	☐	☐	☐
Right shoulder	☐	☐	☐
Upper back	☐	☐	☐
Lower back	☐	☐	☐
Left upper arm	☐	☐	☐
Right upper arm	☐	☐	☐
Left wrist	☐	☐	☐
Right wrist	☐	☐	☐
Left knee	☐	☐	☐
Right knee	☐	☐	☐

Appendix C. Relationships between predictor and predicted variables

Table A.1 Correlation between lifting repetition and physical discomfort for all age group (N = 648)

Repetition of lifting	Physical discomfort							
	All age		Age <40y		40-60y age		Age>60y	
	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.
Less than 5kg	.216**	.000	.472**	.000	.796**	.000	.228**	.000
6 to 10kg	.198**	.000	.725**	.000	.776**	.000	.271**	.000
11 to 15kg	.142**	.000	.256**	.000	.431**	.000	.155*	.013
16 to 20kg	.314**	.000	.690**	.000	.674**	.000	.234**	.000

**. Correlation is significant at the 0.01 level (1-tailed).

Table A.2 Correlation between lifting repetition of lifting to an extent and physical discomfort from lifting for all age group (N = 648)

Repetition of lifting to an extent	Physical discomfort							
	All age		Age <40y		40-60y age		Age>60y	
	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.
Floor to knuckle	-.004	.464	.055	.209	.592**	.000	.116*	.040
Knuckle to chest	.526**	.000	.677**	.000	.707**	.000	.189**	.002
Chest to shoulder	.151**	.000	.545**	.000	.551**	.000	-.155	.231
Above shoulder	.095**	.000	-.036	.301	.514**	.001	.245**	.000

*. Correlation is significant at the 0.05 level (1-tailed). **. Correlation is significant at the 0.01 level (1-tailed).

Table A.3 Relationship between (i) physical discomfort from repetition of lifting, and from repetiton of lifting to an extent; and (ii) upper back musculoskeletal disorders by age groups

Discomfort from repetition and extent of lifting	Occurrences of upper back MSD							
	All (N = 617)		< 40 (N = 215)		40-60 (N = 199)		> 60 (N = 203)	
	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.
Less than 5kg	.336**	.000	.397**	.000	.708**	.000	-.169	.108
6 to 10kg	.612**	.000	.412**	.000	.764**	.000	-.056	.212
11 to 15kg	.523**	.000	.354**	.000	.697**	.000	-.083	.119
16 to 20kg	.557**	.000	.370**	.000	.678**	.000	-.113	.054
Floor to knuckle	.421**	.000	.194**	.002	.349**	.000	.238**	.000
Knuckle to chest	.621**	.000	.347**	.000	.655**	.000	-.017	.402
Chest to shoulder	.417**	.000	.244**	.000	.330**	.000	.232**	.000
Above shoulder	.438**	.000	-.091	.092	.416**	.000	.190**	.003

**. Correlation is significant at the 0.01 level (1-tailed).

Table A.4 Relationship between (i) physical discomfort from repetition of lifting, and from repetiton of lifting to an extent; and (ii) lower back musculoskeletal disorders by age groups

Discomfort from repetition and extent of lifting	Occurrences of lower back MSD							
	All (N = 624)		< 40 (N = 216)		40-60 (N = 201)		> 60 (N = 207)	
	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.
Less than 5kg	.446**	.000	.138*	.022	.772**	.000	-.011	.435
6 to 10kg	.412**	.000	.291**	.000	.712**	.000	.070	.158
11 to 15kg	.446**	.000	.582**	.000	.739**	.000	.078*	.001
16 to 20kg	.459**	.000	.866**	.000	.654**	.000	.065**	.000
Floor to knuckle	.326**	.000	-.048	.241	.320**	.000	-.032	.324
Knuckle to chest	.306**	.000	-.122*	.036	.492**	.000	.105	.066
Chest to shoulder	.153**	.000	.190**	.003	.459**	.001	.077*	.045
Above shoulder	.337**	.000	.352**	.000	.506**	.000	.055*	.032

*. Correlation is significant at the 0.05 level (1-tailed). **. Correlation is significant at the 0.01 level (1-tailed).

Table A.5 Relationship between back posture repetition and physical discomfort

Back posture angle (degrees)	Physical discomfort (nil, slight, moderate, high, very high) by age group							
	All age		<40		40-60		>60	
	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.
Less than 20	.014	.362	.155*	.011	.682**	.000	.115*	.041
20 to 60	.086*	.014	.489**	.000	.425**	.000	.017	.401
More than 60	.012	.385	.235**	.000	.130*	.033	.052	.217

*. Correlation is significant at the 0.05 level (1-tailed). **. Correlation is significant at the 0.01 level (1-tailed).

