The Effects of Worker Age on Lifting: Psychophysical Estimates of Acceptable Loads and Their Link to Biomechanics

by

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Introduction: Canada's workforce, as well as many other countries, is continuing to age as the baby boomer generation (those born between 1946 and 1964) ages and are remaining in the workforce longer. The number of older workers is estimated to double within the next 10 years (Perry 2010). With increased age, there are a number of factors that could influence worker performance and risk of injury. For example, aging is associated with decreased strength and cardiovascular fitness. However, it is unknown whether a worker's estimates of how much they can safely lift (based on an approach called psychophysics, which is often used in the design of manual materials handling tasks) is lower for older compared to younger workers. The primary goal of this thesis was to test the hypothesis that psychophysical estimates of maximum acceptable forces would be lower for older workers than younger workers during selected lifting tasks. The secondary goal was to measure a host of variables to provide insights into what factors (e.g. kinematic, strength, cardiovascular) might be influencing potential age-related differences.

Methods: The experimental testing protocol used a psychophysical approach to identify the maximum acceptable mass of an object during several lifting tasks. Participants comprised a total of 24 female workers (12 older (50+ years old) and 12 younger (20-30 years old)). The primary outcome of interest was the maximum acceptable weight of lift (MAWL) for an 8 hour work day that would allow each participant to 'work as hard as they can without straining themselves, or becoming unusually tired, weakened, overheated, or out of breath' (Snook and Ciriello 1991). The participants completed four lifting tasks: floor-to-knuckle height (1 lift/9s and 1 lift/2 min) and knuckle-to-shoulder height (1 lift/2 min and 1 lift/8 hr) by adding or removing lead shot to a lifting box. Tasks were 30 minute in duration; participants could adjust the load mass at any time during the trial. The dependent variables collected were the MAWL (the load mass at the end of the trial), maximum sagittal plane joint angles of the shoulder, hip and knee, overall and body part specific ratings of perceived exertion, and heart rate.

Results: Older workers selected MAWL values that were significantly lower (by approximately 24%) than their younger counterparts. These age-related differences were more prevalent for tasks which were constrained by strength (i.e. low frequency) compared to those with large cardiovascular requirements (i.e. high frequency). The only significant difference in the sagittal plane joint flexion

angle was for the right hip during the 1 lift/2 min from floor-to-knuckle height lifting task, characterized by 34.4 degree decrease hip angle (more flexed) for the older workers. There were also no significant age-related differences in overall ratings of perceived exertion. The only body part-specific rating of perceived exertion with a significant age-related difference was for the knees, with the younger workers reporting the tasks more taxing on this joint than the older workers. Although there were no age-related differences in absolute heart rate values, the older workers were at a significantly higher percentage of their maximum heart rate.

Discussion: The results of this work suggest there is value in continued research probing whether current ergonomic and work design guidelines need to be updated to accommodate the aging working population. According to the results presented in this study, the current approaches often employed during the design of manual materials handling tasks (i.e. incorporating the loads that 75% of females could perform based on the Snook and Ciriello tables (1991) may not be sufficiently protective for older female workers in the workplace.

Keywords: load limits; older and younger workers; psychophysical evaluation; physical capacity; manual material handling; aging

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List of Acronyms

Bureau of Labour Statistics – BLS

Lactate Dehydrogenase – LDH

Heart Rate - HR

Manual Materials Handling – MMH

Musculoskeletal Disorders – MSDs

Workplace Safety and Insurance Board - WSIB

Maximal Acceptable Weight of Lift – MAWL

Rapid Upper Limb Assessment – RULA

Upper Limb Disorders - ULD

National Institute for Occupational Safety and Health – NIOSH

3D Static Strength Prediction Program – 3D SSPP

Rating of Perceived Exertion – RPE

Category Rating Scale – CR-10

Maximal Acceptable Static Load – MASL

Maximum Acceptable Weights - MAWs

Chapter 1

Thesis Overview

As the baby boomers (those born between 1946 and 1964) continue to age, there is a shift in the working population towards retirement age. Although the majority of the population will be within the retirement age category, many of them are choosing to remain in the workforce. As the lifespan of the population has been increasing, the motivation to continue to work in order to pay for a comfortable retirement also increases (Statistics Canada 2010). The number of older workers is estimated to double within the next 10 years (Perry 2010). These baby boomers are either maintaining full-time work or finding part-time work, and the number of retirees re-entering the workforce is increasing (Finch and Robinson 2003).

Even though we know that older workers will be staying in the workforce longer and that a greater proportion of the workforce will be comprised of older workers, little is known about their ability to remain in the workforce with the same productivity and safety. There are several questions about the aging workforce in terms of their risk of injury, value of experience, ability to return to work following an injury, work capacity, and biomechanical differences in the way that they perform their work.

Aging occurs as a consequence of decreases in tissue structure over time, resulting in accumulation of unrepaired somatic damage (National Research Council, 1998). There have been well documented age-related changes in the cartilage, muscle, bone, and cutaneous sensation. In addition to skeletal and skeletal muscle changes, there are also changes in cardiac muscle including impaired function of the capsular endothelium and a decrease in the peripheral vasodilatory capacity (Martin, Ogawa et al. 1991). These changes have an effect on the quality of daily living for older adults. For my thesis, I looked at female workers (young and older) as they are the limiting population within the manual materials handling field (Snook and Ciriello 1991) and as shown by Breslin and Koehoorn et al (2003), older females were found to have the highest claim rates in comparison to adolescents and young adults.

Many industries (service and manufacturing) involve MMH, which is a contributor to compensable injuries. Some of the tasks involved in MMH include lifting, lowering, pushing, pulling, carrying and holding materials (Dempsey 1998). As an initial study to probe if a difference exists between older and younger female workers, the focus of my thesis was on the biomechanical and psychophysical evaluation of lifting. In general, when looking at the biomechanical approach during lifting tasks, ergonomists and researchers are interested in the tissue tolerance limits. Specifically, some ergonomists are interested in compression limits of intervertebral discs and moments at the individual joints as they can be compared to population strength data.

The purpose of my thesis was to test the hypothesis that psychophysical estimates of maximum acceptable weight of lifts (*MAWL*) would differ across young and older workers during selected lifting tasks, and that these differences are linked to variations in biomechanical indices of lifting strategies across age groups. My primary hypothesis is that:

1. There will be age-related differences in *MAWL* across tasks. Specifically:
    a. *MAWL* will be lower for older workers compared to younger workers. This is based on evidence which shows that aging has been associated with a loss of muscle (sarcopenia), which begins around the age of 50, decreasing at approximately 15% per decade, and then becomes more dramatic after 60 years old (Deschenes 2004)
    b. Age-related differences will be larger for lifting from knuckle-to-shoulder heights. This is based on the evidence which shows that females show a more remarkable decrease in upper limb strength from the ages of 59-69 years old, and a decrease in lower limb strength from 70 years and older (Calmels, Vico et al. 1995).
    c. Age-related differences will be larger for lifting at slower frequencies (strength tasks). This hypothesis is based on the evidence which suggests while dynamic strength tests have found decreases for older groups, no changes have been found with dynamic endurance (Larsson and Karlsson 1978). In addition, sarcopenia is most common among type II muscle fibres (fast twitch) which play a large role in diminished muscle power and strength (Deschenes 2004).

My secondary hypotheses are that:

2. Grip-strength will correlate with the *MAWL* for each task.
3. Age-related intersegmental sagittal plane biomechanical differences in lifting strategies will differ across task conditions. Specifically:
    a. In a floor-to-knuckle height lifting task, older workers will choose techniques that will increase intersegmental sagittal plane knee and hip flexion compared to younger workers. This hypothesis is based on the evidence which suggests that older workers adopt

strategies that protect the back (possibly at the expense of the knee) during lifting tasks (Puniello, McGibbon et al. 2001).

b. Age-related differences in intersegmental sagittal plane right and left knee, hip, and right shoulder angle will not be evident for knuckle-to-shoulder height lifting tasks

4. Age-related overall RPE and body part specific RPE across task conditions:

    a. Overall RPE will be the same for the older and younger workers for each task.

    b. Body part specific RPE will be higher for the upper limb RPEs during the knuckle-to-shoulder height tasks for the older workers compared to the younger workers, while the lower limb RPEs will not show any differences. This is based on evidence which shows that females show a decrease in upper limb strength from the ages of 59-69 years old, and a decrease in lower limb strength from 70 years and older (Calmels, Vico et al. 1995).

5. Following a mass perturbation, participants will be able to return to their pre-perturbation *MAWL* within a 15 min period. This is based on the fact that an adjustment time of 20 minutes has been used in several studies to determine final *MAWL* (Kim and Fernandez 1993; Marley and Fernandez 1995).

Chapter 2

General Introduction & Literature Review

2.1 The Aging Workforce

2.1.1 Scope of the Problem

In 1977, 37% of the salaried workforce was under 30 years old and only 38%, 40 years old or older, in comparison to only 22% under 30 years old and 56% over 40 years old in 2002 (Quinn and Staines 1979). Canada's workforce, as well as many other countries, is continuing to age as the baby boomer generation (those born between 1946 and 1964) ages and are remaining in the workforce longer. The number of older workers is estimated to double within the next 10 years (Perry 2010). These baby boomers are either maintaining full-time work or finding part-time work, and the number of retirees re-entering the workforce is increasing (Finch and Robinson 2003). The Bureau of Labor Statistics (BLS) predicts that the percentage of people over 55 years old in the labour force will increase to 37%, which will account for up to 20% of the total labour force in the year 2015 (2001). According to the 1996 US Census Bureau population projections, during the period from 1995 through 2030, the percentage of the American population that is 65 years of age or older and 85 years of age or older will increase by approximately 107% and 133% (Williams, Higgins et al. 2002) respectively. The percentage of the population under 65 will only increase by 21%, comparatively. By 2050, the average life expectancy will climb to 84.3 and 79.7 years for American women and men. From this, it can be deduced that there will be growing health care costs and will increase 6-fold by the year 2040 (Deschenes 2004). This would be similar to the rapid increase in healthcare costs currently in the United Kingdom (UK). Most of the healthcare costs are associated with age-related loss of skeletal muscle mass (Deschenes 2004).

Even though we know that a greater proportion of the workforce will be comprised of older workers, little is known about their ability to remain in the workforce with the same productivity and safety. There are several questions about the aging workforce in terms of their risk of injury, value of experience, ability to return to work following an injury, work capacity, and biomechanical differences in the way that they perform their work. The purpose of my thesis was to test the hypothesis that psychophysical estimates of maximum acceptable weight of lifts (*MAWL*) would differ across young and older workers during selected lifting tasks, and that these differences are linked to variations in biomechanical indices of lifting strategies across age groups.

2.1.2 Physical Capacity and Age

As a person grows older, there are several natural age-related physical changes that occur that have potential implications on functional abilities. Some of these physical changes are: muscle mass, neuronal changes, cardiovascular changes, and lung capacity changes. Functional limitations of these physical changes due to aging include vision and hearing loss, arthritis, balance and gait problems, and loss of strength and stamina.

Aging occurs as a consequence of decreases in tissue structure over time, resulting in accumulation of unrepaired somatic damage (National Research Council, 1998). There have been well documented age-related changes in the cartilage, muscle, bone, and cutaneous sensation. In addition to skeletal and skeletal muscle changes, there are also changes in cardiac muscle including impaired function of the capsular endothelium and a decrease in the peripheral vasodilatory capacity (Martin, Ogawa et al. 1991). These changes have an effect on the quality of daily living for older adults. One major age-related change that is noticeable to the aging adult, as well as those around them, are decreases in muscle power and strength.

Cross-sectional studies indicate that muscle strength reaches its peak around the age of 30 and is well maintained until 50 years old (Deschenes 2004). Aging has been associated with a loss of muscle (sarcopenia), which begins around the age of 50, decreasing at approximately 15% per decade, and then becomes more dramatic after 60 years old (Deschenes 2004). This loss of muscle is directly related to a decrease in muscle function and force. This decrease in muscle strength and power leads to a higher incidence of accidental falls and inability to maintain the ability to carry out activities of daily living (carrying laundry, garbage, groceries, etc), which can compromise the quality of life for older adults. Sarcopenia is most common among type II muscle fibres (fast twitch) and plays a large role in diminished muscle power and strength(Deschenes 2004). Muscle power loss is first evident by 40 years old and is much more evident than the decline in strength. A study done by Vaillancourt et al, found that older subjects had a slower firing rate (10Hz) than their younger counterparts (40Hz) in the hand muscles. This indicated that there are fewer fast twitch muscle fibres present within aged muscle. This was also evident when examining isolated single muscle fibres from aged and younger adults as the maximal shortening velocity was significantly less for the aged muscle fibres. Not only is there a change in the amount of power and strength generated by the muscle, but also a loss in the amount of muscle present occurs as a person ages.

Loss of muscle mass is greater in muscles of the lower limbs than for the upper limbs, and from 20 to 70 years of age, the lower limb muscle mass has decreased by approximately 25% (Janssen, Heymsfield et al. 2000). In the elderly, it has been found that fascicles are not only shorter, but also less pinnate than in the younger adults (Narici, Maganaris et al. 2003). This may be due to the decrease in contractile tissue packed along the tendon and is similar to what would be seen in disuse atrophy (Narici, Maganaris et al. 2003). This loss in muscle mass has negative effects in the amount of strength (concentric and eccentric) a person is able to produce.

When looking at concentric and eccentric strength, it has been found that aging has a smaller effect on eccentric strength (Deschenes 2004). Several studies have shown that older adults are capable of fully activating motor units during maximal voluntary contractions. While dynamic strength tests have found decreases for older groups, no changes have been found with dynamic endurance (Larsson and Karlsson 1978). This can be attributed to fibre type distribution, fibre areas and lactate dehydrogenase (LDH) isozyme activities (Larsson and Karlsson 1978). Not only are there noticeable decreases in the muscle function as a person ages, there are also noticeable decreases in joint function.

Joints have been shown to have a progressive loss of cartilage from the articular surfaces with increasing prevalence of osteoarthritis, making it painful as well as limiting mobility within the activities of daily living for older people. The deterioration of the collagen and elastic tissues also leads to a decrease in the flexibility for joints as a person ages (Perry 2010). Joints have an effect on the loss of strength, loss of balance, restricted movement, poor postures, slower reaction times, less accurate movements, increase in myofascial pain, slower recovery times, as well as an increased perception of aging and stress attributes to a loss in flexibility. As well as a decrease in joint flexibility, there is also a decrease in the load-bearing capacity as age increases, especially in the spine (Genaidy, Waly et al. 1993). In addition to skeletal muscle changes after the age of 25, there are associated progressive decreases in lung performance.

Oxygen consumption of the lungs reaches its peak between 20 and 30 years of age, and then decreases at a rate of 9% per decade (Murray 1986). This decrease is more pronounced in sedentary subjects than those who remain physically active (Mahler, Cunningham et al. 1986). Unless affected by disease, the respiratory system maintains adequate gas exchange during the entire lifespan (Janssens, Pache et al. 1999). The most important physiological changes associated with aging are a decrease in the static elastic recoil of the lung, a decrease in the compliance of the chest wall, and a decrease in the strength of respiratory muscle (Janssens, Pache et al. 1999). Factors that limit the oxygen consumption in older subjects are: reduced maximal cardiac frequency, reduced maximal cardiac output and reduced peripheral muscle mass (Janssens, Pache et al. 1999). Blood pressure changes also occur as a person ages.

While blood pressure and total peripheral resistance increase with age, it has been found that the magnitude of age related effect on blood pressure during exercise was greater in women than in men (Martin, Ogawa et al. 1991). In comparison to younger participants, it was found that diastolic blood pressure during submaximal exercise was also higher in older participants. In addition to hypertension, it has been found that congestive heart failure and other forms of cardiovascular disease increase in prevalence with age due to impaired function of the capsular endothelium and a decrease in the peripheral vasodilatory capacity (Martin, Ogawa et al. 1991). The measurement of heart rate (HR) is a tool used for assessing the autonomic input to the heart under various physical exertions (Byrne, Fleg et al. 1996). Studies involving HR have shown that there is a decrease in the vagal modulation of HR at rest as a person ages (Lipsitz, Mietus et al. 1990). Although there is a decrease in vagal modulation of the HR at rest, there is a smaller difference seen in the instantaneous HR variability during exercise. From this, it is evident that there are several age-related changes in the muscle, joints, lungs, and cardiac muscle that have an effect on the daily living of people as they age.

Physical changes as a person ages not only has an effect on activities of daily living, but it also has an effect on work capacity. Work capacity decreases as a person ages, which may lead to a disruption of the balance between work demands and work capacity (Broersen, de Zwart et al. 1996). As the differences between the work demands and work capacity for the worker increases, the worker may experience an overload, increasing the potential for health complaints and work absenteeism. In the event that this becomes long term, it could lead to disablement (Broersen, de Zwart et al. 1996). Due to the aging population, the number of workers that are unable to cope with their job demands because of health and age-related causes is likely to increase in the future. As the job demands begin to exceed a worker’s capacity, the worker may compensate by increasing physical effort or taking fewer rest periods in order to complete the task on time.

2.1.3 Age & Musculoskeletal Disorders in the Workplace

According to the World Health Organization (WHO, 1985), musculoskeletal disorders (MSDs) should be characterized as “work-related diseases” rather than “occupational diseases”. Occupational diseases are defined as diseases for which there is a direct cause-effect relationship between hazard and disease; while work-related diseases are defined as multi-factorial when the work environment and the performance of work contribute with a numerous amount of factors to the cause of the disease (WHO 1985). MSDs affect many people in a variety of occupations, involving different body regions. MSDs can be attributed to cumulative trauma disorders, repetitive trauma disorders, repetitive injuries, or overuse syndromes (Armstrong, Buckle et al. 1993). According to the 2009 Workplace Safety and Insurance Board (WSIB) statistical supplement to the 2009 annual report, bodily reaction and exertion account for almost half (46.6%) of the total lost time claims (WSIB 2009). Within this category, overexertion accounts for 22.3% and repetitive motion accounts for 4.9% of the total lost time claims in 2009 (WSIB 2009). Back pain is one of the most expensive health care problems amongst working adults (Cheadle, Franklin et al. 1994).

When looking at work-related back disorders among union carpenters in Washington State, it was found that the total costs incurred for back injuries/disorders were $128 358 522 (Lipscomb, Dement et al. 2009). This represented 97 cents per hour of work. According to Snook (1978), two-thirds of all low back injuries resulting from MMH could be prevented if the job demands were designed to accommodate 75% of the population. In 2009, back injuries accounted for 28.4% of the total injuries involved in lost time claims (WSIB 2009). Another problem area for occupational and work disorders is the shoulders, arms and hands. Some of the tasks in which these injuries occur are prolonged static muscle load; highly repetitive and monotonous work; high force exertions or mechanical compression of tissue (especially at the hands); use of vibrating equipment and tools; and work with many deadlines and little control (Buckle 1997).

A large portion of the workforce experiences upper extremity musculoskeletal disorders (UEMSD), accounting for 3.6% of all claims and 6.4% of all costs (Hashemi, Webster et al. 1998). 19.7% of lost claims in 2009 were due to upper extremity injuries with shoulders accounting for 6.6% of the total lost time claims due to injuries (WSIB 2009). The distribution of the work-related injury costs is skewed with the average cost being 13 times greater than the median. The average length of disability for a person with UEMSD was approximately 87 days (Ciriello, Snook et al. 2001). The demographics of the workers making claims as well as their work environment are important to know in order to make the workplace safer for workers.

In terms of age and its relation to musculoskeletal disorders in the workplace, it has been found from self-report surveys that adolescents are injured frequently and should be considered a public health concern within North America and Europe (Breslin, Koehoorn et al. 2003). Adolescents (15-19 years old) account for a substantial number of workplace injuries, occurring more frequently than their adult counterparts (Breslin, Koehoorn et al. 2003). In terms of injury rates, reports have found that adolescents and young adults (20-24 years old) have injury rates 1.4-4 times higher than males over 25 years old (Breslin, Koehoorn et al. 2003). The differences in the injury rates are most likely due to the types of industries that adolescents and young adults work in, as well as the amount of experience that the workers have in the industry. Most of the injuries are occurring within the retail trade, accommodation, and food and beverage service industries for the adolescents and young adults within the first five months of work. Not only is it important to know the age of the workers being injured, but the type of jobs that the workers are in is also important.

When looking at job complaints, it was found that male blue collar workers had the highest complaints with the white collar workers having the lowest number of complaints (Broersen, de Zwart et al. 1996). Within the blue collar worker category, the younger age groups had the largest number of complaints. As the blue collar workers age, the number of complaints made decrease, while the number of white collar worker complaints increase as they age. White collar females started off with the lowest number of complaints from the younger workers, but as age increased, the number of complaints surpassed blue collar workers (males and females), with the highest number of complaints in the oldest category. For overall white collar employees in the medium to high paying group, there were a decreasing number of complaints after an initial rise before 40 years old, and then continually increasing to 50 years old. After 50, the number dropped to the lowest value in the oldest age group. In general, there was a decrease in the number of health complaints with older age categories, this may be due to the remaining workers having a relatively high work capacity and staying in their job rather than transferring to a less strenuous and demanding job. There may be a decrease in the number of complaints in the workplace because the working conditions that the older workers had been exposed to earlier in their working careers were worse than their current conditions and therefore the frame of reference to judge the working condition is not the same as younger workers. In contrast to these findings, there have been findings showing that males make more injury claims than females. From a self-report survey study, it was found that across all age groups, claims made by males were approximately twice those for females. Young adult males had the highest injury rates, followed by adolescents and adult males. For females, it was found that adult females had the highest claim rates, followed by adolescents and then young adults. For all age groups, most injuries occurred within the manufacturing sectors (Breslin, Koehoorn et al. 2003). One of the most common reasons for work absenteeism and is a leading cause of work disability and an activity limitation among young adults is back pain (Lipscomb, Dement et al. 2009). Although it has been shown that younger workers are more frequently injured than older workers (Breslin, Koehoorn et al. 2003), the amount of time recovery time is not the same.