Table A.6 Relationship between back posture duration and physical discomfort

Back posture angle (degrees)	Physical discomfort (nil, slight, moderate, high, very high) by age group							
	All age		<40		40-60		>60	
	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.
Less than 20	.021	.298	.581**	.000	.665**	.078	.004	.479
20 to 60	.181**	.000	.354**	.000	.414**	.001	-.071	.142
More than 60	.205**	.000	.227**	.000	.384**	.000	.275**	.000

**. Correlation is significant at the 0.01 level (1-tailed).

Table A.7 Relationship between physical discomfort from back posture repetition and duration; and upper back MSD by age groups

Frequency/ duration	Back posture angle (degrees)	Occurrences of upper back MSD							
		All (N = 617)		< 40 (N = 215)		40-60 (N = 199)		> 60 (N = 203)	
		Coef.	Sig.	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.
Repetition requirement	Less than 20	.349**	.000	.131*	.027	.327**	.000	.155*	.013
	20 to 60	.449**	.000	.469**	.000	.494**	.000	.126*	.036
	More than 60	.340**	.000	.330**	.000	.302**	.000	.192**	.003
Duration requirement	Less than 20	.540**	.000	.788**	.000	.356**	.015	.162*	.010
	20 to 60	.376**	.000	.361**	.000	.332**	.027	.137*	.025
	More than 60	.322**	.000	-.006	.463	.394**	.000	.138*	.024

*. Correlation is significant at the 0.05 level (1-tailed). **. Correlation is significant at the 0.01 level (1-tailed).

Table A.8 Relationship between physical discomfort from back posture repetition and duration; and lower back MSD by age groups

Frequency/ duration	Back posture angle (degrees)	Occurrences of lower back MSD							
		All (N = 624)		< 40 (N = 216)		40-60 (N = 201)		> 60 (N = 207)	
		Coef.	Sig.	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.
Repetition requirement	Less than 20	.225**	.000	-.060	.191	.357**	.000	.085	.113
	20 to 60	.383**	.000	.649**	.000	.379**	.000	.045	.262
	More than 60	.336**	.000	.687**	.000	.409**	.000	.093	.091
Duration requirement	Less than 20	.207**	000	.198**	.002	.442**	.000	.010	.441
	20 to 60	.174**	.000	.532**	.000	.369**	.008	.048	.247
	More than 60	.159**	.000	.643**	.000	.480**	.005	.062	.188

**. Correlation is significant at the 0.01 level (1-tailed).

Table A.9 Relationship between exposure from duration of vibration and physical discomfort by age groups

Duration of vibration from	Physical discomfort of vibration			
	All (N = 648)	< 40 (N = 217)	40-60 (N = 203)	> 60 (N = 228)
	Coef. (sig.)	Coef. (sig.)	Coef. (sig.)	Coef. (sig.)
Surface	.613** (.000)	.790** (.000)	.627** (.000)	.290** (.000)
Hand tools	.464** (.000)	.210** (.001)	.845** (.000)	.227** (.000)

*. Correlation is significant at the 0.05 level (1-tailed). **. Correlation is significant at the 0.01 level (1-tailed).

Table A.10 Relationship between physical discomfort from duration of vibration and back MSD by age

Duration of vibration from	Back musculoskeletal disorder							
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
	All (N = 648)		< 40 (N = 217)		40-60 (N = 203)		> 60 (N = 228)	
	Coef. (sig.)		Coef. (sig.)		Coef. (sig.)		Coef. (sig.)	
Surface	.541** (.000)	.309** (.000)	.455** (.000)	.273** (.000)	.663** (.000)	.536 (.043)	.170** (.008)	.028 (.345)
Hand tools	.300** (.000)	-.037 (.178)	.331** (.000)	.160** (.009)	.600** (.000)	.733** (.000)	-.046 (.260)	-.104 (.068)

**. Correlation is significant at the 0.01 level (1-tailed).

Appendix D. Evidence of ethics approved

Dear Dr Ekambaram,

SHR Project 2015/138 – A framework for manual handling job design to ensure musculoskeletal safety of aged workers

A/Prof. Palaneeswaran Ekambaram, Azizur Rahman (Student), Dr Ambarish Kulkarni - FSET

Approved duration: 06-01-2016 to 05-01-2018 [adjusted]

I refer to the ethical review of the above project by a Subcommittee (SHESC2) of Swinburne's Human Research Ethics Committee (SUHREC). Your responses to the review as emailed on 05 January 2015 were put to the Subcommittee delegate for consideration.

I am pleased to advise that, as submitted to date, ethics clearance has been given for the above project to proceed in line with standard on-going ethics clearance conditions outlined below.

- All human research activity undertaken under Swinburne auspices must conform to Swinburne and external regulatory standards, including the *National Statement on Ethical Conduct in Human Research* and with respect to secure data use, retention and disposal.

- The named Swinburne Chief Investigator/Supervisor remains responsible for any personnel appointed to or associated with the project being made aware of ethics clearance conditions, including research and consent procedures or instruments approved. Any change in chief investigator/supervisor requires timely notification and SUHREC endorsement.

- The above project has been approved as submitted for ethical review by or on behalf of SUHREC. Amendments to approved procedures or instruments ordinarily require prior ethical appraisal/clearance. SUHREC must be notified immediately or as soon as possible thereafter of (a) any serious or unexpected adverse effects on participants and any redress measures; (b) proposed changes in protocols; and (c) unforeseen events which might affect continued ethical acceptability of the project.

- At a minimum, an annual report on the progress of the project is required as well as at the conclusion (or abandonment) of the project. Information on project monitoring and variations/additions, self-audits and progress reports can be found on the Research Intranet pages.

- A duly authorised external or internal audit of the project may be undertaken at any time.

Please contact the Research Ethics Office if you have any queries about on-going ethics clearance, citing the Swinburne project number. A copy of this email should be retained as part of project record-keeping.

Best wishes for the project.

Yours sincerely,

Astrid Nordmann

SHESC2 Secretary

Appendix E. Declaration on ethics

I hereby providing a statement that all conditions pertaining to the clearance were properly met, and that annual/ final reports will be submitted on time.

Appendix F. Ground reaction force

Figure A.3 Figure shows the ground reaction force of board lifting.

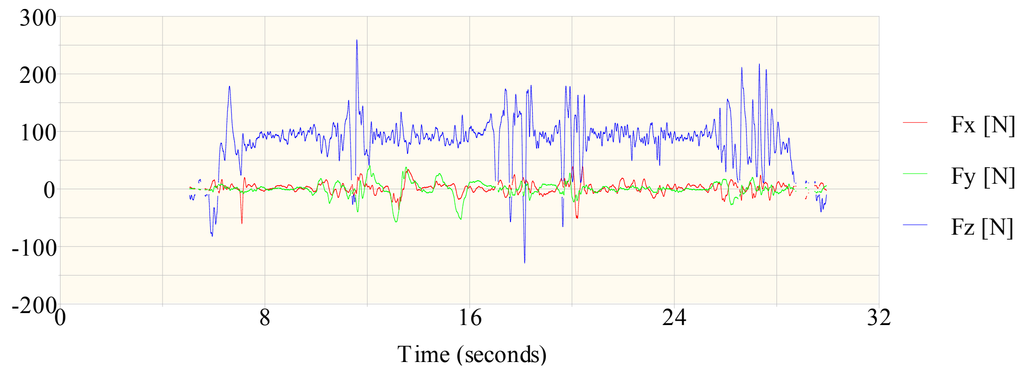

Figure A.3 Ground Reaction Force (GRF) diagram of board (plywood) lifting task

As the thrust of the nail gun was opposing to the ground reaction force, negative ground reaction force was observed in the Figure A.4.

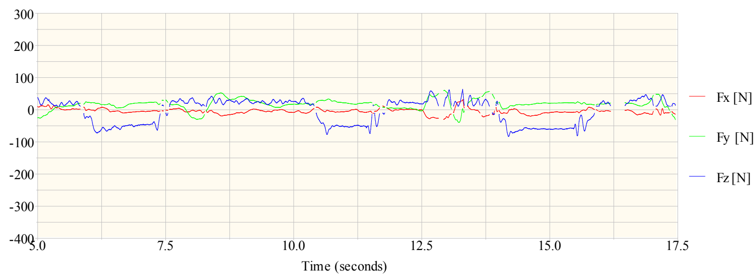

Figure A.4 GRF diagram of nailing with nail gun at or above waist level

High and low pick of ground reaction force (Figure A.5: toward z-axis) indicates the change of position during hammering. All other small picks (between 4 and 14 seconds, 18 and 22 seconds) towards positive and negative z-axis are the result of hammering. From 4 to 14 seconds performer nailed at chest level. From 18 to 22 seconds performer nailed below waist level.

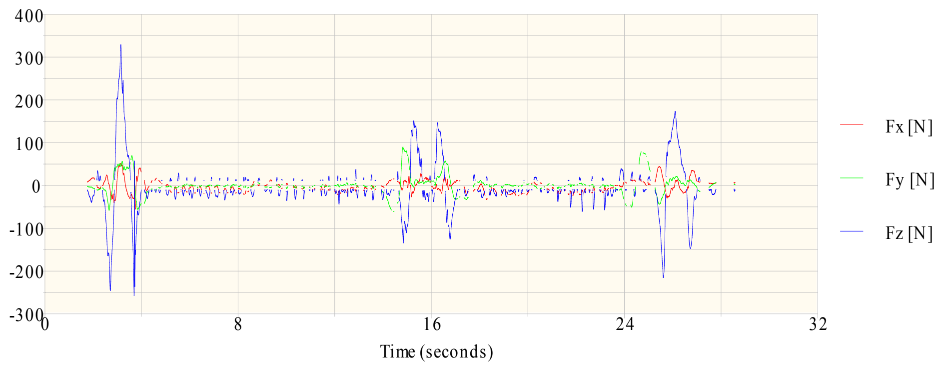

Figure A.5 GRF diagram of nailing using hammer at waist height, chest height, and above shoulder height