Although younger workers and older workers may have the same injury, the average length of disability for the older worker is greater than that of the younger worker (Higgs, Edwards et al. 1993). Time lost due to illness or injuries increase as the age of the worker increases, especially in jobs that involve strenuous physical demands (Ontario Ministry of Labour, 2002). Injuries to older workers are more likely to result in permanent disability than injuries to younger workers regardless of the severity of the injury (Rossignaol, Lock & Burke, 1989). Within the same job, older workers have an increased risk of injury than their younger counterparts.

It has been found that older workers are at an increased risk for job-related injuries and are more likely to suffer permanent disability or a fatality as a result of the workplace injury (Zwerling, Whitten et al. 2003). A large deterrent for companies to keep older workers is the potential cost of the health care benefits, as these have the greatest impact cost-wise for retaining older employees (Head, Baker et al. 2006). As workers age, there are some expected outcomes in terms of health problems and work-related health complaints. It is expected that the work complaints will increase with age as work capacities are decreasing and the prevalence of health problems are increasing.

There may be some decreases in the number of complaints as workers age because older workers are sometimes transferred to less strenuous jobs and may be using more efficient strategies. The workers that maintain their positions and are not transferred to less strenuous jobs are generally those that do not experience negative health-related aging effects. Also, many workers become less sensitive to working conditions as they age (for example, hearing loss). As the demographics of the workplace change, the primary design concerns for the aging employees change in terms of their physical, physiological, and psychosocial capacities (Perry 2010). There are several functional limitations that older workers encounter. These limitations may require workers to have workplace accommodations that will allow them to perform their essential job tasks or reduce safety risks to the worker or other workers (Hansson, DeKoekkoek et al. 1997). These changes suggest that older workers may be more susceptible to cumulative trauma injuries as they age. Mital et al. (1999) suggests that workers over 50 years old should not stay in physically demanding jobs and that age should be treated as a risk factor for MMH injuries.

In this study I looked at older and younger workers as younger workers are the most frequently injured (Breslin, Koehoorn et al. 2003) and older workers have a longer recovery period if injured (Higgs, Edwards et al. 1993). I specifically looked at female workers as they are the limiting population within the manual materials handling field (Snook and Ciriello 1991) and as shown by Breslin and Koehoorn et al (2003), older white collar females were found to have the highest claim rates in comparison to adolescents and young adults in white collar and blue collar sectors.

2.2 Manual Materials Handling Guidelines

The goal of ergonomics is to design the job to fit the individual performing the job. This includes the worker's mental and physical capabilities, limitations and tolerances (Thompson and Chaffin 1993). There are many different ways in order to measure the various tool and safety thresholds for workers. Some examples of tools used to evaluate occupations are rapid upper limb assessments (RULA), National Institute for Occupational Safety and Health (NIOSH), Snook and Ciriello tables, and 3D Static Strength Prediction Program (3DSSPP). In creating guidelines, monitoring heart rate and ratings of perceived exertions are also used to determine how hard a worker feels they are working and which parts of the body they feel is the most taxing while working.

When evaluating ergonomic tools, 83.1 % of ergonomists said that they use NIOSH lifting equations, 73.4% said that they used biomechanical models, and 73.1% use psychophysical data (Dempsey, McGorry et al. 2005). The use of these evaluation tools is consistent with the fact that MMH is the leading source of workers' compensation claims. After the MMH tools, 55.5% of ergonomists use body part discomfort maps and 51.6% use RULA. Body part discomfort maps are tools used for preliminary investigations to find out what problems the job may be causing.

RULA was created to assess the exposure of people to postures, forces and muscle activities known to contribute to upper limb disorders (ULD) (McAtamney and Nigel Corlett 1993). RULA uses an observational technique of postures that are adopted by the upper limbs, neck, back and legs. The values are recorded from the RULA charts. The posture is deemed less desirable if it has a high score at the end of the analysis. If the posture has a high score at the end, it is ideal to decrease the individual scores (e.g. upper and lower arm position, wrist position and twist, neck, trunk and legs). RULA is an easy tool to use and can be very effective if the user understands the ergonomics of the working situations and the technical possibility of changes that can be made. Another form of ergonomic analysis used is the NIOSH equation.

NIOSH was created to include biomechanical, physiological and psychophysical criteria, in addition to epidemiological evidence of musculoskeletal injury rates of low back pain (Waters, Putz-Anderson et al. 1993). The equation takes into account all three criteria as they account for different stresses on the body during lifting. The different criteria used may indicate the limiting loads. The

NIOSH criterion is set in terms of a ‘Recommended Weight Limit’ which is expressed in a formula that takes into account: height at which the lift starts, the vertical distance of the lift, the reach distance to the load, and the frequency of the lift. This equation can be used assuming the baseline limit of 23 kg under the best conditions (sagittal plane lift, occasional lifting, good handles, less than 25 cm vertical displacement of load and a situation in which the lift is made at a vertical height of 75 cm from the floor and a horizontal reach distance of no more than 25 cm from the midpoint between the ankles) (Waters, Putz-Anderson et al. 1993). This weight is the amount that at least 90% of US workers should be able to lift over a defined work period without increasing their risk of lifting-related low back pain. There are several limitations to the NIOSH equation including that it only applies to lifting and lowering tasks, it only applies to standing tasks, does not take into account shifts in load distribution, and is not designed for asymmetrical lifting (Waters, Putz-Anderson et al. 1993). In addition to using equations to determine safe loads to lift, guidelines for lifting, pushing and pulling are also used.

Criteria for static strength and criteria for dynamic strength are two types of psychophysical criteria for establishing acceptable workloads (Snook 1985). Static strength is used to measure static tasks, such as maximum voluntary contractions, while dynamic strength is measured in tasks such as lifting, pushing, or pulling for example. In order to create the MMH guidelines a psychophysical method was used to determine the maximum weight of the load acceptable for a worker to lift for an entire work day (8 hours) (Snook 1978). From his experiment, lifting, lowering, pushing and pulling guidelines were created for males and females. These tables included varying distances, object widths and frequencies that would be encountered in the workplace (Figure A 3). The purpose of these guidelines is to accommodate the worker and decrease injury risks (especially for the low back). Another way to evaluate jobs and determine the static strength requirements is by using computer programs to input the job task information into.

3D SSPP is a software that was created to predict the static strength requirements for tasks such as lifts, pushes, and pulls (University of Michigan). This computer program allows the user to input posture data, force parameters and male/female anthropometry. The output from the program includes the percentage of males and females who have the strength to perform the inputted task, spinal compression forces, and a data comparison to the NIOSH guidelines. The program allows the manikin to be put into positions involving torso twists and bends. The hands can be put into complex positions that allow for a variety of hand force positions. This tool is easy to interpret as the analysis is aided by a posture generation feature and 3D manikin illustrations. This tool is also used for re-evaluating workspaces and evaluating proposed improvements or new workspaces. Slow movements involving heavy materials are assumed in the program as the effects of acceleration and momentum is viewed as negligible within the program. In addition to measuring loads and their influences on the body biomechanically, HR is used as a measure for establishing fatigue criteria.

Several studies have concluded that strains on the circulatory system are the limiting work factors when performing manual labour jobs (Asmussen, Klausen et al. 1960; Suggs and Splinter 1961; Suggs and Splinter 1961). It has also shown that heart rate is a better indicator of job demands than oxygen requirements (Suggs and Splinter 1961; Suggs and Splinter 1961). There are several suggestions for the maximum HR ranging from 110 beats per minute (bpm) to 130 bpm that industrial workers should reach while on the job to keep them safe (Morris and Chevalier 1961; Suggs and Splinter 1961). According to guidelines that have been set by Astrand (1960), workers between the ages of 20-33 years old should not exceed 127 bpm, while workers from 60-69 years old should not exceed 92 bpm while on the job (Table 2. 1). In addition to HR relating to job demands, it has also been shown to relate to psychophysical evaluations such as ratings of perceived exertion (RPE) (Borg 1962).

Table 2. 1: Heart rate for males at 50% aerobic work capacity (Astrand 1960)

		Heart Rate (Beats/Min)	
Age (yrs)	Number of Subjects	Mean	σ
20-33	29	127	8.3
20-29	4	124	____
30-39	13	116	7.4
40-49	9	113	3.5
50-59	66	98	15.0
60-69	8	92	15.3

Borg scales provide a way to measure perceptual intensities along a rating scale, specifically rating of perceived exertion. The RPE scale was designed to grow linearly with exercise intensity and heart rate (Figure 2. 1). It was made based on work on a cycle ergonometer. These scales have become very popular worldwide for evaluating and monitoring exercise intensities.

The newest category rating scale that Borg created was the new category ratio (CR-10) scale, developed to meet the demands of ratio-scaling and level estimation (Figure 2. 2). In this scale, the verbal expressions relate to positions on the ratio-scale according to their quantitative meaning from zero to ten (Figure A 2). Ten implies the extremely strong perceptual intensity (heavy physical activity such as running as fast as possible for several minutes or carrying extremely heavy weights (Borg 1990). This would be equivalent to the strongest physical effort and exertion that a person has ever experienced. The CR-10 scale has a relationship between heart rate and blood lactate concentrations. This scale is often used in ergonomic investigations that involve heavy aerobic work. RPE scales are also widely used in ergonomic research for the whole body as well as body part specific. In cases where body part specific RPEs are used, a figure is provided with the specific body parts outlined (Figure 2.3).

Borg's RPE scale

6	No exertion at all
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

Figure 2. 1: The RPE scale, i.e. the 15-grade scale for ratings (R) of perceived (P) exertion (E) (Borg 1990)

Borg's CR-10 scale

0	**Nothing at all**	
0.5	**Extremely weak**	**(just noticeable)**
1	**Very weak**	
2	**Weak**	**(light)**
3	**Moderate**	
4		
5	**Strong**	**(heavy)**
6		
7	**Very strong**	
8		
9		
10	**Extremely strong**	**(almost max)**
●	**Maximal**	

Figure 2. 2: The CR-10 scale, i.e. the category (C) scale with ratio (R) and properties (Borg 1990)

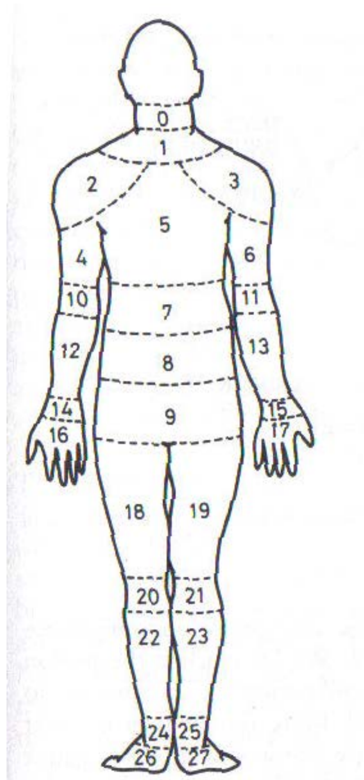


Figure 2. 3: A commonly used body map for evaluating body part discomfort by ergonomists (Corlett and Bishop 1976)

There have been various approaches to determine MMH capacity using an epidemiological method, biomechanical method, physiological method, postural analysis, the psychophysical approach, or a combination of the various methods. Currently, a widely used approach is the psychophysical approach. This approach is used in many studies that involve MMH in order to determine the maximal limits that workers believe they are able to exert in an entire work day (8 hours).

2.3 Psychophysical Evaluation

2.3.1 Psychophysics in Ergonomics

Psychophysics in relation to ergonomics is the ability of people to judge their capacity to perform safely, based on biomechanical and physiological sensations (Armstrong, Buckle et al. 1993; Ayoub and Dempsey 1999). A relationship exists between the stimulus and response magnitude and this relationship can be described as a power function (Stevens 1970; Ayoub and Dempsey 1999). Stevens (1970) created a power law function that relates the sensation (ψ) that grows in proportion to the stimulus (φ), raised to a power function (β) and k is a constant. This equation can be written as follows:

$$\psi = k\varphi^{\beta}$$

Steven's Power Law equation describes the relationship between perceived workload, as assessed by the magnitude of estimation, physical workload and defined the case of weight or the work pace in the lifting task. Psychophysics has been used throughout the literature in order to determine maximum acceptable weights of lifts (MAWLs) for tasks such as lifting, lowering, carrying, pushing, and pulling (Snook, Irvine et al. 1970; Snook 1978; Snook and Ciriello 1991). MAWLs are determined by allowing participants to adjust loads until they satisfy a criteria outlined by the experimenter (e.g. maximum amount of weight that can be lifted without discomfort, perceived injury risk, etc.) (Nussbaum and Lang 2005). Gender, characteristics of the load lifted, frequency and posture have an effect on the MAWL selected. The approach that Snook (1985) uses, is based on subjective feedback regarding preferred levels of sustained work, making the validity of self-reported MAWLs be questioned. It has been found that for lifting frequencies at or below 6 lifts/min have reproducible results for lifting sessions between 4-8 hours (Ciriello and Snook 1983; Karwowski and Yates 1986; Ciriello, Snook et al. 1990; Fernandez, Ayoub et al. 1991; Andrews, Potvin et al. 2008). When looking at manual materials handling, principals of mechanics, psychophysics, and physiology are all used in order to examine the stresses on the body, thresholds for fatigue, discomfort and injury associated with various occupations (Ayoub and Dempsey 1999).

In 1969, Snook and Irvine used the psychophysical approach in order to study physiological criteria in the laboratory and within the workplace. From this study, it was found that there was repeatability with psychophysics in terms of the workloads selected and the heart rates from the participants (Snook and Irvine 1969). They also found that the heart rates of the workers within the industrial setting and the heart rate of the workers within the laboratory setting were similar, indicating that the work rates chosen by both groups may be similar. From this, it is evident that extrapolating data from a laboratory setting using industrial workers gives reliable results. When using the psychophysical approach, it is assumed that the individual is able to rate the perceived effort in a lifting task, that he is able to produce an individually acceptable level of performance on this task, that the level of performance will be safe from manual handling injuries, and that the workers actually do perform a lifting task at the same rate as the one participants choose in the experimental situation (when the participant can choose their frequency and load) (Gamberale, Ljungberg et al. 1987).

When using the psychophysical approach, it is also assumed that the participants will follow the directions in selecting a maximum load that they can lift for an entire 8 hour work day, without straining themselves, or without becoming unusually tired, weakened, overheated or out of breath according to Snook (1978). This criteria has been the basis of many psychophysical studies involving manual materials handling. The study done in 1974, by Snook and Ciriello followed the same protocol as Snook's previous study in 1970, except they included females. The goal of this study was to determine if gender differences exist for studies conducted in the laboratory setting and studies conducted in the industrial setting. They found that there were significant differences in the MMH capabilities of males and females, indicating that gender has a large influence on psychophysical handling capacity (Ayoub and Dempsey 1999). According to Mital et al. (1999), a female's strength is approximately 60-76% of a male's lifting strength. It important to note that psychophysical databases must be made separately for both males and females since they both have different lifting capabilities.

2.3.2 Application of Psychophysics in Ergonomics

The psychophysical approach has been used for setting guidelines for manual material lifting tasks within the ergonomics field. The aim of this approach has been to eliminate and/or minimize the number and severity of musculoskeletal injuries (Liles, Deivanayagam et al. 1984). Snook (1978) conducted a field study and found that one-quarter of industrial tasks examined were acceptable to less than 75% of the workforce, and these jobs accounted for one-half of back injuries. This study provides support for the use of the psychophysical approach in industry, and resulted in job recommendations for at least 75% of the population. A large driving force to use psychophysics in ergonomics is that there was seen to be an advantage to using it in the workplace since there is a high industrial population with and without low back disabilities (Snook 1978; Snook 1999). It has also been found that when the psychophysical method is carefully applied to the task, it provides a practical means for achieving the goal of establishing safe levels of work (Putz-Anderson and Grant 1995).

Psychophysical data is used throughout the industry in order to maximize efficiency and minimize risk of injury to workers. In addition to MMH tables, another way to evaluate lifting data is to use corrective multipliers (Mital 1992). Mital (1992) created several multipliers in order to adjust the load that a worker can lift safely. The multipliers that he used are for work duration, limited headroom, asymmetrical lifting, load asymmetry, couplings, load placement clearance, and heat stress. The psychophysical approach is less costly and time-consuming to use right away in the industry than many other methods of evaluation in ergonomics (biomechanical or physiological) (Han, Stobbe et al. 2005).

Tables of MAWLs that have been compiled from various extensive studies are commonly used by ergonomists for task evaluation and design. The psychophysical approach is well used as it creates an assessment tool that can be applied in the industry as it uses external exposure measures, such as torque and frequency, and is relevant to working populations (Moore and Wells 2005). A large factor for the widespread use of the MAWL tables is that they are easy to use and give reproducible results.

2.3.3 Advantages and disadvantages of using psychophysical metrics to set threshold exposure limits in the workplace

There are several advantages and disadvantages of using psychophysical metrics to set threshold exposure limits in the workplace. The advantages and disadvantages have been discussed in several papers, and although there are many disadvantages to using psychophysics, there are also many advantages, which is why this is still a commonly used method today. There are many stated advantages when using the psychophysical method in order to determine MAWLs including:

1) Psychophysics allows the realistic simulation of industrial work (Snook 1985);
2) Currently, there are considerable amounts of psychophysical data for MMH tasks available that was collected from industrial workers. Many physiological models are based upon data collected from university students. Similarly, cadaver data used to set spinal compression limits are of questionable value (Ayoub and Dempsey 1999);
3) Psychophysical results are consistent with the industrial engineering concept of a “fair day’s work for a fair day’s pay” (Snook 1985);
4) Psychophysics can be used to study intermittent tasks that are common in industry (Snook 1985). Physiological analyses are not appropriate in such situations;
5) Psychophysical results are very reproducible (Snook 1985);
6) Psychophysical judgments take into account the whole job, and integrate biomechanical and physiological factors (Karwowski and Ayoub 1984; Haslegrave and Corlett 1995);
7) Psychophysical results appear to be related to low-back pain (Snook 1978; Liles, Deivanayagam et al. 1984; Snook 1985);
8) For MMH tasks that must be performed under postural restrictions (i.e. maintenance work and mining), psychophysics can be used to develop handling limits specific to the tasks being examined (Ayoub and Dempsey 1999);

9) The psychophysical approach is less costly and time consuming to apply in industry than many of the biomechanical and physiological techniques (Ayoub and Dempsey 1999)

Although there are many advantages to using psychophysics in the workplace, there are also many disadvantages. A few of the stated disadvantages to using psychophysics include:

1) Inexperienced participants require adequate training in psychophysical studies (Ayoub and Dempsey 1999);
2) Whether or not workloads selected in short periods (20-25 minutes) are valid for an 8 hr work day (Ayoub and Dempsey 1999);
3) Subjects may not be able to adequately project the physiological burned of a given workload to an entire work day (Ayoub and Dempsey 1999);
4) The assumptions that the subjective workloads selected by the subjects are below the threshold for injury has not been validated (Gamberale 1988). This is the most important limitation;
5) Psychophysics is a subjective method (Snook 1985);
6) Psychophysical results for high-frequency tasks exceed energy expenditure criteria and is susceptible to errors in loads selected (Snook 1985; Karwowski and Yates 1986);
7) Some psychophysical values may violate biomechanical criteria (Ayoub and Dempsey 1999);
8) Psychophysics does not appear to be sensitive to bending and twisting while performing MMH tasks, both of which have been related to compensable low-back pain cases (Snook 1985);

As the literature on psychophysical evaluations involving different working conditions increases, they become more applicable to various tasks encountered in the workplace.

2.3.4 Biomechanics and Psychophysics

When evaluating an occupation, it is important to look at the impact of the occupation on the worker psychophysically, physiologically and biomechanically. Each of these criterion interplay with each other and have an effect on the worker's productivity and health. Some of the tasks within these occupations include lifting, lowering, pushing, pulling, holding and carrying materials (Dempsey 1998). The focus of my thesis was on the biomechanical and psychophysical evaluation of MMH, specifically lifting. In general, when looking at the biomechanical approach during lifting tasks, ergonomists and researchers are interested in the tissue tolerance limits. Specifically, some ergonomists are interested in compression limits of intervertebral discs and moments at the individual joints. The ability for workers to predict any possible potential biomechanical tolerances within their bodies through the perception of stress could provide a simple mechanism to minimize risks associated with manual materials handling, especially musculoskeletal injuries.