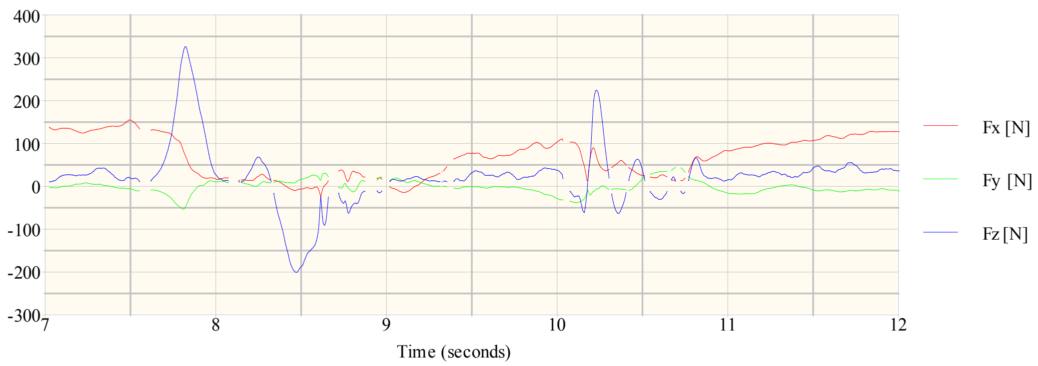

Figure A.6 GRF diagram of bricklayers during activity 1

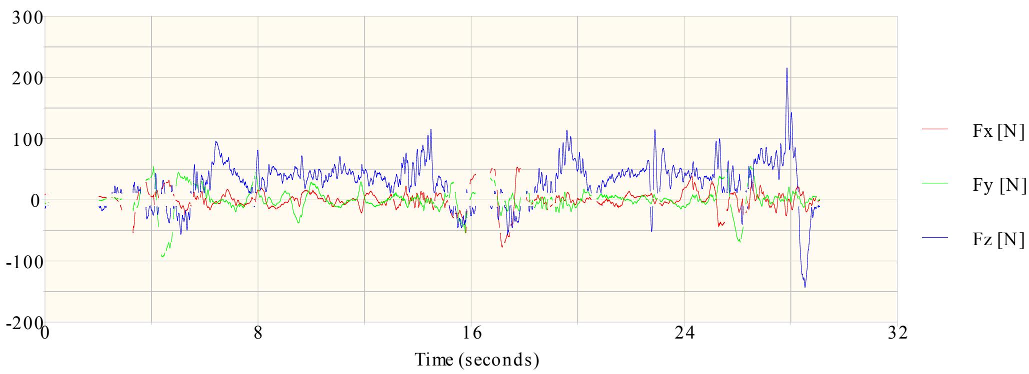

Figure A.7 GRF diagram of bricklayers during activity 2

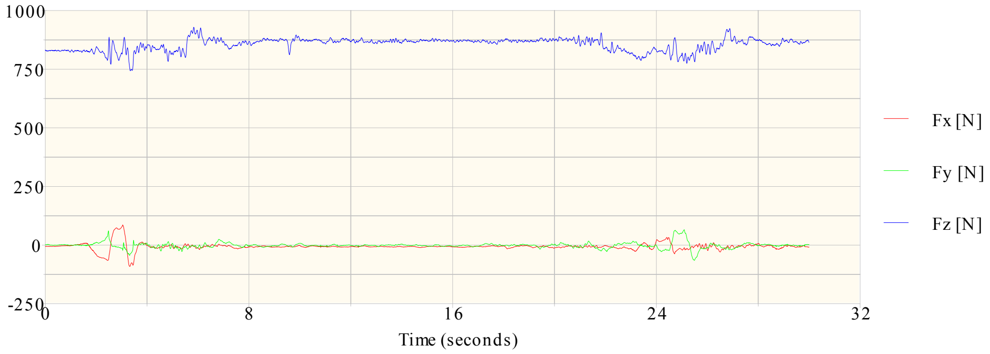

Figure A.8 GRF diagram of bricklayers during activity 3

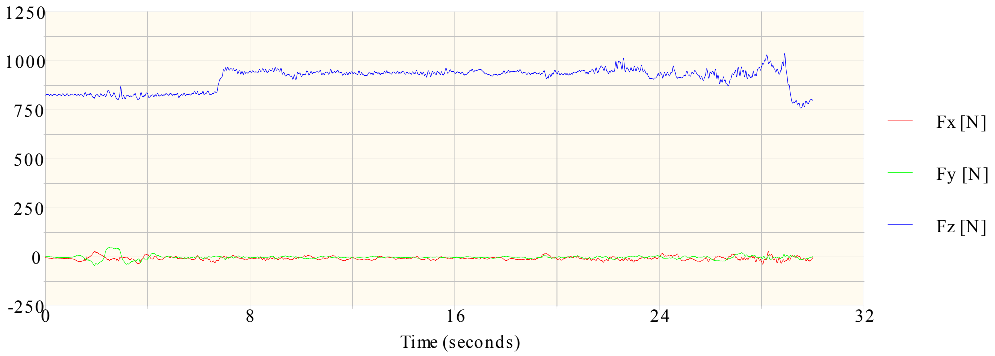

Figure A.9 GRF diagram of metal fitter and machinists during loading and unloading gas bottles on trolley phase 1

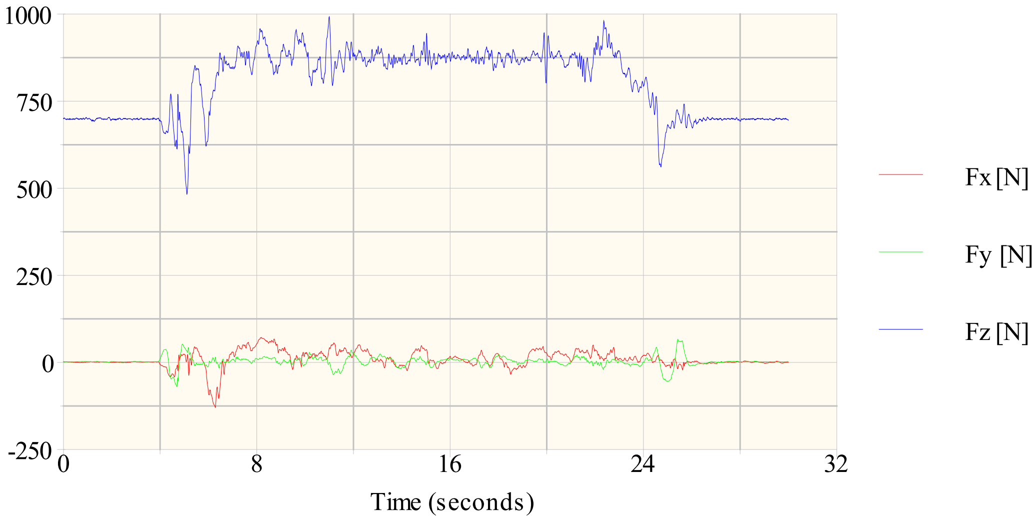

Figure A.10 GRF diagram of metal fitter and machinists during loading and unloading gas bottles on trolley phase 2

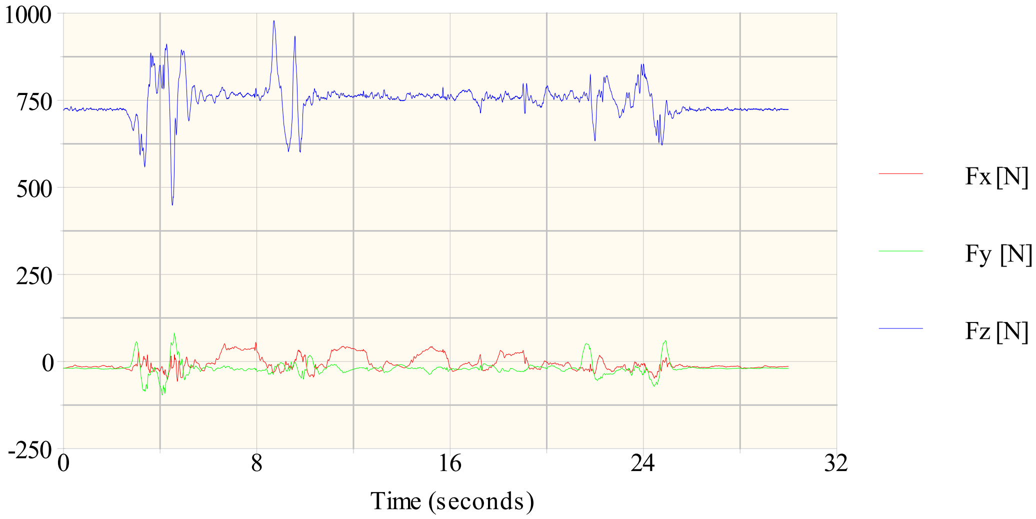

Figure A.11 GRF diagram of metal fitter and machinists during loading and unloading gas bottles on trolley phase 3

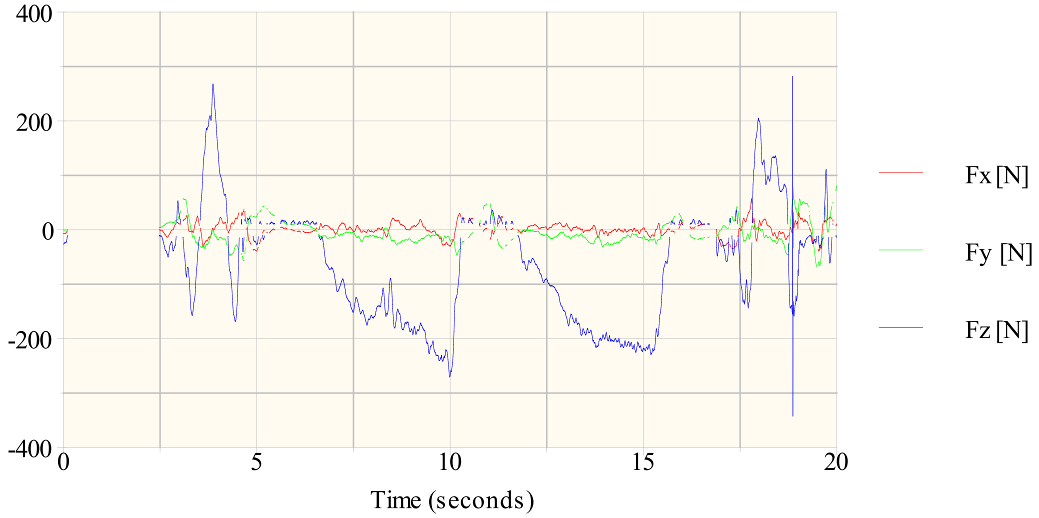

Figure A.12 GRF diagram of metal fitter and machinists during lifting of weldign gun and paren materials from floor