It has been found that the psychophysical approach and the accuracy of the approach decreases at a very low or very high frequencies (Ayoub and Dempsey 1999). Nicholson (1989) calculated the lumbosacral compression for the psychophysical load values from Snook (1978) and found that the floor to knuckle height lifting tasks exceeded the 3400 N limit by approximately 10%. Although the study showed that the compression values exceeded the 3400 N limit by only 10%, the model assumed that the lifting tasks were static, thus Nicholson (1978) assumed that the calculations would underestimate the dynamic forces by approximately 40%. In agreement with this study, another study showed that with infrequent lifting frequencies, people are not necessarily aware of and may not perceive levels of physical stress equally, as the physical stress increases (Thompson and Chaffin 1993). In this case, there is potential to choose loads that exceed their physical tolerance, which may lead to loads in which may cause injuries.

There have been various sources indicating that psychophysically set MAWLs may not protect the low back when lifting loads under certain conditions (Karwowski and Yates 1986; Nicholson 1989; Kumar and Mital 1992). These conditions include infrequent lifting (1 lift/5 min or longer) from near the floor and with an asymmetric torso load. Another issue is frequent lifting (6 or more lifts/min) (Karwowski and Yates 1986). Although the specific lifting tasks show issues when looking at biomechanical evaluations, these issues are common lifting conditions that people are unable to adequately judge or perceive loads that they can both subjectively tolerate and physiologically/biomechanically tolerate.

It has been found that as the spine ages, the 3400 N of spinal compression limit does not provide an appropriate comparison for MAWL values (Kumar and Mital 1992). After looking at cadaver studies, it was found that the mean compression failure values of the spine decreases from 6700 N (SD 2600 N) for younger (<40 years old) cadavers, at a rate of approximately 1000 N for each additional decade of life (Jager and Luttmann 1992). It was determined that 90% of working age men under 40 years old are protected under the 3400 N limit; however, older workers would have to have the ‘safe’ level of the spine compression tolerance much lower at approximately 2400 N for 90% of the older workers to be protected.

This limit is so low that it could be exceeded simply by bending over and getting back up quickly based on the biomechanical models used in this study (Jager and Luttmann 1992).

The physiological workload (heart rate) also increases when the perceived workload increases (Gamberale, Ljungberg et al. 1987). The relationship between these two factors was linear. The relative increases in the perceived workload were also met by increases in heart rate. This was especially evident when the workload increased by increasing the weight lifted. Current studies that involve biomechanics and psychophysics for spine loading have been restricted to analyses of only short periods of lifting (Snook and Ciriello 1991; Granata and Marras 1993; Marras and Granata 1997). From a previous study, it was found that frequency increases spine loading, due to an increase in muscle coactivity when participants are exposed to conditions that they are unfamiliar with (Marras, Parakkat et al. 2006).

2.4 Considerations for Assessing Psychophysical Strength during Manual Materials Handling Tasks

2.4.1 Participants

In choosing participants to be in a psychophysical study, it is important that the participants are experienced workers and are familiar with the task (have an initial training period) in order to obtain reliable results. Skilled and unskilled participants respond differently when they must choose loads that they believe they can lift for an entire day. In choosing participants that are familiar with the task (experienced workers), it has been found that in lifting, experienced participants exhibited 13% less compressive load on their spines compared to the inexperienced participants (Marras, Parakkat et al. 2006). This trend was dependent on the magnitude of the moment exposure. It was found that spine loading was reflective of the worker's experience in that the motor programs are selected based on the MMH experience with the duration of lifting, frequency of lifting, and load weight influencing the muscle recruitment profiles. When looking at spinal load for experienced workers, there was an increase in spine loads when there was a greater load moment exposure at greater lifting rates, while the inexperienced participants behaved in an unpredictable manner with the lowest loads having the greater than expected spinal loads (Marras, Parakkat et al. 2006). From this, participant selection is important and choosing the right participants for the expected outcome.

Gender has a large influence on the outcomes of psychophysical studies as strength plays a large factor in the loads and forces selected. Males have been found to choose larger loads and forces when selecting MAWLs as well as when performing other MMH studies in comparison to females (Snook

1985; Snook and Ciriello 1991; Potvin, Chiang et al. 2000). In order to make a comparison between groups (e.g. gender, skilled and unskilled), it is important that the groups have the same (or very close to the same) amount of people; otherwise comparisons between the two groups is very difficult or sometimes cannot be made (Potvin, Chiang et al. 2000). As skilled workers produce more reliable results since they are familiar with the experimental tasks, workers familiar with manual materials handling, specifically lifting tasks, were hired for this experiment.

2.4.2 Training

The order in which participants are trained may have an effect on the psychophysical determined loads and forces that they choose. A familiarization period/training period is important to allow the participants to become familiar with the experimental conditions and procedures as well as the equipment being used. In addition, the participants must be trained on the methods of psychophysical evaluations. The familiarization period and training session is also used to increase the cooperation between the participant and the experimenter (Kim and Fernandez 1993). The amount of training that the participants get ranges from one hour to several days depending on the experiment. A study done my Marley and Fernandez (1995) had a training session for a minimum of two hours spanning two days. The participants were given additional time to train if the subject experienced any difficulty with the aspect of the procedures. Longer training sessions are planned for experiments that require either many tasks or very specific movements.

Longer training sessions have been used for unskilled participants, while skilled participants were given a shorter training period (Potvin, Chiang et al. 2000). In this study, skilled participants were trained for 4 hours in a single day, while unskilled participants were trained for 8 hours over two days. It was assumed that skilled participants would require less training as they were already familiar with the task. The data indicated that the unskilled participants were at an acceptable skill level compared to the skilled participants after the training session was completed. In order for psychophysical evaluations to be reliable, the participants in the study must be trained and instructed appropriately.

It has been found in a study done by Ciriello et al (2001) involving job rotations and choosing psychophysically determined loads, that the constant rotation through several tasks that should have separate psychophysical set points, caused the participants to choose psychophysical set points closer to the limiting movement (in this case the extension movements that participants were required to do). They also found in this task that, for the single tasks the participants were introduced to in the training session, a training effect that was more pronounced than the multitask training was produced. The amount of training varies across studies for experienced and inexperienced workers; however, there are no conclusive results on how long an experienced worker needs to be trained for.

2.4.3 Psychophysics Instructions

The instructions given to the participants in a psychophysical study are very important as they let the participant know what needs to be done in the study. Gamberale, Ljungberg et al (1987) found that the selection of the workloads was very sensitive to the instructions actually dictated to the subjects. During the study they found that reminding some of the subjects during the lifting task that they could adjust the workload at any time they felt, tended to produce an unexpected systematic increase in the workloads selected by the subjects. This indicated that the procedure chosen when instructing the participants may induce a potential source of bias of the loads selected.

Commonly used instructions in psychophysical studies have been adapted from the instructions given to the participants in the study done by Snook and Ciriello (1991). In this study participants were instructed to "work as hard as they could without straining themselves, or without becoming unusually tired, weakened, overheated, or out of breath". In these studies, participants were choosing a load that they were able to lift, push or pull for an entire work day (8 hours). The participants were given 20 minutes for each task to determine the maximum load. In another study, participants were told to "imagine you are on piece-work, getting paid for the amount of work you do, but working a normal 8-hour shift that allows you to go home without feeling bushed, unusually tired or weakened"; in addition to adding and removing lead shot to obtain the maximum amount they could without strain or discomfort (Gamberale, Ljungberg et al. 1987). In this experiment, participants were given the same instructions as those presented by Snook and Ciriello (1991).

2.4.4 Time Required to Obtain a Stable Psychophysical Estimate

The time taken to obtain a stable psychophysical estimate has been tested over 30 years in order to determine the optimal amount of time for a person to reach a final load that they believe they can lift for an entire work day. Originally, the use of psychophysical lifting tasks was designed to be used for slow intermittent tasks in order to determine MAWLs (Snook and Irvine 1967). At frequencies of 6 -7 lifts/min and up to 12 lifts/min, psychophysics produces overestimations of maximum weights that can be lifted in terms of oxygen consumption criteria (Ciriello and Snook 1983; Karwowski and Yates 1986). A lifting duration, 40 minutes in length to determine MAWLs, did not change after lifting was continued for 4 hours (Ciriello, Snook et al. 1990). In addition to no change in the load selected after 4 hours, there was also no change in heart rate of the participant after 4 hours. It was found that psychophysics is a valid tool for intermittent tasks with frequencies up to 4.3 lifts/min (Ciriello, Snook et al. 1990).

MAWL values obtained in 25 minutes have been used in psychophysical lifting capacities, assuming that the 25 minute period is a sufficient amount of time to reach a load that represents a lifting capacity for an entire 8 hour day. In a study done by Fernandez, Ayoub et al (1991) found that participants had 25 minutes to adjust the load that they thought represented their MAWL. After the MAWL was selected, the participant was required to lift the load for another 10 minutes. The load was then lifted by the participants during another session for an entire 8 hour shift. It was found that the weight decreased on average to 87.8% of the MAWL for during the 2 lifts/min frequency and to 82.9% of the MAWL during the 8 lifts/min lifting session (Fernandez, Ayoub et al. 1991). The large adjustments in the weights were thought to be due to the subjects coming back after a lunch break, which may have caused an increase in their cardiac output to support the lifting and digestive activities. From this study, it was concluded that the psychophysical approach is valid to measure lifting capacity across the lower and moderate lifting frequency range.

Many studies have found that adjustments made in short periods (20-25 minutes) which are to be extrapolated to longer work periods, need to be adjusted (Mital 1983; Karwowski and Yates 1986). This was found to be especially true for tasks that involved frequencies higher than 6 lifts/min (Mital 1983). In the case of higher frequencies, the lifting capacity was overestimated. For the higher frequency range, it was suggested that the physiological approach may be a more reasonable approach for looking at lifting capacity. Ciriello (1990) concluded that weights and forces that were selected in shorter periods were valid for frequencies below 4.3 lifts/min.

Currently, the use of an adjustment time of 20 minutes to determine the final MAWL has been used in many studies (Kim and Fernandez 1993; Marley and Fernandez 1995). After the 20 minutes, the load, force or frequency selected is considered to be the maximum. There is also no consensus on the appropriate amount of time to determine a psychophysically acceptable load. In this study, an adjustment period of 30 minutes was used for frequencies of 1 lift/9 s and 1 lifts/2 min.

2.4.5 Choosing a Psychophysical Protocol

Choosing a psychophysical protocol is highly dependent upon the task that the participants must perform and the type of participants that have been recruited to do the study. Studies that involve tasks requiring the participants to use fine movements (e.g. drilling) as opposed to gross movements (e.g. lifting task) require longer training periods. In addition, if the participants chosen are novices and have not completed the tasks required for the experiment before, they will require longer training periods as opposed to participants that are skilled in the task to be performed (Potvin, Chiang et al. 2000). Whatever the task the study involves and, whoever is chosen as participants, it is important to use a consistent method when instructing participants during the experimental protocol (Gamberale, Ljungberg et al. 1987). This section described the various ways to determine a psychophysically acceptable load or force. A number of considerations have been presented and the outcomes associated with choosing psychophysically acceptable forces. The purpose of this section was to provide rationale to support the design of the study.

2.5 Current Research in Manual Materials Handling

Much of current research in manual materials handling involves handle types, lower and lifting, pushing, pulling, and hand forces (Snook and Irvine 1967; Snook, Irvine et al. 1970; Ciriello and Snook 1983; Fernandez, Ayoub et al. 1991; Cheadle, Franklin et al. 1994; Nussbaum and Lang 2005). Many of the MMH and psychophysical studies that have been done are based on the Snook and Ciriello (1991) manual materials handling guidelines. These guidelines were made based on studies conducted by Snook and Ciriello, supported by Liberty Mutual. In these studies, the participants were instructed to adjust the weight of the box by adding or removing lead shots to the maximum amount that they could lift comfortably at a rate of 3, 6 or 9 lifts per minute for one hour. The participants were instructed to work on an incentive basis, working as hard as they could without straining themselves, or becoming unusually tired, weakened, overheated or out of breath (Snook 1985). The participants were allowed to make adjustments to the weight that they were lifting in the first 45 minutes. After 45 minutes, the MAWL was to be selected and lifting at the frequency for the rest of the hour (15 minutes). The initial weight of the box was randomly varied. The box had a false bottom so that the participants would not know how much weight was in the box to begin with and to minimize visual cues (Snook and Irvine 1967). At the end of each lifting task, the box was weighed in kilograms in order to determine the MAWL.

In addition to using psychophysics to determine an acceptable load or force, in studies as well as in ergonomics, ratings of perceived exertions are used. RPEs are commonly used to find out how hard a person feels as though they are working and which parts of the body they find the most taxing from the different tasks that they must perform on the job. A study done by Nussbaum and Lang (2005) looked at the maximum acceptable static loads (MASL) while participants were in four different postures. From this study it was found that there was a consistent linear relationship between the participant's whole body

RPE and %MASL held while in all four postures. The effect of posture was not significant (p=0.63), with only minor differences being in the mean RPE between postures. It was found that increasing lower torso demands caused a decrease in the MASL selected as well as the postures with higher shoulder demands. At the conclusion of the study, it was found that lower torso and shoulder demands as well as participant specific factors are the limiting factors in choosing MASLs (Nussbaum and Lang 2005).

A recent study was done that looked at the effects of container size, frequency and extended horizontal reach on maximum acceptable weights of lifting for female industrial workers (Ciriello 2007). The participants used in this study were females as the results were to be compared to a previous study done with males (Ciriello, Snook et al. 1993; Ciriello 2003). Females were also used so that a more precise estimate of MAWLs for the industrial population could be determined. The study concluded that the existing guidelines for female industrial workers (Snook and Ciriello 1991) is an accurate estimate for lifting large boxes for all fast frequencies down to one lift every thirty minutes. Through incorporating the results from this study in future guidelines, the design of MMH for female industrial workers should improve.

The most recent study published by Ciriello et al (2011) looked at gender differences in psychophysically determined maximum acceptable weights and forces for industrial workers after twenty years. This study investigated gender differences of the current industrial population in lifting, lowering, pushing, pulling, and carrying tasks compared to those presented in the 1991 Snook and Ciriello paper. The average age of the workers in this study was 40.4 (9.65) years. The boxes in this study had false bottoms that could hold up to 11 kg. In terms of the lifting in this study, there were significant differences found for the low lift (one lift/min) ($p<0.001$). It was found that the female maximum acceptable weights (MAW's) for lifting, lowering and carrying were approximately 67% of the 1991 female values (Snook and Ciriello 1991). The MAW's were significantly different ($p<0.05$) for the height range for the lifting and lowering tasks (floor-to-knuckle and knuckle-to-shoulder height range); however the MAW's were not affected by the absolute height (51 cm). From this, it is thought that the lower MAW's are associated with the female industrial workforce having a lower set point (value at which worker's believe they are able to lift) based on an acceptance for a lower burden on the MSK system (Ciriello, Maikala et al. 2011).

In addition to the previous study mentioned, Wright and Mital (1999) conducted studies involving lifting and carrying of boxes to compare older and younger, male and female adults. These studies will be discussed further in section 2.6. MMH has been a well-researched topic for over 50 years and continues to be a topic for research now.

2.6 Aging and lifting biomechanics

There have been many studies conducted involving manual materials handling (specifically lifting), but not many involving a separation between an older and younger population. Wright and Mital (1999) have done two studies involving lifting and carrying. These studies were done in order to recreate the situations presented by Snook and Ciriello (1991) to investigate the muscle strengths used by an older population when performing routine activities in industrial and home environments (Wright and Mital 1999; Wright and Mital 1999).

In the first study conducted by Wright and Mital (1999), they found that lift height did not affect any of the responses significantly and that frequency was the only significant factor on MAWL selected. They found that there was no effect of age on the MAWL selected by the participants. The participants recruited in this study were young (18-35 years old) and older (55-74 years old), males and females. Each group had 10 participants, giving a total of 40 participants for the study. The population selected for the study was only those working full-time or part-time (or physically active) at least three times per week. Physically active individuals included those who exercised, walked or performed yard work. The measurements that were taken were dynamic psychophysical measures (using the Borg scale) and the MAWL. The lift heights consisted of a floor to 80 cm and from 80 cm to 132 cm. In addition to this study, Wright and Mital (1999) also did a study involving carrying. The same participants were used in this study. The objective was to determine the dynamic psychophysical carrying strengths (maximum acceptable weight of carry, MAWC) through a range of motions (Wright and Mital 1999).

As previously stated, Wright and Mital (1999) completed two studies involving older and younger participants (males and females) with tasks of lifting and carrying. No differences were found between the older and younger population during the lifting task, while differences were found for the carrying task. In this study it was found that there were significant differences for age, gender, oxygen uptake and gender, and heart rate. Overall, older males had a higher physiological burden while carrying a lighter load compared to their younger counterparts. Although no differences were found between the older and younger participants during the carrying task, this may be because the participants selected were not experienced manual materials handlers. The population as stated earlier were people that worked or were physically active (including walking) three times per week. As stated in section 2.4.1. it is important to choose experienced participants when conducting a psychophysical study as experienced participants produce reliable results and inexperienced participants tend to select heavier weights than they could actually handle over an entire work day (Potvin, Chiang et al. 2000; Marras, Parakkat et al.

2006). In addition to the participants being inexperienced MMH, there participants also had a large variation in their body mass, with the older males weighing up to 20 kg on average more than the younger males. The MAWL values chosen by the older males and younger males had a high variability (older males 15.4 kg and younger males 11.2 kg). Currently, there have not been any studies done that compare older and younger workers within the MMH industry relating to lifting tasks. In this study, older (50 years and older) and younger (20-30 years old) manual materials handlers were recruited.

2.7 Summary of what is currently not known

Currently, no study has looked at aging workers using a combined psychophysical and biomechanical assessment protocol for determining safe load limits for lifting. Since younger workers are the most frequently injured (Breslin, Koehoorn et al. 2003) and older workers have a longer recovery period if injured (Higgs, Edwards et al. 1993), both populations were selected as the participants in my study. I specifically looked at female workers as they are the limiting population within the manual materials handling field (Snook and Ciriello 1991) and as shown by Breslin and Koehoorn et al (2003), older white collar females were found to have the highest claim rates in comparison to adolescents and young adults in the white collar and blue collar sectors.

As many industries (service and manufacturing) involve MMH, which include lifting, lowering, pushing, pulling, carrying and holding materials (Dempsey 1998), the focus of my thesis was on the biomechanical and psychophysical evaluation of lifting. In general, when using a biomechanical evaluation approach, ergonomists and researchers are often interested in the applied loads compared to tissue tolerance limits. However, although the Wright and Mital (1999) papers examined lifting and carrying for the younger and older population, they only looked at the final mass of the selected loads (e.g. biomechanics were not explicitly evaluated or reported). In my study, younger and older working populations were used to examine potential age-related differences, and I measured the maximal acceptable weight of lift for several tasks in addition to conducting kinematic evaluations including shoulder, hip, and knee sagittal plane joint angles.

2.8 Thesis Objectives

The objective of this thesis was to determine if psychophysical estimates of maximum acceptable lifting mass differ across young and older female workers during selected lifting tasks. In addition to determining if the maximum acceptable lifting masses differed between young and older female workers, potential age-related differences in kinematic lifting strategies, grip strength, ratings of perceived exertion and heart rate were also investigated. It was of interest to determine if it is feasible to apply a discount factor in terms of the differences in the mass selected by older workers in comparison to younger workers for the varying tasks. It was also of interest to determine if the mass selected for the various task categories (cardiovascular or strength) differed across the two populations. Overall, the data collected in this study increases the available literature on female manual materials handling, as well as contributes to the biomechanical and psychophysical data which assist in the development of evidence-based age-specific guidelines for safely designing manual materials handling tasks.

Chapter 3

Thesis research study

3.1 Introduction

Canada's, as well as many other countries', workforce is continuing to age as the baby boomer generation (those born between 1946 and 1964) ages and are remaining in the workforce longer. The number of older workers is estimated to double within the next 10 years (Perry 2010). These baby boomers are either maintaining full-time work or finding part-time work, and the number of retirees re-entering the workforce is increasing (Finch and Robinson 2003). As a person grows older, there are several natural age-related physical changes that occur, having potential implications on functional abilities. Some of these physical changes are: muscle mass, neuronal changes, cardiovascular changes, and lung capacity changes. Some of the functional limitations due to aging include vision and hearing loss, arthritis, balance and gait problems, and loss of strength and stamina (refer to section 2.1.2).

After completing studies involving older and younger, male and female adults doing lifting and carrying tasks, it was found that there was no significant difference ($p>0.01$) between the weights selected for the tasks between the older and younger participants (Wright and Mital 1999). However, there are several methodological factors that might explain this lack of significant findings. First, there was a large variation in the mass of loads selected by the older adults (and thus a large variance for the aged group). Second, there was a large standard deviation between the weight of the older and younger participants, with the older males being approximately 20 kg heavier than the younger males. As strength is influenced by body mass (Liao 2010), this added mass in the older participants may, in part, overshadow potential age-related effects. In addition, the participants chosen for the study were not experienced manual materials handlers but, instead were made up of people that did more than three days of physical activity per week (refer to section 2.6). I chose to address some of these limitations in my thesis to further probe whether age-related differences exist in estimates of safe lifting loads during MMH.

In choosing participants to be in a psychophysical study, it was important that the participants were experienced workers and were familiar with the task (have an initial training period) in order to obtain reliable results. Skilled and unskilled participants respond differently when they must choose loads that they believe they can lift for an entire day. In choosing participants that are familiar with the task (experienced workers), it has been found that in lifting, experienced participants exhibited 13% less compressive load on their spines compared to the inexperienced participants (Marras, Parakkat et al. 2006). As skilled workers have been found to produce results similar to those that were found in the workplace since they are familiar with the experimental tasks, workers familiar with manual materials handling, specifically lifting tasks, were hired for this experiment. As the rates of WMSD are relatively high for MMH tasks in both young and older workers (as adolescents are frequently injured (Breslin, Koehoorn et al, 2003) and the average length of disability is greater for older workers (Higgs, Edwards et al. 1993), both populations were selected as the participants in my study (refer to section 2.1.3). I specifically looked at female workers as they are the limiting population within the manual materials handling field (Snook and Ciriello 1991) and as shown by Breslin and Koehoorn et al (2003), older white collar females were found to have the highest claim rates in comparison to adolescents and young adults in the white collar and blue collar sectors.

MMH is comprised of many tasks such as lifting, lowering, pushing, pulling, carrying and holding materials. As an initial study to probe if a difference exists between older and younger female workers, the focus of my thesis was on the biomechanical and psychophysical evaluation of lifting. Additional studies can be done later to look at potential age-effects during other MMH tasks (such as lowering, pushing, pulling and carrying). In general, when looking at the biomechanical approach during lifting tasks, ergonomists and researchers are interested in the tissue tolerance limits. Specifically, some ergonomists are interested in compression limits of intervertebral discs and moments at the individual joints as they can be compared to population strength data. Although the Wright and Mital (1999) papers examined lifting and carrying for the younger and older population, they only looked at the final mass of the selected loads.

3.1.1 Rationale for my thesis

Currently, there are no studies that have been done that compare maximum loads chosen by younger and older female industrial workers during lifting tasks. In addition, there is a distinct lack of information on whether the kinematics of performing MMH tasks link to or associate with psychophysical estimates of safe lifting loads. Finally, only one study to date (Wright and Mital 1999) has compared whether potential age-related differences in psychophysically and biomechanical outcomes are dependent on task demands that are predominantly strength vs. cardiovascularly challenged, where no significant differences between loads chosen between the older and younger participants were found. This study suffers from the limitations discussed in section 2.6.

3.2 Purpose and Hypotheses

The general purpose of this study was to assess whether psychophysical estimates of maximum acceptable weight of lifts (*MAWL*s) would differ across young and older workers during selected lifting tasks, whether a range of secondary variables (including kinematics, heart rate, ratings of perceived exertion) would differ across age groups, and whether these secondary variables would appeared to relate to any age-related differences in *MAWL*s. My primary hypothesis is that:

1. There will be age-related differences in *MAWL* across tasks. Specifically:
    a. *MAWL* will be lower for older workers compared to younger workers. This is based on evidence which shows that aging has been associated with a loss of muscle (sarcopenia), which begins around the age of 50, decreasing at approximately 15% per decade, and then becomes more dramatic after 60 years old (Deschenes 2004)
    b. Age-related differences will be larger for lifting from knuckle-to-shoulder heights. This is based on the evidence which shows that females show a decrease in upper limb strength from the ages of 59-69 years old, and a decrease in lower limb strength from 70 years and older (Calmels, Vico et al. 1995).
    c. Age-related differences will be larger for lifting at slower frequencies (strength tasks). This hypothesis is based on the evidence which suggests while dynamic strength tests have found decreases for older groups, no changes have been found with dynamic endurance (Larsson and Karlsson 1978). In addition, sarcopenia is most common among type II muscle fibres (fast twitch) which play a large role in diminished muscle power and strength (Deschenes 2004).

My secondary hypotheses are that:

2. Grip-strength will correlate with the loads selected at for each task.
3. Age-related intersegmental sagittal plane kinematic differences in lifting strategies will differ across task conditions. Specifically:
    a. In a floor-to-knuckle height lifting task, older workers will choose techniques that will increase intersegmental sagittal plane knee and hip flexion compared to younger workers. This hypothesis is based on the evidence which suggests that older workers adopt

strategies that protect the back (possibly at the expense of the knee) during lifting tasks (Puniello, McGibbon et al. 2001).

b. Age-related differences in intersegmental sagittal plane knee, hip, and right shoulder angle will not be evident for knuckle-to-shoulder height lifting tasks

4. Age-related overall RPE and body part specific RPE across task conditions:

   a. Overall RPE will be the same for the older and younger workers for each task.

   b. Body part specific RPE will be higher for the upper limb RPEs during the knuckle-to-shoulder height tasks for the older workers compared to the younger workers, while the lower limb RPEs will not show any differences. This is based on evidence which shows that females show a decrease in upper limb strength from the ages of 59-69 years old, and a decrease in lower limb strength from 70 years and older (Calmels, Vico et al. 1995).

5. Following a mass perturbation, participants will be able to return to their pre-perturbation *MAWL* within a 15 min period. Based on the fact that an adjustment time of 20 minutes has been used in several studies to determine final *MAWL* (Kim and Fernandez 1993; Marley and Fernandez 1995).

3.3 Methods

3.3.1 Participants

The participants were recruited through an employment agency (Work Pro Staffing Services, Kitchener, ON). Study participants were comprised of 24 female members of the industrial workforce that have experience in manual materials handling (specifically lifting) from two age groups (Table 3.1). Based on evidence that $VO2_{max}$ peaks as early as 30 years of age, the 'younger' worker group spanned the range of 20-30 years of age (12 participants, mean (SD): 24.4 (4.3) years). Based on reports that the muscle strength undergoes a pronounced decrease after the age of 50 years, our 'older' worker group included persons 50+ years of age (12 participants, mean (SD): 55.4 (4.2) years).

The younger participants (20-30 year olds) were individually matched based on weight (within ±8 kg) of the older participant group (50+ year olds). As a result, there was no difference in body mass across age groups (mean (SD) = 73.2 (18.9) vs. 76.1 (15.8) for young vs. older groups, t=0.39, p=0.694). Height, weight, shoulder and hip ROM, and weight lifted during current and previous manual labour jobs were not significantly different between the older and younger workers (Table 3.1). The older participants were, on average, 31 years older than the younger participants. In addition the knee ROM for the older participants was significantly lower than the knee ROM of the younger participants (93.2 (25.5) vs. 51.8 (15.7)) (t=4.78, p<0.001) (measurements discussed in section 3.3.4). The amount of work experience within the manual materials handling field between the older and younger workers was also significantly different (t=3.8, p=0.002), as the older workers had approximately 6 more years of work experience than the younger workers. Lastly, when asked about their willingness to continue manual materials handling (specifically the lifting) there was a significant difference between the older and younger workers (t=2.3, p=0.028) with some of the older workers not willing to continue and all of the younger workers willing to continue in the same field of work. The participants in the 50 years or older age group were those whom used do to or are currently doing manual labour jobs, while younger participants were those whom were currently doing manual labour jobs. The participants were able to speak and understand English. In addition, they did not have any musculoskeletal injuries in the past year that affected their ability to perform manual labour tasks (specifically lifting).

Table 3. 1: Participant anthropometrics as well as number of years of work within manual materials handling, the minimum and maximum loads lifted and their willingness to continue within the MMH field of work.

Age Group	Older	Younger	t (p)
Age (Years)	55.4 (4.2)	24.4 (4.3)	
Height (cm)	160.7 (7.7)	164.3 (5.4)	-1.31 (0.202)
Weight (kg)	76.1 (15.8)	73.2 (18.9)	0.39 (0.694)
Knuckle Height (cm)	72.3 (4.9)	74.4 (5.1)	-0.97 (0.341)
Shoulder Height (cm)	133.9 (6.3)	138.3 (6.7)	-1.65 (0.113)
Shoulder ROM (°)	150.4 (11.5)	155.2 (6.2)	-1.25 (0.223)
Hip ROM (°)	68.8 (6.6)	73.7 (11.5)	1.28 (0.213)
Knee ROM (°)	86.8 (25.5)	128.2 (15.7)	4.78 (<0.001)*
Years of Work (Years)	8.75 (5.4)	2.6 (2.5)	3.57 (0.002)*
Minimum Mass Lifted at Work (kg)	7.4 (6.3)	4.9 (5.5)	1.04 (0.312)
Maximum Mass Lifted at Work (kg)	10.2 (6.3)	14.1 (16.5)	-0.75 (0.459)
Willing to Continue Manual Materials Handling (1=Yes, 2=No)	1.3 (0.5)	1.0 (0.0)	2.35 (0.028)*

Notes: ROM represents 'range of motion' in the sagittal plane. 180 degrees hip and knee ROM represents that observed during standing.

* indicates significant difference across age-groups

3.3.2 Apparatus

During the tasks, subjects handled a custom-built industrial tote box. To enhance our ability to compare age-related differences across cardiovascular vs. strength challenge tasks, box dimensions (34 x 56 x 16 cm) and lift distance remained constant. The box handles were at the midpoint of the box width and would have a "good" hand-to-object coupling according to NIOSH's Hand-to-Container Coupling Classification (Waters, Putz-Anderson et al. 1993) (as shown in Figure 3. 1). Box dimensions and handles are the same as those used in the Snook and Ciriello MMH lifting tables (Snook and Ciriello 1991). At the center, a cylinder affixed to the center of the box in which the lead shot was inserted in order to prevent the center of mass from shifting when the box was lifted. The mass of the box when it was empty was approximately 5.2 kg. The initial mass of the box was set to a mass that is equivalent to the 90%ile female as per the Snook Tables (Snook and Ciriello 1991) (i.e. 90% of females felt they could safely lift this mass over an 8 hour shift at the appropriate lifting frequency and height) (Figure A 3). The shelves on the shelving unit were adjusted to each participant to ensure she was lifting from floor-to-knuckle and knuckle-to-shoulder according to her height (mimicking the approach used by Snook and Irvine (1967)).

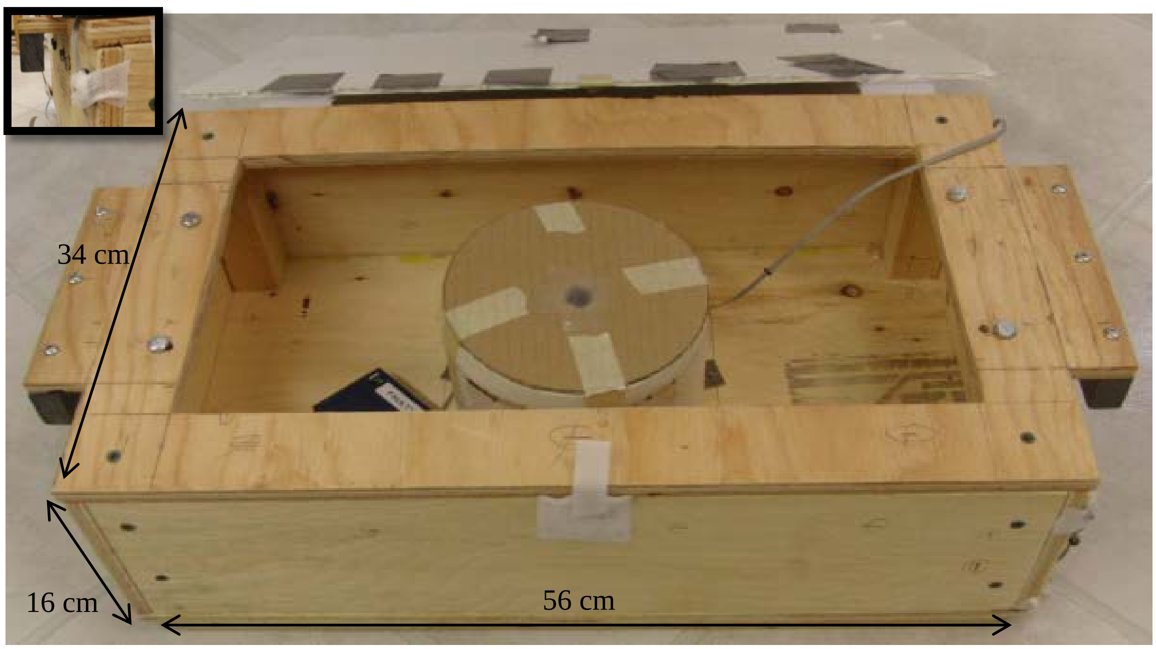


Figure 3. 1: Custom built tote box (with cylinder to insert lead shot into to maintain center of mass) and side view of box handle (top left).

Figure 3. 2: Adjustable shelving unit (shelves adjustable to knuckle and shoulder height) and instructions

3.3.3 Lifting Tasks

Based on evidence that cardiovascular systems, muscle strength, and flexibility are compromised with advanced age, four lifting tasks from the revised Snook tables (Snook and Ciriello 1991) were chosen that were most likely to differentially challenge these systems (Table 3. 2).

Table 3. 2: Description of lifting tasks selected to probe cardiovascular and strength factors

Task	System Challenged	Lift Type	Body Part Challenged	Box Width (cm)	Lift Frequency (1 lift every)
1	Cardiovascular	Floor-to-Knuckle	Lower limb/trunk	34	9 s
2	Strength	Floor-to-Knuckle	Lower limb/trunk	34	2 min
3	Strength	Knuckle-to-Shoulder	Upper limb	34	2 min
4	Strength	Knuckle-to-Shoulder	Upper limb	34	8 h

3.3.4 Experimental Protocol

In general, the experimental testing protocol used a psychophysical approach to identify the maximum acceptable weight of lift of an object during manual materials handling tasks. The participant was required to monitor their own feelings of effort or exertion, and adjust the load mass (by adding or removing lead shot) until they achieved what they felt was the maximum acceptable mass for the task (definition provided below).

A PAR-Q & YOU (Figure A 1) form was filled out prior to arriving to the laboratory by the participants (issued by Work Pro Staffing Services). This ensured that all of the appropriate documentation was brought so that the participant was cleared to participate in the study. Upon arriving in the laboratory and providing informed consent, a series of ancillary measures were collected including mass, height, resting heart rate using a wireless HR monitor (Garmin, Forerunner 305, Olathe, Kansas), and a medical history related to musculoskeletal injuries/disorders. In addition, a hand dynamometer (Takei, Hand Grip Dynamometer – Analogue Dial (A5001)) was used to measure grip strength (measured three times and averaged for dominant hand), and a goniometer to measure flexion/extension range of motion across the right shoulder, right hip and right knee joints in the sagittal plane. Knuckle height was measured using a tape measure (in cm) from the floor to the third metacarpo-phalangeal joint. Shoulder height was measured from the floor to the right acromion (in cm). Active markers were then applied via marker clusters with 4 markers on each to the participant (over the sacrum, T12, right forearm, upper arm, left and right shoes, shanks and thighs), from these rigid marker clusters, the following bony landmarks were digitized: eighth and tenth thoracic vertebrae, left and right acromion, suprasternal notch, xiphoid process, right lateral and medial epicondyles, right radial and ulnar styloids, left and right greater trochanters, lateral and medial femoral condyles, lateral and medial malleolus and first and fifth metatarsals, (Figure 3. 3) to allow kinematics of the lifting task to be captured with a motion capture system.

Figure 3. 3:Active markers were then applied via marker clusters with 4 markers on each to the participant (over the sacrum, T12, right forearm, upper arm, left and right shoes, shanks and thighs).

The experimental session consisted of a familiarization period followed by the experimental lifting tasks. The familiarization period was 40 minutes in length, during which the participant practiced lifting the box in a manner that is compatible with the shelving system, in addition to varying the mass of the box by adding or removing lead shot. The frequency as well as the lifting height was varied throughout the familiarization period. The participants spent 10 minutes for the first task and 15 minutes for the second and third task. During the familiarization task participants were instructed to assume they were working on an incentive basis, and to 'work as hard as they can without straining themselves, or becoming unusually tired, weakened, overheated, or out of breath' (Snook and Ciriello 1991)(these instructions were posted in front of the participant throughout the session). Specifically, the following instructions were read out to the participants before each task:

> "We want you to lift the box from the ____ to _____ height. We want you to adjust the weight of this box until you feel that it is the maximum amount that you can lift once every ________ without straining yourself. You will adjust the weight of the box by putting in or taking out lead shot. Do not hurry your lift. Test the weight as many times as you feel necessary. Do not strain. You will be removing and placing the box onto shelves from the front, while avoiding twisting as much as possible. The box is to be lifted by the handles. Remember that we are not interested in how much you are capable of lifting, but rather in the maximum amount that you can lift for an 8 hour period without straining yourself."

In addition, the participants were able to choose any foot position that they felt comfortable lifting throughout the entire lift. The start of the lift was considered when box is moved from its original position. The end of the lift was established as when the box was placed on the shelf (the box height and the final shelf height is the same). The participant varied the load mass until she arrived at what she perceived to be the maximum acceptable weight of lift (*MAWL*).

After the familiarization period, the experimental trials were conducted. The first lifting task completed was the once per day task (Task 4) from knuckle-to-shoulder height, followed by the remaining three lifting tasks (described in Table 3. 2) in a random order. The lifting rate across tasks were as follows: 1 lift every 9 seconds for the cardiovascular task, 1 lift every 2 minutes for 2 of the strength tasks and one strength task being 1 lift every 8 hours. The duration of the tasks was 30 minutes for the all of the tasks except for the strength task that is to be done once every 8 hours (3 in total – see Table 3. 2). The initial loads were set at a value where 90% of manual materials handlers thought they could lift the mass safely for an entire 8-hour work day (Snook and Ciriello 1991) (Figure A 3). For each task, the participant was asked to vary the mass until she arrived at what she felt is the *MAWL* she could safely lift at this frequency for an entire 8-hour work day.

During the protocol, the participant was required to place the box on a force platform (AMTI, Watertown, MA, USA) whenever she added or removed mass from the tote box to determine the load masses lifted throughout the task period. The lead shot was added to the box by inserting a funnel into the center hole of the cylinder at the center of the box and pouring lead shot in (Figure 3.1). A tab under the box was pulled when the participant wanted to remove lead shot. This allowed lead shot to be added and removed without the participant having any visual feedback as to how much lead shot was in the box. This force platform was sampled at 100 Hz for 6 seconds. The mass was averaged over the period of time that it was measured.

During each task, heart rate was collected with a wireless monitor/data logger (Garmin, Forerunner 305, Olathe, Kansas), and participant kinematics (synchronized with digital video) were collected with a four camera bank (12 individual cameras) motion capture system (Optotrak Certus Motion Capture System, NDI, Waterloo, ON, Canada) . Every ten minutes, the participant evaluated their overall rate of perceived exertion ($RPE_{Overall}$) on the Borg CR-10 scale (Figure 2. 2). Prior to filling out the RPE, the participants were read `Borg`s CR10 Scale Instructions` (Borg 1990) (Figure A 2). If the participant's heart rate reached above 85% of the maximum (220 bpm-age) or if the participant had an overall RPE more than 6, the participant was asked to reduce the mass in the box. Following each task, participants used body maps to indicate regions associated with the highest physical effort, in addition to reporting ratings of perceived effort (RPE) on the Borg CR10 scale (Figure 2. 2) for the shoulder ($RPE_{Shoulder}$), elbow (RPE_{Elbow}), upper back ($RPE_{UpperBack}$), lower back ($RPE_{LowerBack}$) for the knuckle-to-shoulder height lifting tasks and the $RPE_{LowerBack}$, thigh (RPE_{Thigh}) and knee (RPE_{Knee}) for the floor-to-knuckle height lifting tasks (Figure 2. 3). $RPE_{Overall}$ was collected for all tasks.

Field notes were taken at the end of each collection session based on participant interactions. These field notes are provided in Appendix D.

3.3.5 Data Collection

Several measurements were taken throughout the study with the primary outcome being the *MAWL* chosen at the end of the 30 minute lifting and adjustment period. The kinematic data was collected using a four camera bank motion capture system (Optotrak Certus Motion Capture System (NDI, Waterloo, ON, Canada) at 50 Hz.

Whole body $RPE_{Overall}$ using a Borg CR-10 scale (Figure 2. 2) was recorded every ten minutes during the session and then at the end of the session. At the end of the session, body part specific RPEs (Figure 2. 3) were also recorded. In addition, heart rate of the participants was collected throughout the entire lifting session and recorded every ten minutes of the lifting session.

3.3.6 Data Analysis

The primary psychophysical dependent variable from each lifting task was the *MAWL*. As noted above, a range of secondary dependent variables were collected including body-specific ratings of perceived exertion, and heart rate (*HR*).