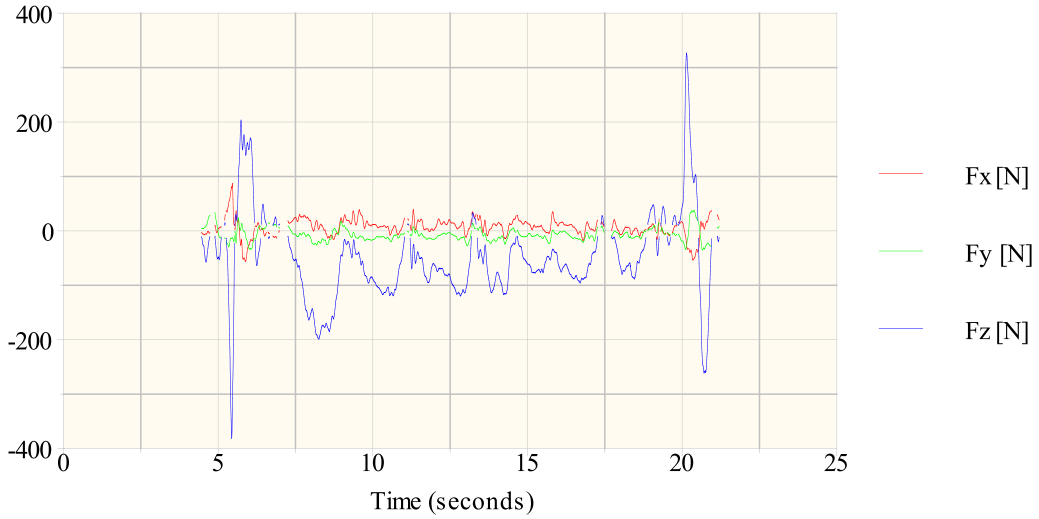

Figure A.13 GRF diagram of metal fitter and machinists during frequent lifting of weldign gun and paren materials from floor

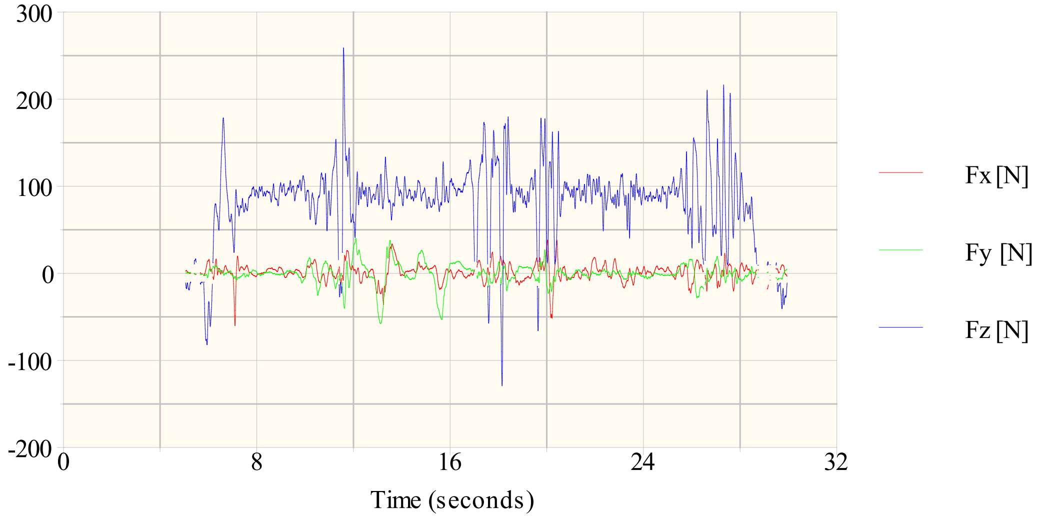

Figure A.14 GRF diagram of metal fitter and machinists during welding in reaching and forward bending pose

Appendix G. Body parameters and centre of gravity

In biomechanical modelling the force and moments on the lower back, shoulders and wrists were calculated. This calculation was applied to all postures in a cycle of task. The gravity is one of the most consistent and influential forces that the human body encounters in posture and movement. It is therefore the force and moment on the human joints is depending on the mass of the body. Based on C. Meeh's body mass parameter (Drillis, Contini and Bluestenin 1964) and total mass of the subject, the mass of the subject's segment was calculated (Hanson et al. 2009). Figure A.15 shows the body segments of the body and its number. Table A.11 shows the calculation of the segments mass of subject body.

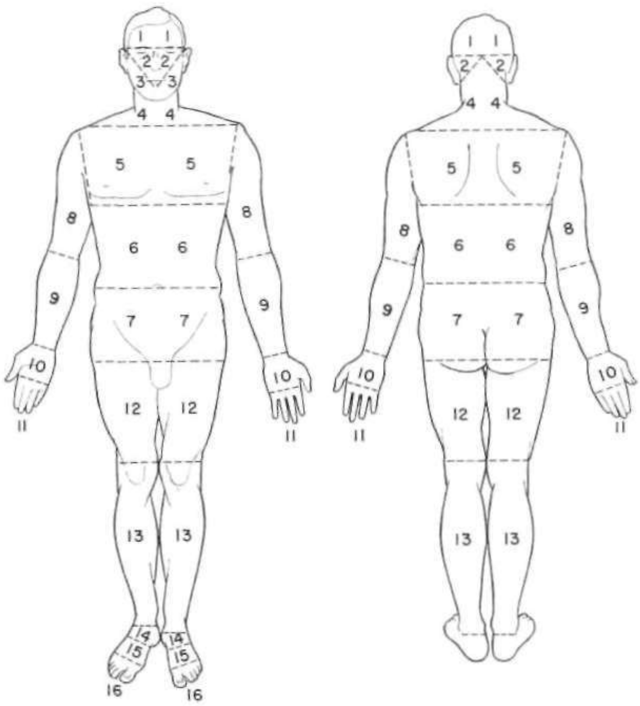

Figure A.15 Number Represents the Body Parts

Table A.11 Body Parameter of the Subject (Base on C. Meeh's body parameter) (Drillis, Contini and Bluestenin 1964)