Primary biomechanical dependent variables were derived from the kinematic data, which was processed using Visual 3D (V3D Standard v4.95.0, C-Motion Research Biomechanics, Maryland) and Matlab (Matlab R2010b, Mathworks, Natick, Massachusetts). All kinematic analysis focused on only the lifts completed after the participant selected their load max value (the total number of lifts differed across participants). Missing data was filled using a cubic spline following guidelines outlined by Howarth and Callaghan (2010). The data was then filtered with a dual pass 2nd order Butterworth filter. Based on a residual analysis performed under similar lifting conditions, a cut off frequency of 3 Hz was used (Chen and Laing 2011). After filtering, the data was ensemble averaged to % of total lift cycle. The start of the lift was defined as the point when the box started to move and the end of the lift was defined as the time when the box was placed into its final position on the shelf (both determined through visual inspection of kinematic data). 3D joint angles were calculated for the right and left knee, hip and right shoulder (symmetry was assumed for right and left shoulder) were determined by calculating the three dimensional joint angles within Visual 3D, while averaging data, finding the maximum joint angles, and the time in which the maximum intersegmental sagittal plane angles occurred in Matlab. The joint angles were calculated by defining segment coordinate systems for the right upper arm, torso, pelvis, right and left thigh and shank. The coordinate system was with the positive x-axis of the right side lateral, positive y-axis anterior, and positive z-axis up (Figure 3. 4). The Cardan sequence used to calculate the joint angles was x-y-z (C-Motion Wiki Documentation 2012). This sequence is equivalent to flexion/extension, abduction/adduction, and axial rotation. The maximum intersegmental sagittal plane angles are shown in Figure 3.4. As the lifting tasks performed were primarily in the sagittal plane, maximum intersegmental sagittal plane joint angles of the right shoulder, right and left hip and knee were the focus of this thesis. Frontal and transverse joint angles were also calculated, although they were not the focus of this thesis. Specific dependent variables were the maximum flexion angle of the knee ($knee_{max}$), right shoulder ($shoulder_{max}$), and hip (hip_{max}), during the final segment of the task after the participant has selected and is lifting *MAWL* as shown in the figure below (Figure 3. 4). In addition to calculating the maximum intersegmental sagittal plane flexion angles, the percent of the lift cycle in which each maximum intersegmental sagittal plane joint angle of the right shoulder, left and right hip and knee was also determined.

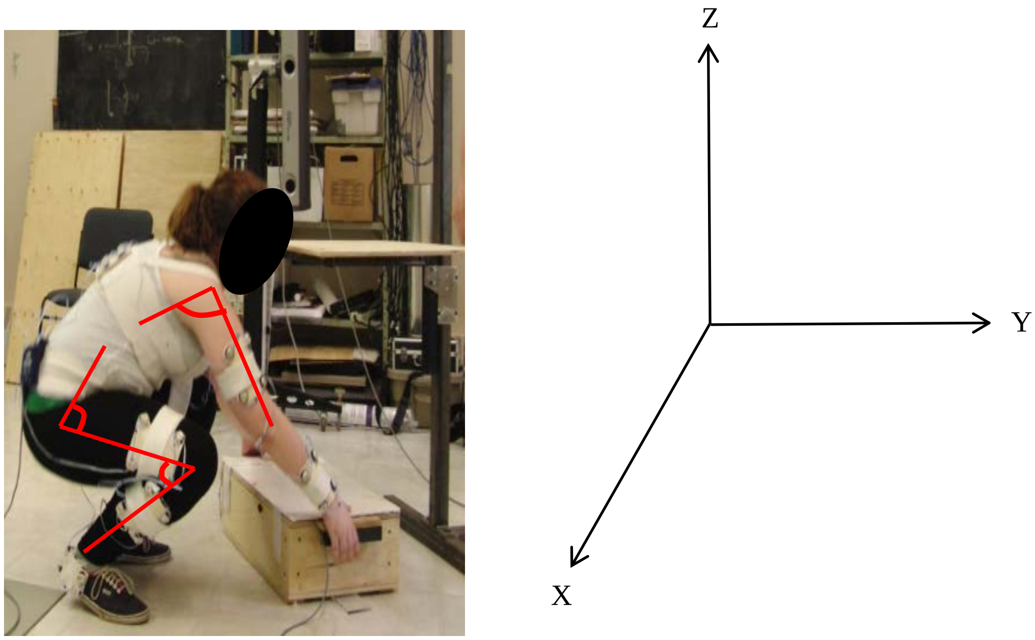


Figure 3. 4: Individual maximum flexion angles of the right shoulder, hip and knee in the sagittal plane (left) and segment coordinate system in anatomical position (right)

3.3.7 Statistical Analysis

For each of the hypotheses tested, a separate statistical analysis was performed using SPSS statistical software (SPSS, International Business Machines Corp., New York) with an alpha value of 0.05. The following statistical tests correspond with each of the hypotheses:

Hypothesis 1: Age-related differences in *MAWL* across lifting conditions:

a. A mixed model analysis of variance (ANOVA) with one repeated factor (task) and a between factor (age group) was used to test for age-related differences in *MAWL* across lifting tasks. Interaction and main effects were examined.

b. A mixed model analysis of variance (ANOVA) with one repeated factor (lift height) and a between factor (age group) was used to test for age-related differences in *MAWL* across lift height tasks with a frequency of 1 lift/2 min. Interaction effects were examined. This was also done to test for age-related differences at floor-to-knuckle height for frequencies of 1 lift/9 s and 1 lift/2 min.

Hypothesis 2:

A Pearson Product Correlation test was used between grip strength and final *MAWL* for each task with the entire participant pool. Separate Pearson Product Correlation tests were then done for older and younger worker groups.

Hypothesis 3: Age-related biomechanical difference in lifting strategies will differ across task conditions:

a. Separate mixed ANOVA with the repeated factor (lift frequencies) and a between factor (age group) was used to test for age-related differences for the maximum intersegmental sagittal plane flexion angle of the $knee_{max}$, hip_{max}, $shoulder_{max}$. Main effects of age were focused on. If interaction effects exist, separate t-tests across ages was performed for each task to determine in which tasks age-related differences exist. Based on the hypotheses, particular attention was paid to interpreting any effects of age on $knee_{max}$ and hip_{max} flexion angle during floor-to-knuckle lifts.

b. Similar mixed ANOVA as above, but for $knee_{max}$, hip_{max}, and $shoulder_{max}$ for knuckle-to-shoulder height lifting tasks.

Hypothesis 4:

An ANOVA with one repeated factor (task) and a between factor (age group) was used to test for age-related differences in $RPE_{Overall}$ across lifting tasks. Interaction and main effects were examined. Separate ANOVAs were completed similarly to test for age-related differences in body part specific RPE

Hypothesis 5:

A 3 way ANOVA with two repeated measures (task and time) and a between factor (age group) was used to test for time and age-related differences for the mass chosen prior to the perturbation and at the end of the task. Interaction and main effects were also examined.

In addition to the ANOVAs described above, T- tests were used to test between conditions where appropriate when results demonstrate significant effects.

3.4 Results

3.4.1 *MAWL* across Age Groups and Tasks

ANOVA indicated there were significant main effects of age (F_1 = 8.186, p=0.009) and task (F=23.468; p<0.001) on *MAWL* (Figure 3.5). There was no interaction effect between age and task on *MAWL* (F=1.332, p=0.273). Averaged across tasks, the older worker values were 23.8% lower than younger workers (9.6 kg vs. 12.6 kg, respectively). Although not strictly required if the absence of an interaction effect, pairwise comparisons post hoc tests were performed and indicated that significant age-related differences existed for the following tasks: 1 lift/2 min from floor-to-knuckle height (mean(SD) older: 10.18 (3.57) kg vs. younger: 13.53 (4.03) kg) (t_{22}=-2.153, p=0.043), 1lift/2 min from knuckle-to-shoulder height (mean(SD) older: 8.98 (2.32) kg vs. younger: 12.44 (3.17) kg) (t_{22}=-3.051, p=0.006) and 1 lift/8 hr from knuckle-to-shoulder height (mean(SD) older: 11.25 (2.45) kg vs. younger: 14.92 (3.23) kg) (t_{22}=-3.131, p=0.005). Based on no significant interaction effect, it was surprising that there was no significant difference in *MAWL* for the 1 lift/9 s from floor-to-knuckle height lifting task (mean (SD) older: 7.96 (2.69) kg vs. younger: 9.76 (2.61) kg) (t_{22}=-1.661, p=0.111).

Strictly looking at the tasks (combining older and younger workers) it was found that frequency and lift height had an effect on the final *MAWL* chosen. Regarding height, there was no significant difference in the MAWLs between the 1 lift/2 min from floor-to-knuckle height (11.9 (4.1) kg) and 1 lift/2 min from knuckle-to-shoulder height (10.7 (3.2) kg) (t=1.07, p=0.288), with the participants being able to lift approximately 1 kg more (~10.1%) for the floor-to-knuckle height lifting task. The *MAWL* selected for the floor-to-knuckle height lifting at the two frequencies (1 lift/9s and 1 lift/2 min, 8.9 (2.8) vs. 11.9 (4.1) kg) were significantly different (t=-2.98;p=0.005); participants were able to lift approximately 3 kg more (~25.2%) for the 1 lift/2 min than the 1 lift/9 s from floor-to-knuckle height. Similarly, the *MAWL* selected for the knuckle-to-shoulder height lifting at two frequencies (1 lift/2 min and 1 lift/8 hr, 10.7 (3.2) vs. 13.1 (3.4) kg) were significantly different (t=-2.48;p=0.017); participants lifted approximately 2 kg more (~18.3%) for the 1 lift/8 hr frequency. Overall, these results indicated that frequency had significant effects on the *MAWL* selected, while height did not.

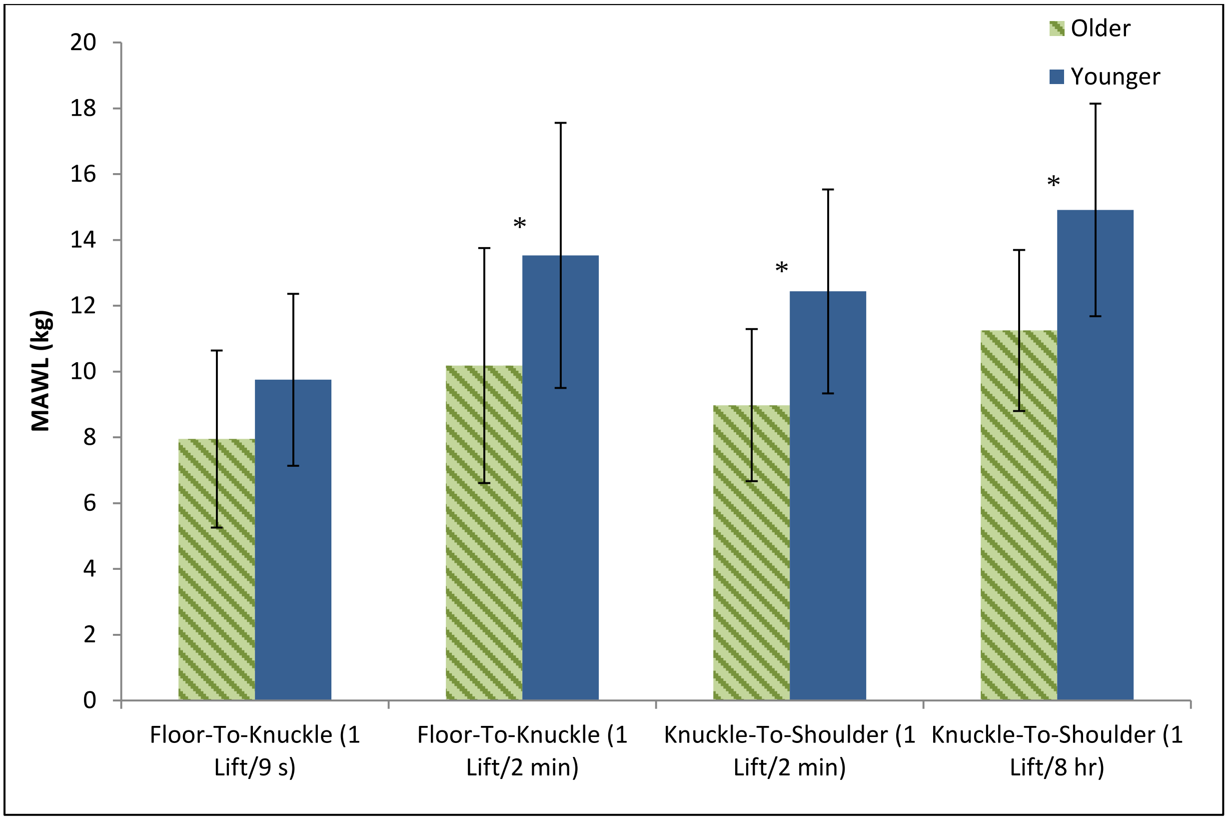


Figure 3. 5: Comparison between older and younger workers of mean (SD) MAWL selected for each task. * indicates significant differences between MAWL values for older and younger workers ($p < 0.05$).

Table 3. 3: Percent difference between the *MAWL* selected between older and younger workers for each task

Task	% Difference
Floor-to-Knuckle (1 Lift/9 s)	18.5
Floor-to-Knuckle (1 Lift/2 min)	24.7
Knuckle-to-Shoulder (1 Lift/2 min)	27.8
Knuckle-to-Shoulder (1 Lift/8 hr)	24.5

3.4.2 Grip-Strength

The difference in grip strength between the older and younger workers is shown in Table 3. 4. There is a significant difference (p=0.014) between the older and younger workers' grip strength as the older workers had a grip strength 23.8% lower than the younger workers (250.4 N vs. 328.7 N, respectively). In relation to the *MAWL* chosen for each task, the differences between older and younger workers' dominant hand grip strengths and the differences between older and younger workers' in *MAWL*s for the strength tasks were similar (Table 3. 3).

There was a significant correlation (R=0.51-0.62) between the grip strength of the dominant hand and the *MAWL* chosen for each task for the younger and older workers as shown below in Table 3. 5. When separating the older and younger workers, it was found that there were positive correlations between grip strength and final *MAWL*, however, these correlations did not reach significance (older: p=0.055-0.244; younger: p=0.032-0.447), except for the younger worker's grip strength and 1 lift/9 s from floor-to-knuckle height. From this, looking at the percent difference between grip strength of older and younger workers and *MAWL* of older and younger workers is similar. Although there were correlations between grip strength and *MAWL* selected, these correlations were not very high. The current study provides no rationale for using grip strength as a means for screening people.

Table 3. 4: Comparison of mean (SD) grip strength (in N) between younger and older workers for the dominant hand

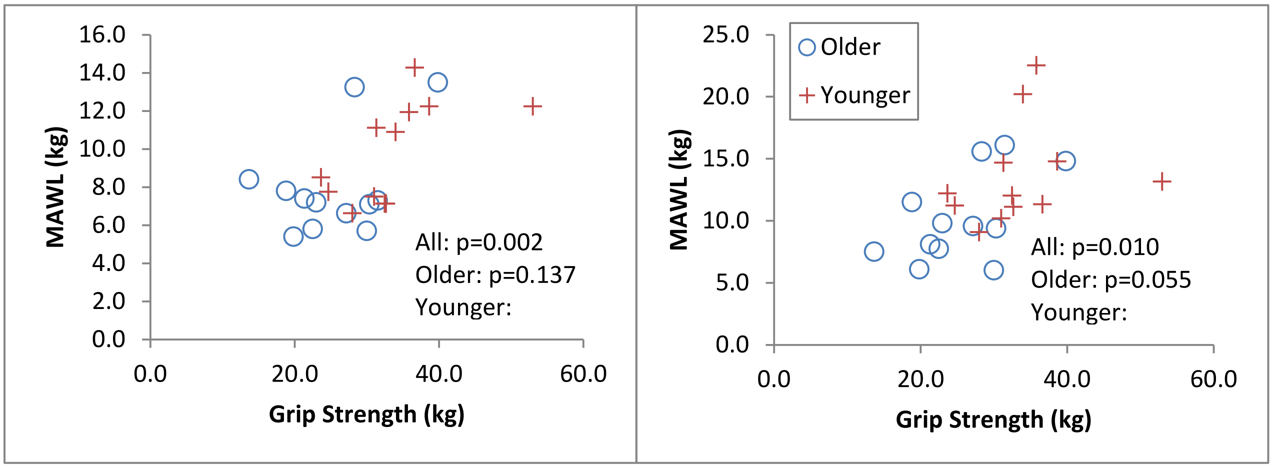
	Grip Strength (SD)	Mean difference (N)	% Difference	t (p) values
Older	250.4 (68.9)	78.3	23.8	-2.669 (0.014)
Younger	328.7 (74.8)			

Table 3. 5: Pearson correlation results between mean participant grip strength and mean final *MAWL* for each task.

		Correlations			
		MAWL Floor-to-Knuckle (1 lift/9 s)	*MAWL* Floor-to-Knuckle (1 lift/2 min)	*MAWL* Knuckle-to-Shoulder (1 lift/2 min)	*MAWL* Knuckle-to-Shoulder (1lift/8 hr)
All participants	R	0.606**	0.513*	0.629**	0.596**
	P	0.002	0.010	0.001	0.002
Older workers	R	0.455	0.566	0.470	0.379
	P	0.137	0.055	0.123	0.224
Younger workers	R	0.618*	0.243	0.515	0.494
	P	0.032	0.447	0.087	0.102

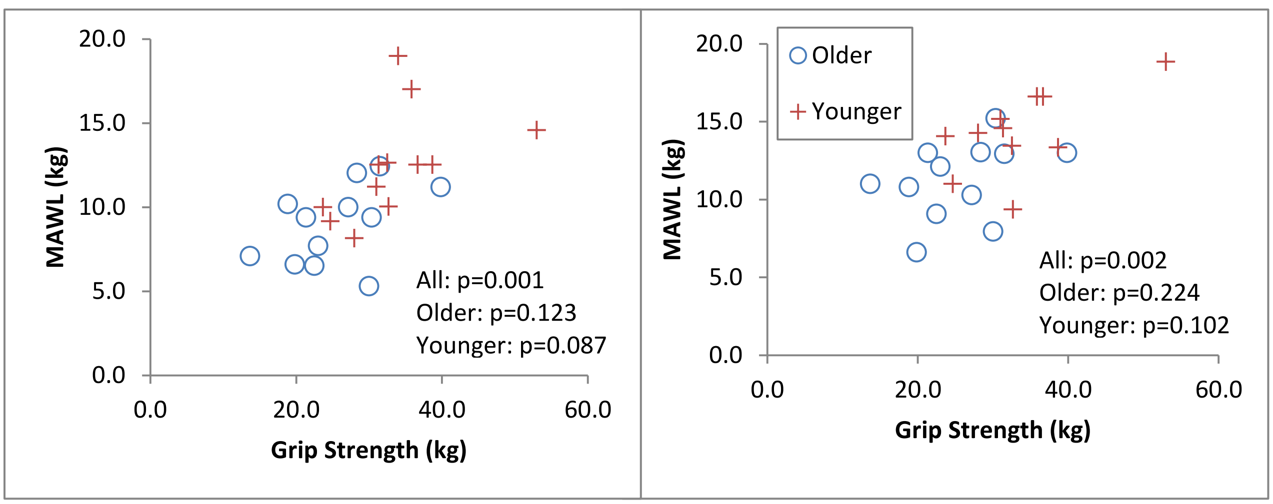
** Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)



1 lift/9 s **1 lift/2 min**

Floor-to-Knuckle Height



1 lift/2 min **1 lift/8 hr**

Knuckle-to-Shoulder Height

Figure 3. 6: Scatterplots between participant-specific MAWL (kg) and grip strength (kg) for each task. P values from Pearson correlations indicated for all participants combined, and separately for the older and younger age groups.

3.4.3 Maximum Sagittal Plane Joint Angles of the Shoulder, Hip and Knee

ANOVA demonstrated that there were no effects of age or task, and no age*interactions, on maximum sagittal plane joint angles at the right $shoulder_{max}$, left hip_{max} and left and right $knee_{max}$ (Table 3. 6). Although there were no significant difference between the older and younger workers, there were age*task interactions (F=4.152, p=0.015) for the right hip_{max} (Table 3.7). T-tests for each task indicated that there were significant differences between older and younger workers for the right hip_{max} during the 1 lift/2 min (t=-2.22, p=0.041) from floor-to-knuckle height lifting task, but no significant differences between the older and younger workers for right hip_{max} for the remaining tasks (Table 3. 7.). During the 1 lift/2 min from floor-to-knuckle height, the older participants flexed their hips more than the younger workers (mean(SD) 104.8 (48.32) vs. 139.2 (23.0) degrees). Overall trends will be discussed. Although there were no significant differences between the older and younger workers' joint angles (at the shoulder, left hip or left and right knee), the older workers flexed at their hips and knees more than the younger workers in the floor-to-knuckle height lifting tasks (Table 3. 8). In addition to having larger flexion angles than the younger workers at the hips and knees, older workers also had larger shoulder flexion angles (indicating that they were reaching out in front of themselves more shown by an increase in shoulder flexion)(Table 3. 8).

Table 3. 6: F-ratio (p-value) from the repeated measures ANOVA tests on maximum sagittal plane joint angles

	ANOVA		
Joint Angle	**Age**	**Task**	**Interaction**
Shoulder $_{max}$***(°)***	1.563 (0.225)	1.879 (0.169)	0.315 (0.716)
Right Hip $_{max}$***(°)***	2.037 (0.168)	13.034 (<0.001)*	4.152 (0.015)*
Left Hip $_{max}$***(°)***	0.727 (0.403)	8.854 (<0.001)*	2.378 (0.092)
Right Knee $_{max}$***(°)***	0.007 (0.935)	35.020 (<0.001)*	0.448 (0.674)
Left Knee $_{max}$***(°)***	1.507 (0.233)	12.358 (<0.001)*	0.149 (0.898)

* represents a significant effect (p < 0.05)

Table 3. 7: Mean (SD) maximum sagittal plane joint angles (°) of the right hip for younger and older workers for each task with t(p) values from a t-test

Task	Older	Younger	t(p)
Floor-to-knuckle (1 lift/9 s)	93.5 (9.9)	85.1 (9.5)	-1.99 (0.069)
Floor-to-knuckle (1 lift/2 min)	101.9 (10.0)	85.3 (9.8)	-2.22 (0.041)*
Knuckle-to-shoulder (1 lift/2 min)	99.5 (13.0)	76.4 (12.5)	0.29 (0.777)
Knuckle-to-shoulder (1 lift/8 hr)	85.4 (14.0)	66.4 (13.4)	-0.33 (0.748)

* represents a significant effect (p < 0.05)

Table 3. 8: Mean (SD) maximum sagittal plane joint angles (°) of the shoulder, right and left hip and knee for older and younger workers for each lifting task.

Joint	Age Group	Floor-to-knuckle (1lift/9s)	Floor-to-knuckle (1lift/2min)	Knuckle-to-shoulder (1lift/2min)	Knuckle-to-shoulder (1lift/8hr)
Shoulder	Older	93.5 (9.9)	101.9 (10.0)	99.5 (13.0)	85.4 (14.0)
	Younger	85.1 (9.5)	85.3 (9.8)	76.4 (12.5)	66.4 (13.4)
Right Hip	Older	113.9 (11.2)	108.4 (11.4)	161.5 (3.9)	156.5 (4.4)
	Younger	140.7 (10.5)	139.1 (10.6)	149.8 (5.5)	158.4 (4.1)
Left Hip	Older	117.6 (12.3)	117.6 (9.6)	157.3 (4.5)	156.0 (5.5)
	Younger	135.3 (11.5)	139.7 (9.1)	159.9 (4.2)	142.2 (7.9)
Right Knee	Older	89.8 (10.1)	76.0 (9.0)	143.9 (6.8)	146.1 (7.1)
	Younger	78.0 (9.6)	85.5 (9.3)	142.5 (8.7)	149.7 (6.7)
Left Knee	Older	122.4 (11.5)	117.3 (10.7)	146.2 (5.5)	146.9 (5.8)
	Younger	128.4 (10.9)	130.9 (9.9)	157.7 (5.3)	160.3 (5.8)

Age and task had significant effects on the point in the lifting cycle where maximum joint angles occurred. For $shoulder_{max}$, there was no significant difference (F=0.052; p=0.822) between the older and younger workers (Table 3.9) and a significant interaction effect (F=4.529, p=0.036). T-tests for each task indicated that there were significant differences between older and younger workers in terms of the percentage lift cycle that their $shoulder_{max}$ was occurring for the floor-to-knuckle height tasks, but not for the knuckle-to-shoulder height tasks (Table 3. 10). Younger participants in for both floor-to-knuckle height lifting tasks forward flexed their arms earlier than the older participants (mean (SD): 8.81 (4.92) vs. 27.56 (5.26) for 1 lift/9 s and 13.63 (6.92) vs. 35.84 (7.40)). There were also interaction effects for the point in the lift cycle in which the maximum sagittal plane flexion angle at the right knee occurred (F=5.208, p=0.003), although there were no age effects (F=1.052, p=0.317) (Table 3.9). T-tests for each task indicated that there were significant differences between older and younger workers in terms of the percentage lift cycle that their right $knee_{max}$ was occurring for the 1 lift/8 hr for the knuckle-to-shoulder height tasks, but not for the other tasks (Table 3. 10). Younger participants bent their right knee earlier than the older participants while picking up the box off of the shelf (mean (SD): 28.58 (9.29) % vs. 56.64 (9.84) %).

Younger workers were increased their shoulder flexion to pick up the boxes for the floor-to-knuckle height lifting tasks within the first 15% of the lift cycle, while the older workers' maximum sagittal plane shoulder flexion occurred between 27-35% of the lift cycle (Table 3. 11). The percent of the lift cycle in which the maximum sagittal plane hip and knee angles occurred were not significantly different between the older and younger workers (p>0.200). For the floor-to-knuckle height lifting task, the hip_{max} and $knee_{max}$ flexion angles occurred within the first 30% of the lift cycle.

Table 3. 9: F-ratio (p-value) from the repeated measures ANOVA tests on percent of lift cycle in which maximum sagittal plane joint angles occur

	ANOVA		
Joint	**Age**	**Task**	**Interaction**
Shoulder	0.052 (0.822)	16.491 (<0.001)*	4.529 (0.036)*
Right Hip	0.929 (0.346)	6.629 (0.001)*	0.204 (0.879)
Left Hip	<0.001 (0.996)	5.977 (0.002)*	0.003 (0.999)
Right Knee	1.052 (0.317)	3.368 (0.027)*	5.208 (0.003)*
Left Knee	2.352 (0.140)	2.938 (0.040)*	0.262 (0.852)

* represents a significant effect (p < 0.05)

Table 3. 10: Average (SD) percent lift cycle where maximum sagittal plane joint angle (°) occured for younger and older workers for each task with t(p) values from a t-test.

Joint	Task	Older	Younger	t(p)
Shoulder	**Floor-to-knuckle (1 lift/9 s)**	27.6 (5.3)	8.8 (4.9)	2.92 (0.013)*
	Floor-to-knuckle (1 lift/2 min)	35.8 (7.4)	13.6 (6.9)	2.51 (0.025)*
	Knuckle-to-shoulder (1 lift/2 min)	57.6 (11.3)	76.4 (10.5)	-1.34 (0.194)
	Knuckle-to-shoulder (1 lift/8 hr)	46.3 (11.7)	75.3 (10.9)	-1.83 (0.081)
Right Knee	**Floor-to-knuckle (1 lift/9 s)**	21.4 (7.6)	36.9 (7.3)	-0.83 (0.418)
	Floor-to-knuckle (1 lift/2 min)	17.9 (8.2)	44.2 (7.7)	-1.82 (0.082)
	Knuckle-to-shoulder (1 lift/2 min)	41.7 (8.4)	57.9 (7.9)	-1.24 (0.226)
	Knuckle-to-shoulder (1 lift/8 hr)	56.6 (9.8)	28.6 (9.3)	2.09 (0.049)*

* represents a significant effect ($p < 0.05$)

Table 3. 11: Average (SD) percent of lift cycle where maximum sagittal plane shoulder, hip and knee angle occured for older and younger workers across tasks.

Joint	Age Group	Average	Floor-to-Knuckle (1Lift/9s)	Floor-to-Knuckle (1Lift/2min)	Knuckle-to-Shoulder (1Lift/2min)	Knuckle-to-Shoulder (1Lift/8hr)
Shoulder	Older	41.8 (5.5)	27.6 (5.3)	35.8 (7.4)	57.6 (11.3)	46.3 (11.7)
	Younger	43.5 (5.2)	8.8 (4.9)	13.6 (6.9)	76.4 (10.5)	75.3 (10.9)
Right Hip	Older	31.9 (3.9)	18.3 (6.1)	19.9 (6.2)	49.7 (8.5)	39.9 (9.3)
	Younger	26.9 (3.7)	15.8 (5.7)	19.7 (5.8)	42.4 (7.9)	29.3 (8.7)
Left Hip	Older	32.6 (5.9)	26.3 (8.7)	26.1 (8.3)	49.1 (9.1)	28.9 (7.3)
	Younger	32.7 (5.7)	26.8 (8.3)	25.5 (7.8)	49.9 (8.5)	29.3 (6.8)
Right Knee	Older	34.5 (5.3)	21.4 (7.6)	17.9 (8.6)	41.7 (8.4)	56.6 (9.8)
	Younger	41.9 (5.0)	36.9 (7.3)	44.2 (7.7)	57.9 (7.9)	28.6 (9.3)
Left Knee	Older	41.7 (4.9)	32.9 (8.8)	30.8 (7.4)	52.3 (7.8)	51.0 (10.2)
	Younger	31.3 (4.8)	26.9 (8.3)	23.6 (6.9)	41.7 (7.3)	32.5 (9.8)

3.4.4 Body Part Specific (mean (SD)) and Whole Body RPE Values across Each Task for Older and Younger Workers

There were no significant differences in the $RPE_{Overall}$ of the older and younger workers (F=0.679, p=0.419; Table 3. 12) or any interaction effects (F=1.154, p=0.334). The participants scored the first task (1 lift/9 s from floor-to-knuckle height) with the highest $RPE_{Overall}$ score (5.17 (0.38)) indicating that the task was "strong/heavy" (Figure 2. 2). The other three tasks were rated fairly similarly with a "moderate" overall score (score ranged between 3 and 4). The cardiovascular task had a significantly higher $RPE_{Overall}$ than the strength tasks; there were no significant differences between the $RPE_{Overall}$ for the strength tasks (Figure 3.7).

The older and younger workers ratings for the RPE_{Elbow}, $RPE_{Shoulder}$, $RPE_{UpperBack}$, and $RPE_{LowerBack}$ for the knuckle-to-shoulder height lifting tasks were not significantly different (p=0.682) (Table 3. 12), there were also no interaction effects (Table 3. 12). The RPE for the task knuckle-to-shoulder height at a frequency of 1 lift/2 min and knuckle-to-shoulder height at a frequency of 1 lift/8 hr, were not significantly different (F=0.172, p=0.682) either. The RPE_{Elbow} had the lowest score (1.35 (2.89)) indicating that the task did not affect them at the elbow ("weak"). The workers rated their $RPE_{Shoulder}$, $RPE_{UpperBack}$, and $RPE_{LowerBack}$ as "weak/light" for these two tasks. The $RPE_{Shoulder}$ had the highest RPE rating (2.30), with the older workers rating their shoulders higher than the younger workers for the 1lift/2 min (2.25 vs. 2.17), however, the younger workers rated their shoulders higher than the older workers for the 1 lift/8 hr (2.42 vs 2.33).

There was no significant difference for older and younger workers for the $RPE_{\mathrm{LowerBack}}$ or RPE_{Thigh}, (F=1.708, p=0.205) for the floor-to-knuckle height lifting task (Table 3. 12). Although there were no significant differences between the older and younger workers for the $RPE_{\mathrm{LowerBack}}$ or RPE_{Thigh}, there were significant differences between older and younger workers for RPE_{Knee} (F=4.681 p=0.042). Younger workers scored their knees significantly higher than the older workers (4.66 vs 2.58) during the 1 lift/ 9s from floor-to-knuckle height. Younger workers scored their RPE_{Thigh} a higher ("moderate") RPE than the older workers for both of the floor-to-knuckle height lifting tasks (4.00 vs. 3.25) ("moderate"). The older workers scored their $RPE_{\mathrm{LowerBack}}$ higher than the younger workers for the 1 lift/2 min from floor-to-knuckle height; however, the difference was only by 0.4.

Table 3. 12: F-ratio (p-value) from the repeated measures ANOVA tests on RPE for overall and body part specific for each task

	ANOVA			
	Body Part	**Age**	**Task**	**Interaction**
	Overall	0.679 (0.419)	9.108 (<0.001)*	1.154 (0.334)
Floor-to-Knuckle	**Knee**	4.681 (0.042)*	4.853 (0.038)*	0.229 (0.673)
	Thigh	1.917 (0.180)	0.514 (0.481)	0.159 (0.694)
	Low Back	0.415 (0.526)	5.604 (0.027)*	0.185 (0.671)
Knuckle-to-Shoulder	**Low Back**	0.038 (0.847)	0.253 (0.620)	1.379 (0.253)
	Upper Back	0.024 (0.879)	1.471 (0.238)	0.529 (0.475)
	Shoulder	<0.001 (1.000)	0.134 (0.717)	0.034 (0.856)
	Elbow	1.093 (0.307)	2.789 (0.109)	0.310 (0.583)

* represents a significant effect ($p < 0.05$)

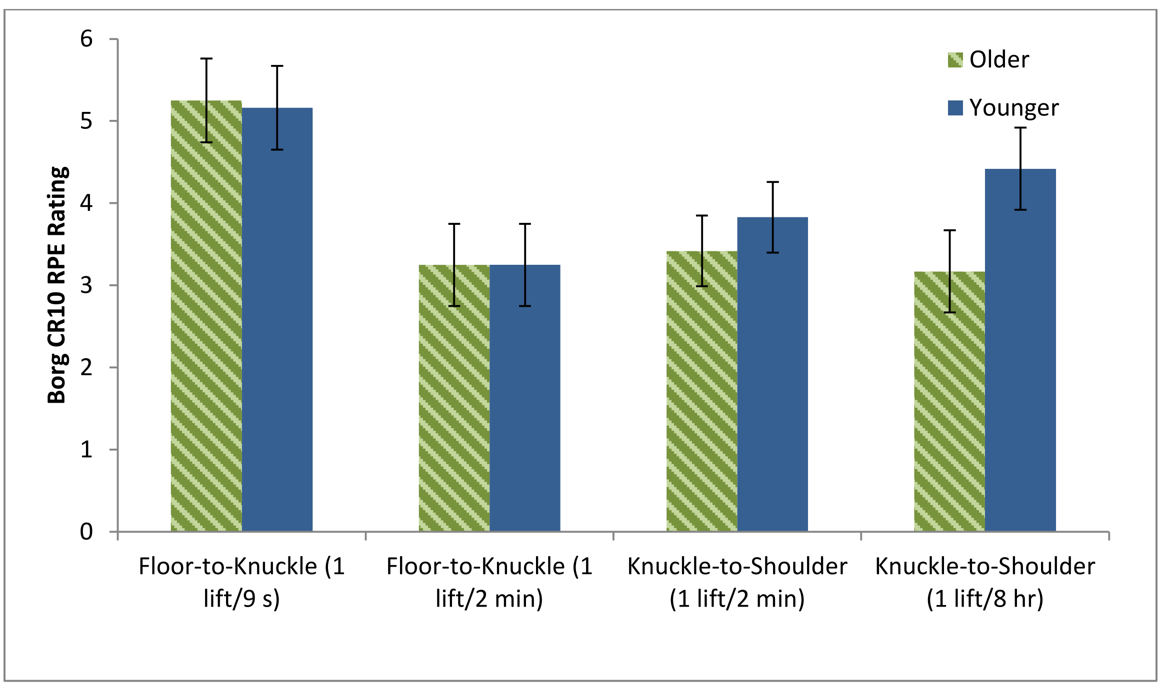


Figure 3. 7: Mean (SD) overall RPE of older and younger workers at the end of the lifting task

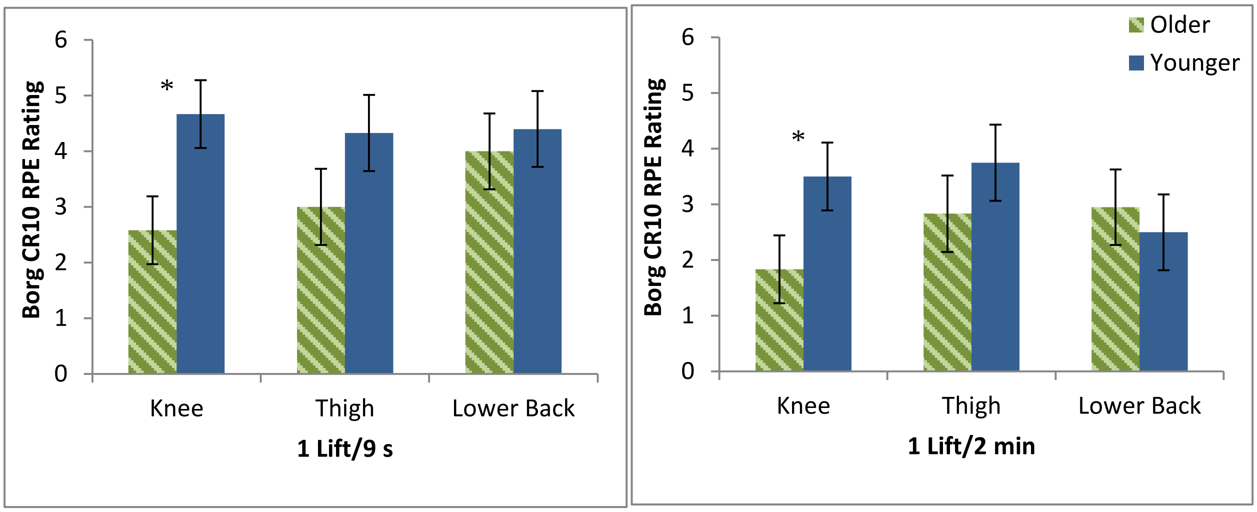


Figure 3. 8: Mean (SD) Body part specific RPE for floor-to-knuckle height lifting tasks (1lift/9s and 1lift/2 min) for older and younger workers. * indicates significant differences between RPE values for older and younger workers ($p < 0.05$).

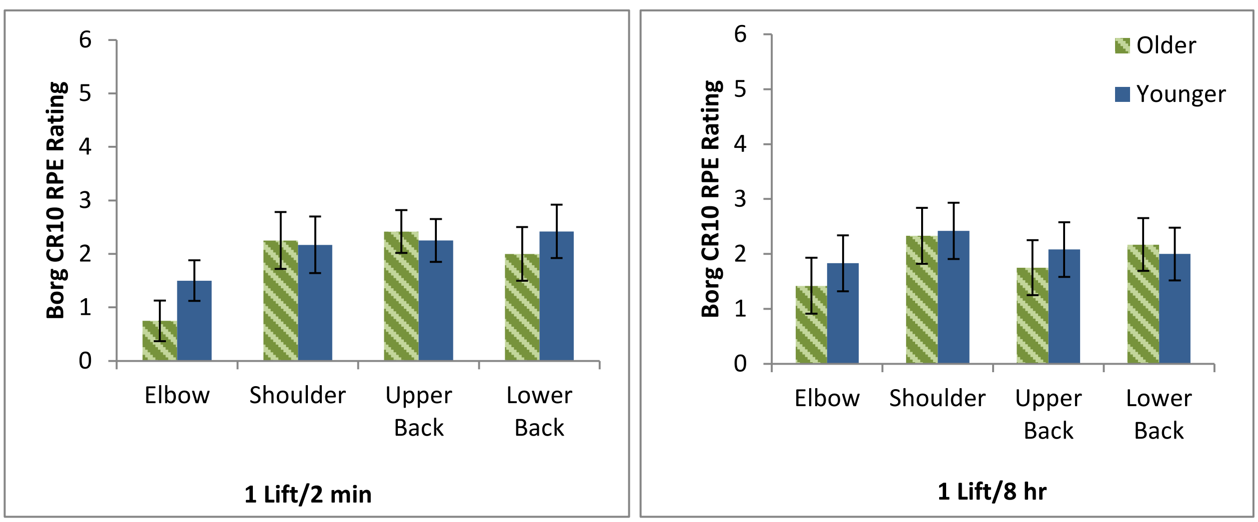


Figure 3. 9: Mean (SD) body part specific RPE for knuckle-to-shoulder height lifting tasks for older and younger workers

3.4.5 Self-Selected Mass throughout 30 Minute Adjustment Period and Final *MAWL*

For the 1 lift/ 9 s from floor-to-knuckle height lifting task, the difference between the mass chosen at the end of the 30 minute task was not significantly different to the mass chosen prior to the perturbation halfway through the lifting task for both older and younger workers (Table 3. 14). For the 1 lift/2 min from floor-to-knuckle and knuckle-to-shoulder height, the older workers chose masses approximately 7 and 8% higher than the mass chosen to the perturbation at 15 minutes into the lifting session (halfway) (Figure 3. 10). This indicates that the women were constantly thinking about the load that they were able to lift throughout the task and adjusting it according to what they were comfortable lifting at each frequency for an entire work day (8 hr). Similar to the older workers, the younger workers chose loads higher than their estimate at 15 minutes prior to the perturbation for 1 lift/2 min from floor-to-knuckle and knuckle-to-shoulder height, approximately 10 to 13% higher (Figure 3. 11). For the 1 lift/9 s from the floor-to-knuckle height lifting task, the younger workers chose loads that were approximately 1% higher than their estimate prior to the perturbation (Figure 3. 11).

Although the loads prior to the perturbation were similar to the loads post-perturbation, there were significant differences between these values (F_1=9.252, p=0.006) (Table 3. 13). There were also interaction effects between task and time (F_2=6.658; p=0.007). The participants were selecting masses that were significantly higher after the perturbation than before (pre-perturbation: 9.77 (0.493) kg post perturbation: 10.474 (0.568) kg difference: 0.704 kg). For the 1 lift/9 s from floor-to-knuckle height task there was a difference of 0.1 kg between the pre-perturbation value and the post-perturbation value (Table 3. 14). For the 1 lift/2 min from floor-to-knuckle height task, the mass chosen pre-perturbation and post-perturbation was 0.9 kg difference and the 1 lift/2 min from knuckle-to-shoulder height difference was 1.2 kg.