Segment	***Males (8 Subjects)***		***Segment Parameter of the subject (Kg)***	
Cranium (1) and Upper Jaw (2)	71.64		6.09	
Low Jaw (3) and Neck (4)	38.32		3.26	
Head and Neck (1+2+3+4)		109.96		9.35
Chest (5)	186.1		15.82	
Abdomen (6)	137.47		11.68	
Pelvis (7)	182.95		15.55	
Whole Truck (5+6+7)		506.52		43.05
Upoer Arm (8)	28.04		2.38	
Forearm (9)	14.9		1.27	
Palm and Thumb (10)	5.2		0.44	
The Four Fingers (11)	1.95		0.17	
The whole Hand (10+11)	7.15		0.61	
Both Upper Extremities		100.18		8.52
Thigh (12)	81.63		6.94	
Shank (13)	43.56		3.70	
Base of Foot (14) *Middle Foot (15)*	13.77		1.17	
The five Toes (16)	2.7		0.23	
The whole Food (14+15+16)	16.47		1.40	
Both Lower Extremities		283.32		24.08
Total Body		1000		85

The gravity force of segments is acting on the point of application at the centre of gravity (CoG) of that object or section. Figure A.16 shows the location of mass centres of body segment. According to this figure and the subject body length, the centre of mass (CoM) of the subject was calculated. Figure A.17 shows the location of mass centres of subject's body segment.