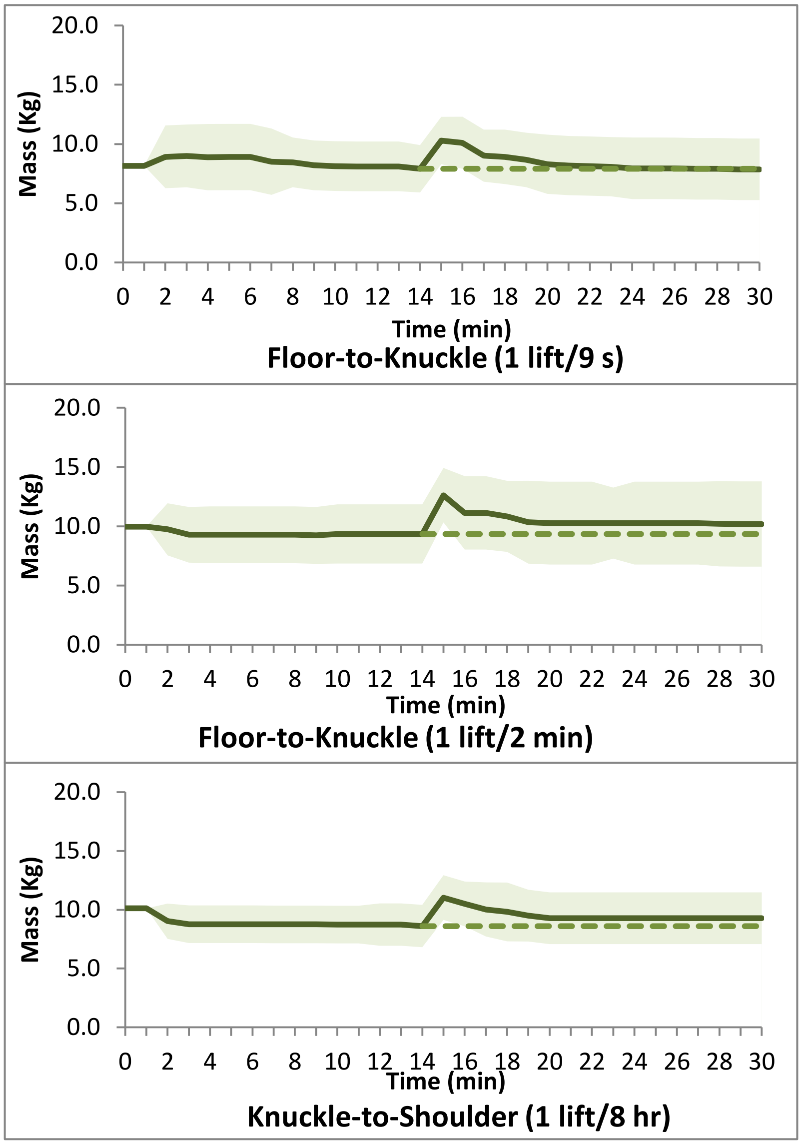


Figure 3. 10: Older worker mean (SD) load selections throughout 30 minute tasks. Note that a perturbation equal to a 2 kg (for floor-to-knuckle at 1 lift/9 s and knuckle-to-shoulder at 1 lift/2 min) and 3 kg (for floor-to-knuckle at 1 lift/2 min) increase was introduced at t = 15 min.

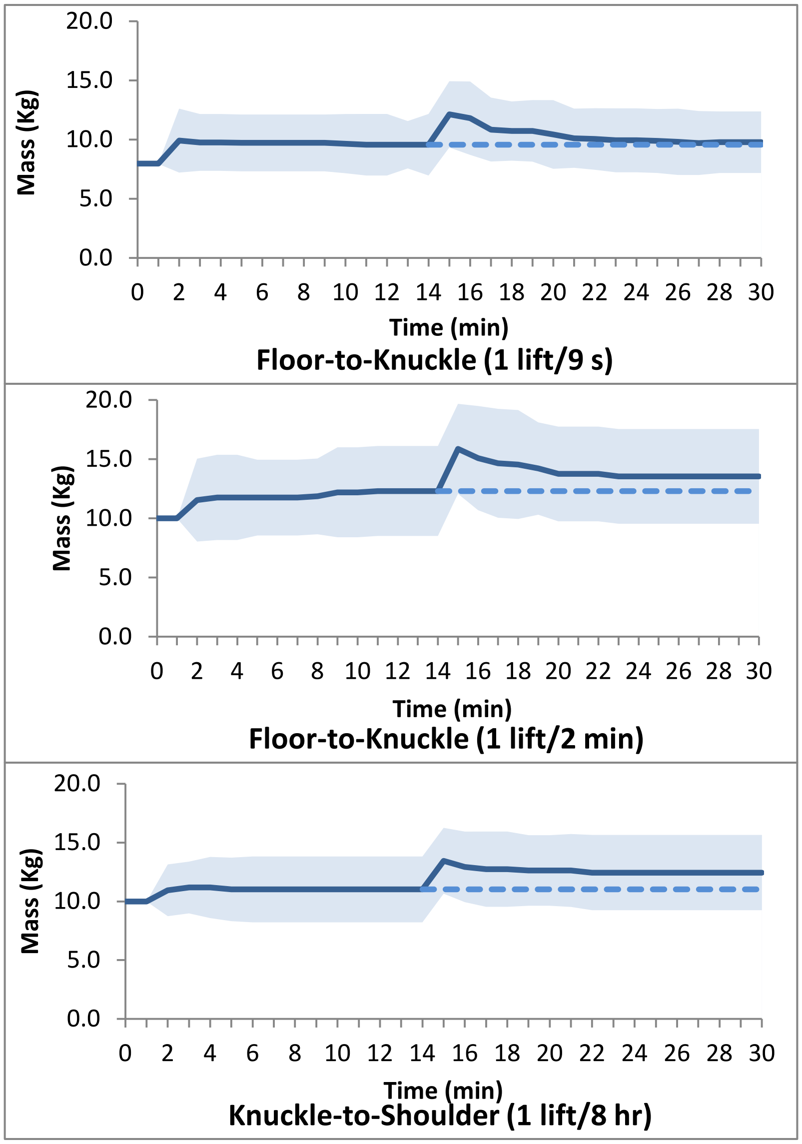


Figure 3. 11: Younger workers mean (SD) load selection throughout 30 minute tasks. Note that a perturbation equal to a 2 kg (for floor-to-knuckle at 1 lift/9 s and knuckle-to-shoulder at 1 lift/2 min) and 3 kg (for floor-to-knuckle at 1 lift/2 min) increase was introduced at t = 15 min.

Table 3. 13: F-ratio (p-value) from the repeated measures ANOVA tests on the MAWL at pre- and post-perturbation

	ANOVA						
	Age	**Time**	**Task**	**Task*Age**	**Time*Age**	**Time*Task**	**Task*Time* Age**
MAWL	6.466 (0.019)*	9.252 (0.006)*	20.158 (<0.001)	1.656 (0.203)	1.224 (0.281)	5.658 (0.007)*	0.331 (0.720)

* represents a significant effect ($p < 0.05$)

Table 3. 14: Mean (SD) participant mass selection pre- and post-perturbation.

Task	Group	Pre MAWL (kg)	Final MAWL (kg)	Pre-Final Difference (kg)	Percent Difference from Pre (%)
Floor-to-Knuckle (1 lift/9 s)	Older	7.904 (0.659)	7.885 (0.763)	0.019	0.2
	Younger	9.565 (0.922)	9.777 (0.763)	-0.212	-2.2
Floor-to-Knuckle (1 lift/2 min)	Older	9.533 (0.922)	10.193 (1.099)	-0.66	-6.9
	Younger	12.309 (0.922)	13.541 (1.099)	-1.232	-10.0
Knuckle-to-Shoulder (1 lift/2 min)	Older	8.298 (0.676)	8.998 (0.801)	-0.7	-8.4
	Younger	11.018 (0.676)	12.449 (0.801)	-1.431	-12.9

3.4.6 Heart Rate

The heart rates between the younger workers and older workers were not significantly different at the end of each task (F=1.059, p=0.315) and during rest (F=0.669, p=0.422). The heart rate at the end of each task and the resting heart rate of the workers were significantly different (p<0.001) (Table 3.16). The heart rate was the highest (131.1 (3.54) bpm) for 1 lift/9 s from floor-to-knuckle height and the lowest during rest. The 1 lift/2 min lifting tasks as well as the 1 lift/8 hr task had similar heart rate values as seen in Table 3.15. There were significant differences (F=1.457, p=0.046) between the older and younger workers for the percentage of their age-adjusted maximum heart rates for the tasks, with older workers' heart rate closer to their maximum heart rate than the younger workers (Table 3.15). There were also significant differences between the older and younger worker's heart rates from resting to each task (F=4.878, p=0.038). In this case, the younger workers had a larger difference between their final heart rate at the end of each task compared to their resting heart rate than the older workers.

Table 3. 15: F-ratio (p-value) from the repeated measures ANOVA tests on heart rate for participants at the end of each lifting task

	ANOVA		
	Age	**Task**	**Interaction**
Heart Rate	0.669 (0.422)	121.167 (<0.001)*	1.576 (0.188)
% of Age-adjusted Max Heart Rate	4.457 (0.046)*	116.586 (<0.001)*	0.441 (0.779)
Difference from Resting	4.878 (0.038)*	102.308 (<0.001)*	0.329 (0.805)

* represents a significant effect (p < 0.05)

Table 3. 16: Mean (SD) heart rate (SD) for older and younger workers at rest and at the end of each lifting task.

Task	Age Group	Heart Rate (SD) (bpm)	% of Max Heart Rate (SD)	Difference from Resting (SD)(bpm)
Rest	Older	76.7 (3.2)	54.9(2.08)	---
	Younger	74.1 (3.2)	44.6 (4.08)	---
Floor-to-Knuckle (1 lift/9 s)	Older	125.3(6.3)	89.6 (4.08)	48.6 (4.62)
	Younger	134.8(6.3)	81.2 (4.08)	60.8 (4.62)
Floor-to-Knuckle (1 lift/2 min)	Older	91.2 (4.9)	65.2 (3.10)	14.6 (3.81)
	Younger	96.8 (4.9)	58.3 (3.10)	22.8 (3.81)
Knuckle-to-Shoulder (1 lift/2 min)	Older	92.3 (4.3)	66.1 (2.70)	15.8 (3.10)
	Younger	97.4 (4.2)	58.6 (2.70)	23.3 (3.10)
Knuckle-to-Shoulder (1 lift/8 hr)	Older	89.8 (4.8)	64.3 (2.92)	13.2 (3.07)
	Younger	96.8 (4.8)	58.2(2.92)	22.7 (3.07)

3.5 Discussion

The purposes of this thesis were to test the hypothesis that psychophysical estimates of maximum acceptable loads would differ across young and older workers during selected lifting tasks, and to gain insights into whether these results corresponded to age-related differences across a range of secondary biomechanical, cardiovascular, and perceived exertion factors. This Discussion section will reflect these goals. First, I will summarize the *MAWL* results with respect to my specific hypotheses, and critically interpret them within the framework of the existing literature in the area. This will be followed by a discussion of age-related effects on each secondary variable, and how these results potentially relate to my primary interest on age-related differences in *MAWL*.

3.5.1 Discussion of *MAWL* Results

Regarding my main hypothesis, older workers chose *MAWL* values that were 23.8% lower than younger workers (9.6 kg vs. 12.6 kg, respectively). The *MAWL*s selected by the older workers were significantly lower than the younger workers during the three of the four lifting tasks (1 lift/2 min from floor-to-knuckle height, and 1 lift/2 min and 1 lift/8 hr from knuckle-to-shoulder height) (refer to section 3.4.1). Although a significant interaction effect did not exist, age-related effects for each specific lifting task were also looked at.

In support of hypothesis 1 b, I found that the significant differences between the absolute *MAWL* chosen for the knuckle-to-shoulder height lifting tasks were greater than the differences between the absolute *MAWL* chosen for the floor-to-knuckle height lifting tasks. This follows the evidence indicating that females show a decrease in upper limb strength from the ages of 59-69 years old, and a decrease in lower limb strength from 70 years and older (Calmels, Vico et al. 1995). In support of hypothesis 1 c, I found that the older workers were selecting significantly lower *MAWL*s for the strength tasks (1 lift/2 min from floor-to-knuckle height and knuckle-to-shoulder height, and 1 lift/8 hr from knuckle-to-shoulder height) than the younger workers. There was no significant difference between the *MAWL* selected for the 1 lift/9 s task between the older and younger workers. Although there was no significant difference between the older and younger workers for this task, the older workers were selecting loads approximately 2 kg lower than the younger workers. The differences in *MAWL* were hypothesized as it has been shown that muscle strength reaches its peak around the age of 30 and is well maintained until 50 years old (Deschenes 2004). After 50 years of age, it has been shown that aging is associated with a loss of muscle and continues to decrease at approximately 15% per decade and becomes more dramatic after 60 years old (Deschenes 2004). This loss of muscle is directly related to a decrease in muscle function and force. No significant differences for the *MAWL* during the cardiovascular task follows previous literature stating that dynamic strength tests have found decreases for older groups and that no changes have been found with dynamic endurance (Larsson and Karlsson 1978). Also that sarcopenia is most common among type II muscle fibres (fast twitch) which play a large role in diminished muscle power and strength (Deschenes 2004).

Contrary to what I found in my study, Wright and Mital (1999) reported that there was no effect of age on the MAWL selected by the participants. The measurements taken in the Wright and Mital (1999) study were dynamic psychophysical measures (using the Borg scale) and the MAWL. The lift heights consisted of a floor to 80 cm and from 80 cm to 132 cm. In addition to this study, Wright and Mital (1999) also did a study involving carrying. The same participants were used in this study. The objective was to determine the dynamic psychophysical carrying strengths (maximum acceptable weight of carry, MAWC) through a range of motions (Wright and Mital 1999). In this study it was found that there were significant differences for age, gender, oxygen uptake, and heart rate. Overall, older males had a higher physiological burden while carrying a lighter load compared to their younger counterparts. Although no differences were found between the older and younger participants during the lifting task, this may have been because the participants selected were not experienced manual materials handlers. However, these studies suffered from the following limitations.

The population as stated earlier were people that worked or were physically active (including walking) three times per week. As stated in section 2.4.1. it is important to choose experienced participants when conducting a psychophysical study as experienced participants produce reliable results and inexperienced participants tend to select heavier weights than they could actually handle over an entire work day (Potvin, Chiang et al. 2000; Marras, Parakkat et al. 2006). In addition to the participants being inexperienced MMH, their participants also had a large variation in their body mass, with the older males weighing up to 20 kg on average more than the younger males. The MAWL values chosen by the older males and younger males had a high variability (older males 15.4 kg and younger males 11.2 kg). The findings from my study are different than those presented in the Wright and Mital (1999) lifting paper. In contrast, my study addressed some of these limitations by recruiting participants that were all manual material handlers by a temporary agency, the results may be more applicable to the work force as the workers were all doing or had previously done manual labour jobs. In addition, the participants in the younger group for my study were weight matched with the older participants in order to avoid the large differences in weight between the participant groups like those recruited in the Wright and Mital (1999) study. The standard deviation in the *MAWL* for my study was approximately 8 kg for the older workers and 8 kg for the younger workers (section 3.4.1), while the females in the Wright and Mital (1999) study had a variation of approximately 5.0 kg for older and 4.5 kg for younger workers. Although the participants were weight matched in my study, there was still a larger variation in mass of the participants by group (approximately 16 kg vs.2.6 kg for older and 18.9 kg vs. 17.8 kg for younger). This may have contributed to the larger variation in *MAWL* values. By having a participant pool that consisted of experienced manual material handlers, the results in my study are more representative of the current female working population within the manual material handling field. These participants produced results that had significant differences between the younger and older working population in comparison to the active population in the Wright and Mital (1999) study.

There are several possibilities as to why the *MAWL* values were significantly different between the older and younger workers in my study in comparison to the Wright and Mital (1999) lifting study where they did not find any significant differences in the MAWL selected between the older and younger participants. Some of these are work experience, previous injuries (fear avoidance), overall strength, heart rate, and limiting joints. Firstly, having a lot of work experience would have an effect on the amount that a person would think that they could lift safely for an entire 8 hr work day. Older workers had worked in the manual labour positions longer than the younger workers as they had been in the industry longer. This gave them more experience and ability to judge how much they are able to lift over the younger workers. Secondly, previous injuries have a large effect on how much a worker would choose to lift over an 8 hr work day at various frequencies. Workers that have had previous injuries are more likely to choose loads that they would not reinjure themselves lifting. This would have a greater effect on older workers as the time lost due to injuries increases as the age of the worker increases (Ontario Ministry of Labour 2002). Next, workers take into account how much they are capable of lifting by adjusting the mass of the box and determine if it was an acceptable weight. Heart rate also is an important factor when choosing *MAWL* values. Workers chose the maximum loads that they would be able to lift at each frequency without straining themselves. Although older and younger workers were working at similar heart rates, older workers were working at a higher percentage of their maximum heart rate (section 3.4.6). Even working at a higher percentage of their heart rate, older workers were still choosing lower loads than the younger workers. Lastly, limiting joints may have had a higher impact on older workers than younger workers. Gripping onto the box each time to lift the box seemed to affect the older workers more than the younger workers (from conversations with the participants). Some of the older workers said that it was getting difficult to have to grip the handles each time at the higher frequency (1 lift/9s). The grip strength difference between older and younger workers may have also attributed to the difference in the *MAWL* value selected as the older workers had a harder time gripping the box for each lift than the younger workers. Of these possibilities for the differences in *MAWL* values for the older and younger workers, previous work experience, previous injuries, grip strength and heart rate was collected. Limiting joints, such as hands (finger joints) and fear avoidance was not collected. Although the limiting joints of the hands was not collected, RPE values of the elbow, shoulder, upper back, lower back, thigh and knee were collected. Should the guidelines currently in place be revised in order to accommodate older workers within the workforce, the number of injuries to older workers may be reduced. Accordingly, my study was more appropriately designed to observe potential age-related differences. My findings demonstrate that there are indeed age-related differences in *MAWL*. Additional studies are warranted to determine whether these results extend to a range of different MMH tasks, whether they exist for male workers, and the specific age at which age-related differences begin to appear.

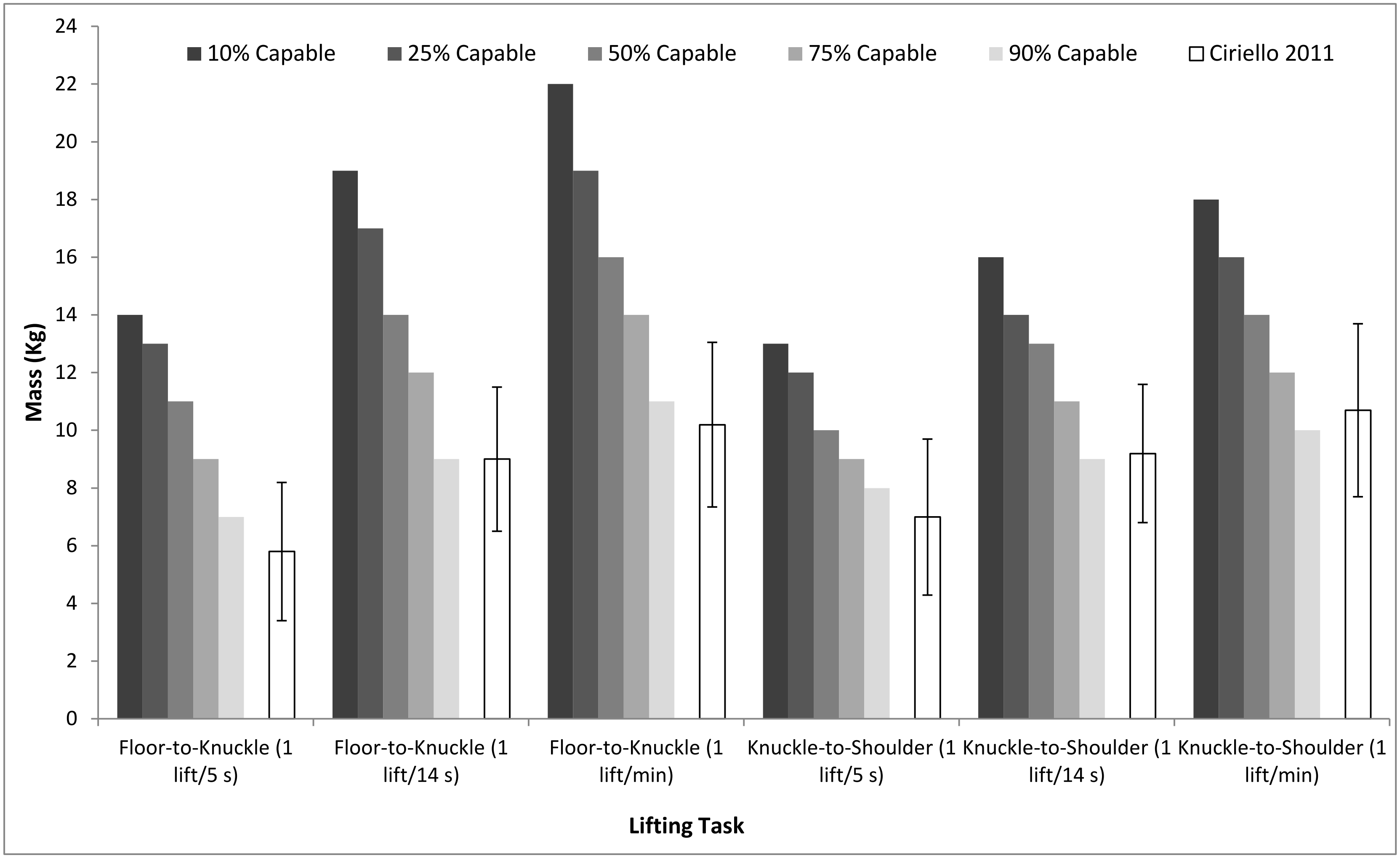


Figure 3. 12: Comparison of Snook and Ciriello (1991) female MAWL values with mean (SD) Ciriello et al. (2011) female values for floor-to-knuckle height and knuckle-to-shoulder height lifting tasks at 1 lift/5s, 1 lift/14s, and 1 lift/min.