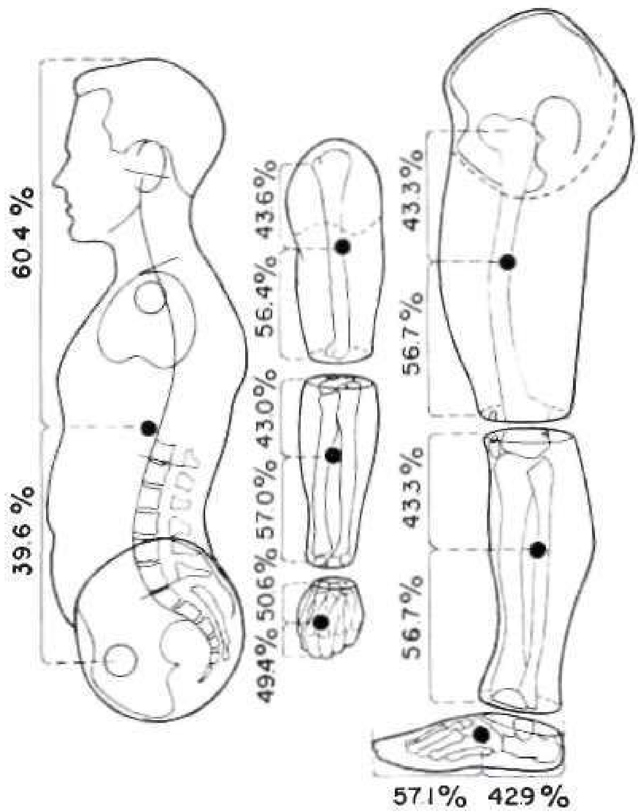

Figure A.16 Location of mass centres of body segments

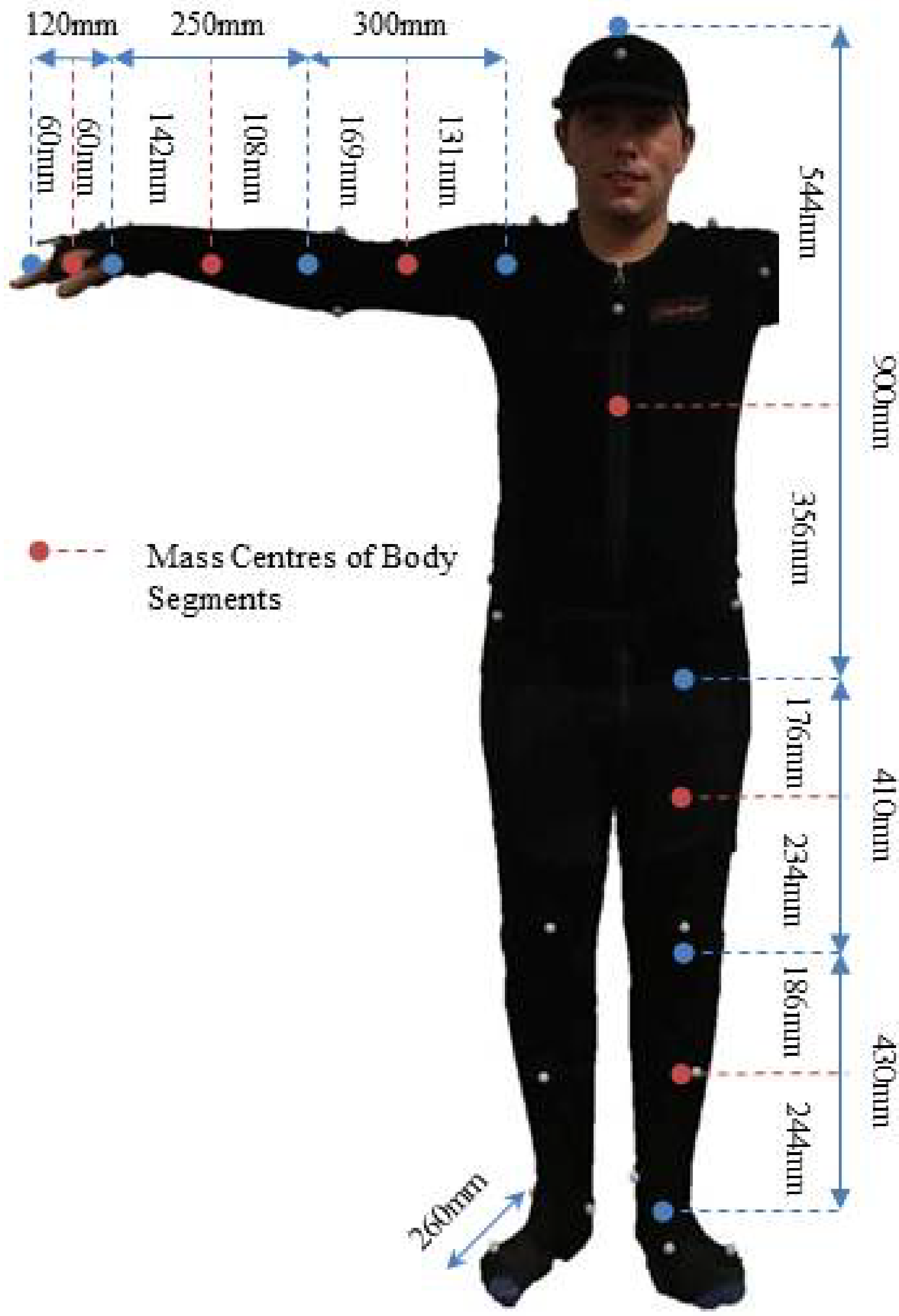

Figure A.17 Location of mass centres of subject's body segments

Appendix H. List of publications

Published:

Rahman, A, Palaneeswaran, E, Kulkarni, A and Patrick Zou. 2015, 'Musculoskeletal Health and Safety of Aged Workers in Manual Handling Works,' International Conference on Industrial Engineering and Operations Management, Dubai, United Arab Emirates (UAE), March 3 – 5, 2015.

Rahman, A, Palaneeswaran, E and Kulkarni, A. 2015, 'Virtual Reality Based Ergonomic Risk Evaluation of Welding Tasks', Proceedings 19th Triennial Congress of the IEA, Melbourne 9-14 August 2015.

Under review:

Rahman, A and Palaneeswaran, E. 2016, 'Modelling Back Problems from Lifting and Lowering Tasks in Australian Construction Industry', Int. J. Environ. Res. Public Health 2016, 13, x; doi: FOR PEER REVIEW, ww.mdpi.com/journal/ijerph

Draft ready:

Effect of Physical and Environmental Risk Factors on Metal Fitter and Machinist's Lower Back Problems from Lifting Lowering Tasks

Modelling Carpenters and Joiners Back and shoulder Problems from Lifting Lowering Tasks in Australian Construction Industry

Modelling Bricklayers Back Problems from Lifting Lowering Tasks in Australian Construction Industry

Appendix I. Lumber joints

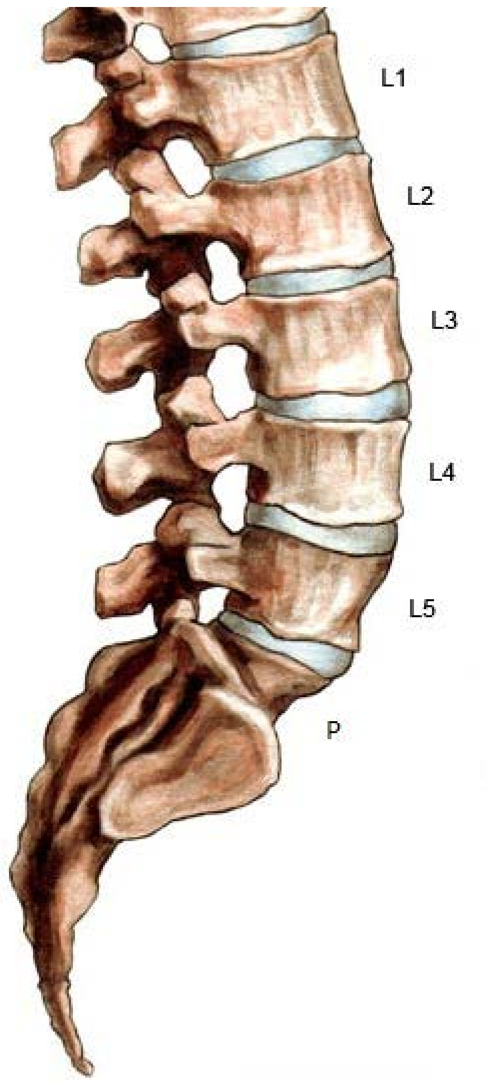

Figure A.18 Lumber joints