A recent study provides some insights into potential shifts in maximal acceptable workload at a societal level over the last two decades. Ciriello et al. (2011) study, found that the female maximum acceptable weights (MAW's) for lifting, lowering and carrying were approximately 67% of the 1991 female values (Snook and Ciriello 1991) (Figure 3. 12). The participants in this study were 40.4 (9.6) years old and weighed 73 (15.6) kg. The participants were required to perform six different tasks which included lifting from floor-to-knuckle and knuckle-to-shoulder height at three frequencies (1 lift/5 s, 1 lift/14 s and 1 lift/min). The lift heights were a distance of 51 cm from each starting position. The MAW's were significantly different ($p<0.05$) for the height range for the lifting and lowering tasks. In comparison to the Snook and Ciriello (1991), the females in the Ciriello et al. (2011) study chose loads between 10-35% lower than what 75% of females thought they would be capable of lifting for and 8 hr work day in the earlier study. The larger differences between the recent study and the Snook and Ciriello (1991) study, was for the 1 lift/5 s tasks, with the smaller differences between selected loads for the 1 lift/min tasks (Figure 3. 12). From this, it is thought that the lower MAW's are associated with the female industrial workforce having a lower set point based on an acceptance for a lower burden on the MSK system (Ciriello, Maikala et al. 2011). The older females in my study may have chosen lower loads to lift for a similar reason, to lower the burden on the MSK system. Ciriello et al (2011) concluded that adjusting existing guidelines may not be appropriate until the findings have been confirmed by replicating the psychophysical experiments on a larger subject pool across the US and other countries. Contrary to this study, the participants in my study were between the ages of 20-30 years old and 50+ years old. The age of the participants within the most recent Ciriello et al (2011) paper closer resemble those in the 50+ age category of my study. This may indicate that choosing lower MAWL values starts as early as 40 years old or that there is a secular change within the working population. There are many studies involving manual materials handling (specifically lifting), but not many look at differences between an older and younger population.

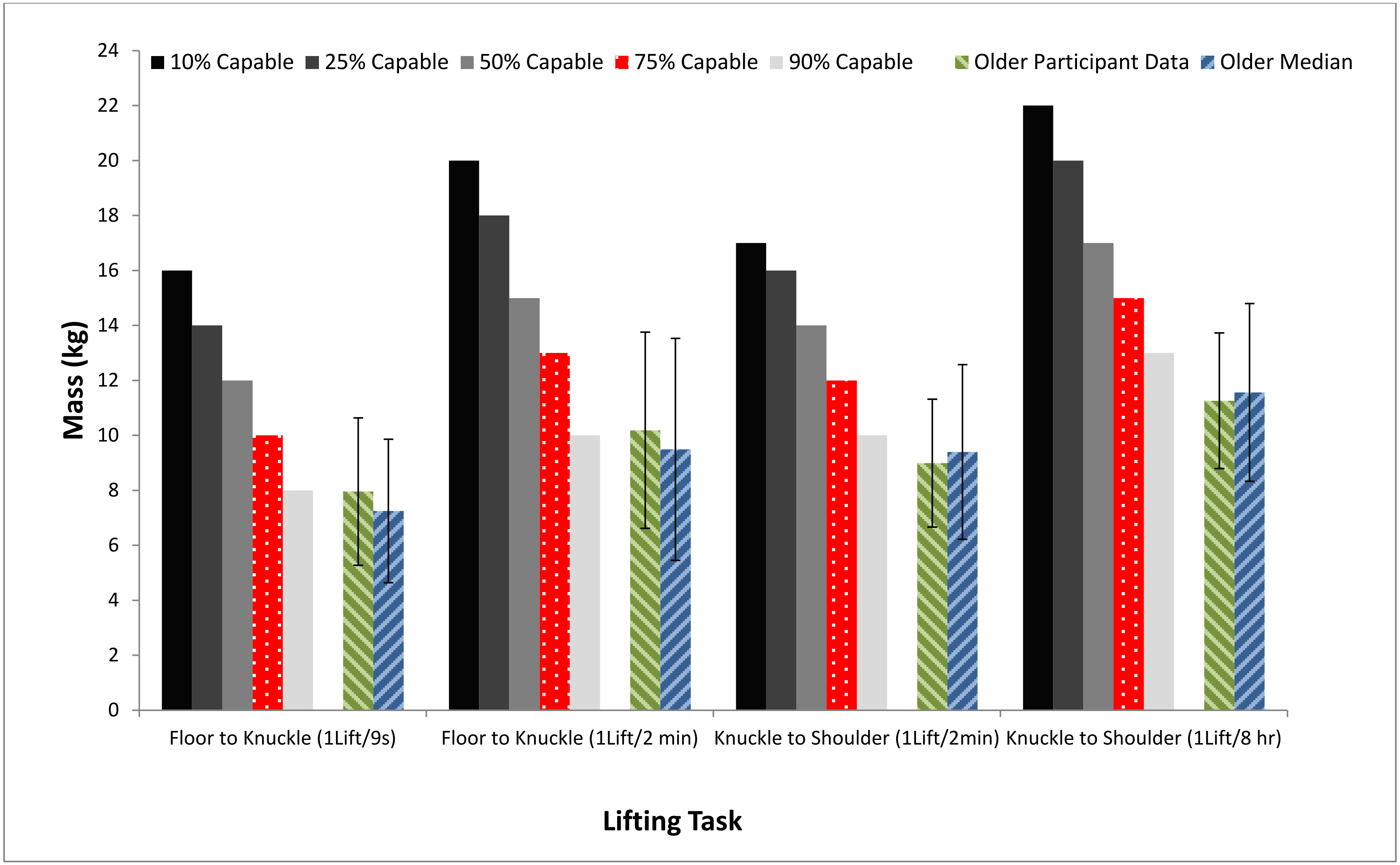


Figure 3. 13: Comparison between mean older and younger workers MAWLS with Snook and Ciriello (1991) values for each task

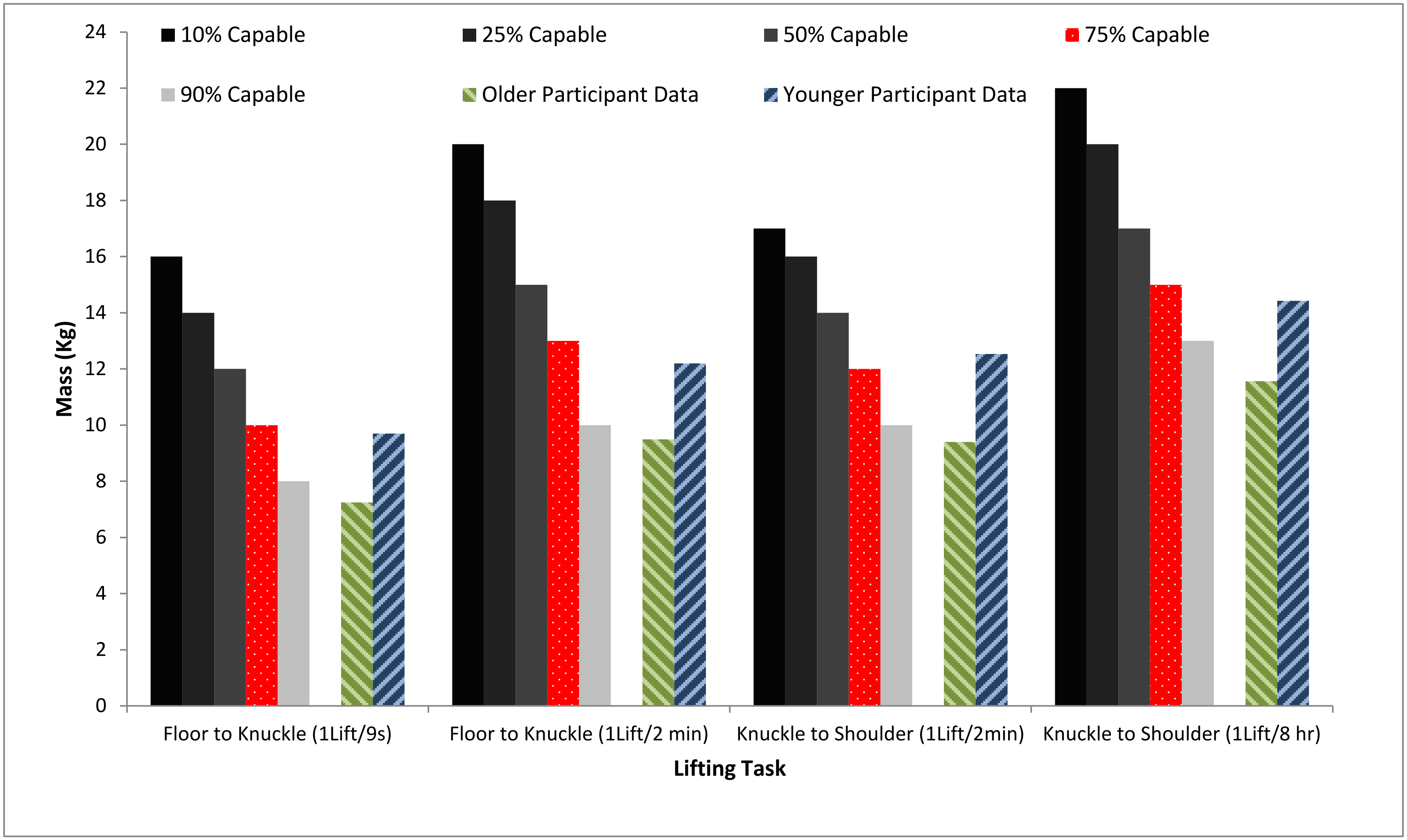


Figure 3. 14: Comparison between median older and younger workers MAWLS with Snook and Ciriello (1991) values for each task

From a work design perspective, it is helpful to compare my results to guidelines used to design MMH tasks in industry. Not only was it found that the older workers were selecting *MAWL* values lower than the younger workers, it was also found that the older workers were also selecting lower loads than the suggested load limits by Snook and Ciriello (1991) in the workplace (Figure 3. 13 and Figure 3.14). Snook (1978) conducted a field study and found that one-quarter of industrial tasks examined were acceptable to less than 75% of the workforce, and these jobs accounted for one-half of back injuries. Therefore, the MAWL that is suggested to be used within the workplace is at what 75% of women would be capable of lifting (Snook 1978; Liberty Mutual Insurance 2012). The older participants chose loads between 21-28% lower than the 75% capable (Snook and Ciriello 1991). In contrast to this, younger participants chose loads from 6.1% lower to 4.5% higher than the 75% capable (Snook and Ciriello 1991). Since the *MAWL* values selected by the younger workers were similar to 75% capable values from the Snook and Ciriello (1991) tables, this indicates that the results in my study are comparable to those of the Snook and Ciriello (1991) paper (Figure 3. 12). This indicates that older workers are choosing *MAWL* values that they think they can lift safely for these four task conditions (1 lift/ 9s and 1 lift/2 min from floor-to-knuckle height, and 1 lift/2 min and 1 lift/8 hr from knuckle-to-shoulder height) for an 8 hour work day are lower than the guidelines currently in place. From (Figure 3.14), almost all of the older workers in my study chose self-rated *MAWL*s lower than the current guidelines. This indicates that the current guidelines in place are not accommodating the older population in how much they believe they can safely lift for an entire work day at each of the experimented frequencies.

Regardless of changes in *MAWL* over time from a longitudinal perspective, the current results (derived from a cross-sectional approach) indicate that there age-related differences in *MAWL* that employers, labour groups, and health and safety professionals may want to consider.

3.5.2 Discussion of Secondary Variable Results

Considering the significant effects of age on MAWLs discussed above, I will discuss the results of my secondary variables, and the extent to which they correspond or ‘map onto’ *MAWL* findings. Grip strength was measured in this study to determine if there is a relationship between it and the *MAWL* of a female worker during various lifting conditions. In support of Hypotheses 2 it was found that grip-strength correlated with the *MAWL* selected for each task. Although the correlation did reach significance for all of the participants combined, it did not reach significance for the older and younger workers when separated (refer to section 3.4.2). Had there been more participants in each group, significance may have been met for the correlation between grip-strength and *MAWL* selected. Looking at the data collectively, grip-strength may be an indicator as to the overall strength of a female worker in terms of how much she is able to lift for each of the tasks outlined in this study. Previous research has shown that there is a relationship between grip strength and total muscle strength in healthy children, adolescents, and young adults (Wind, Takken et al. 2010). Wind et al. (2010) found that the correlation was weaker when it was controlled for weight of the participants (0.485-0.564, $p<0.01$). In relation to my study, grip strength being related to overall strength indicates that the *MAWL* selected by the participants may have been influenced by their overall strength as the older and younger workers had significantly different dominant hand grip strengths as well as significantly different *MAWL* values for the strength tasks. Although the current study found a significant association between *MAWL* and grip strength, the current results should not be interpreted as support for the use of grip strength as a screening tool to indicate the individual-level manual materials handling loads that persons perceive as safe..

The amount that a person chooses to lift can influence kinematic techniques used when performing lifting tasks (Hagen, Sorhagen et al. 1995). It was hypothesized that older and younger workers would have different lifting techniques (in the sagittal plane at the shoulder, hip and knee) during the floor-to-knuckle height lifting tasks. In contrast to hypothesis 3a, the results showed that older and younger workers chose similar lifting strategies (in terms of maximum sagittal plane flexion angles) for both the floor-to-knuckle and knuckle-to-shoulder height lifting tasks. The results also provide insights on the techniques that the workers were using to lift the boxes (refer to section 3.4.3). Not only were the joint angles similar, the percent of the lift cycle in which each maximum sagittal plane flexion angle occurred was also similar (refer to section 3.4.3). This indicates that the older and younger workers also had similar timing for their technique.

In a previous study it was found that the moment at the L5/S1 increased as the amount of weight lifted increased, with a decrease in the knee moment (Schipplein, Trafimow et al. 1990). When there was an increase in weight by 5 times, the increase in moment at L5/S1 was not 5 times. The changes in the moment were found to be from the load lifted and the acceleration of the load and trunk. This change had a linear relationship with the load lifted. In their study it was found that the participants increased the rate of leg extension with heavier weights when lifting from the floor. The study concluded that the quadriceps muscle strength limits the ability of the participants to lift with their knees flexed and lift more with their back (Schipplein, Trafimow et al. 1990). Meaning, when the mass of the load increased to a point where the participants were no longer lifting in a squat posture, but chose to lift in a stoop posture. In the present study, lack of differences between the maximum sagittal plane flexion angles may be because the participants were choosing *MAWLs* that they were comfortable with lifting for 8 hr rather than lifting a mass that may have been too heavy for them. In addition to load having an effect on lifting technique, frequency also has an effect.

Increasing the frequency of squat and stoop lifts was investigated to determine if an increase in frequency or an increase in load would cause changes to either technique (Hagen, Sorhagen et al. 1995). Increasing the load (1-17kg) and the frequency (10-20 lifts/min) during stoop lifts did not have an effect on technique; however, increasing the frequency during lifting caused a decrease in thigh displacement in the sagittal plane. This indicated that the participants were attempting to reduce the demand on the quadriceps during the squat lift. It was found that the variation in motion ranges increased during the squat lifts than during the stoop lifts (Hagen, Sorhagen et al. 1995).

From this, no differences in maximum sagittal plane flexion angles between older and younger workers in my study may have been due to the participants choosing loads that they were comfortable with lifting for the entire work day and the frequency not being high enough to produce a difference in the maximum sagittal plane joint angles. Also, there may have been no significant differences in the maximum intersegmental sagittal plane flexion angles between older and younger workers as their maximum flexion angles may have been driven by the start and end locations of the box. This is supported by the maximum flexion angles occurring during 20-30% of the lift cycle during the floor-to-knuckle height lifting task and during 60-70% of the lift cycle during the knuckle-to-shoulder height lifting task (Table 3. 11). The participants in my study took 0.5 seconds longer when lifting at the 1 lift/2 min frequency (2.5 seconds), than at the 1 lift/9 s frequency (2.0 seconds) (Table C 1). Since the participants were only lifting 0.5 seconds slower during the 1 lift/2 min frequency than the 1 lift/9 s frequency, this indicates that the participants may not have been rushed during the increased frequency, resulting in no change in maximum sagittal plane joint flexion angles. A lack in differences in maximum sagittal plane flexion angles at the shoulder, hip and knee between older and younger workers indicates that technique was not the cause of the differences in *MAWL* for older and younger workers.

Overall RPE and body part specific RPE was used as an indicator of how the participants felt at the end of each task condition. In support of hypothesis 4a, the older and younger workers' $RPE_{Overall}$ was not significantly different for each task (refer to section 3.4.4). This is because participants were asked to "adjust the weight of the box until [she] felt that it is the maximum amount that [she could] lift once every _____ without straining [herself]." This caused the participants to have to find a load that they were comfortable with lifting for an 8 hr work day. During the each lifting task, if a participant reached a rating of over ‘6’ on the BORG CR10 RPE Scale, she was considered to be at a workload with substantial strain, and was asked to reduce the amount of weight in the box. This ensured that participants were not working above a ‘strong’ workload according to the table. Although participants were given the same instructions on rating their overall RPE, the overall RPE was much higher during the cardiovascular task (1 lift/9 s from floor-to-knuckle height) than the strength tasks (1 lift/2 min and 1 lift/8 hr) (Figure 3. 7). One potential explanation is that participants were putting more weight on how they felt cardiovascularly than on pain or effort, with the former being challenged to a greater extent during the cardiovascular task (1 lift/9 s from floor-to-knuckle height) (Table 3. 16). Future work could look to characterize the differences in system weightings (e.g. cardiovascular, strength, pain, etc.) on perceived effort across a range of task conditions.

Contrary to hypothesis 4b, the body part specific RPE for the elbow and shoulder were not significantly different between the older and younger workers. As hypothesized, there was no significant difference between the older and younger workers in the $RPE_{Thigh.}$ However, there were significant differences between the older and younger worker RPE_{Knee} (refer to section 3.4.4). Lack of differences in the body part specific RPEs may also be due to the workers choosing loads that would not strain themselves, not only overall, but also in their specific body parts. If a worker was feeling a strain on her shoulders for knuckle-to-shoulder height lifting tasks, she may have reduced the load in order to prevent her from feeling the strain any longer. This may go along with older workers adopting strategies that protect the back during lifting tasks (Puniello, McGibbon et al. 2001); in addition to protecting the rest of their body parts that may be exposed to a strain. The participants were following instructions and were basing their MAWL on overall RPE, as there were no differences in overall RPE. However, the added mass handled by the younger workers may explain why their knee-specific RPEs were higher for the two floor-to-knuckle tasks.

Hypothesis 5 was partially supported, stating that participants would be able to return to their pre-perturbation *MAWL* within a 15 minute period. On average, the final MAWL was within 1% of the pre-perturbation value for the 1 lift/9 s from floor-to-knuckle height (refer to section 3.4.5), but only 8% for 1 lift/2 min from floor-to-knuckle height and 11% for 1 lift/2 min from knuckle-to-shoulder height lifting task (Table 3. 14). This likely has to do with the number of times the lift was performed within each frequency condition. Specifically, participants were able to lift the box 150 times in the 15 minute period at this 9 lift/min frequency, while the 1 lift/2 min lifting tasks, the participants were only able to lift the box 7 times (30 times including the familiarization period). Regardless of the percent differences, the absolute pre-and post-perturbation values were less than 1.5 kg different from each other across all tasks, indicating limited effect of task duration on the general findings in this study. Although participants had the opportunity to vary the mass until they found a mass that they believed was acceptable at each frequency for an 8 hr work day, there were times in which the participant was asked to lower the mass of the box if her heart rate reached above her age-adjusted maximum heart rate or if her overall rating of perceived exertion was over 6 at 10 minutes or 20 minutes into the lifting task (Appendix E). Decreases to load due to the participant's heart rate reaching the age-adjusted maximum heart rate occurred four times for the older workers (three of which were from one participant), and none for the younger workers. A rating of over 6 on the CR-10 Borg scale for the overall RPE at the 10 or 20 minute mark during the task required the participants to decrease the load as well. This occurred ten times for the older workers and four times for the younger workers (Appendix E).

Previous studies have suggested that tasks involving frequencies higher than 6 lift/min required longer adjustment times (longer than 20-25 min) as people are unable to adequately judge or perceive loads that they can both subjectively tolerate and physiologically/biomechanically tolerate (Mital 1983; Karwowski and Yates 1986). This study showed that an adjustment time of 15 minutes to determine the final MAWL is reasonable for a frequency of 1 lift/9 s as a 20 minute adjustment period has been used in many studies (Kim and Fernandez 1993; Marley and Fernandez 1995). After the 20 minutes, the load, force or frequency selected is considered to be the maximum. Although participants were able to come within 1% of their pre-perturbation value within 15 minutes, based on a time constraint, participants were only required to do the task for 30 minutes rather than an entire 8 hr work day. Currently, there is no consensus on the appropriate amount of time to determine a psychophysically acceptable load. By having a perturbation half-way through the task, participants were forced to re-evaluate the mass in the box and find a mass that they were comfortable with lifting for an 8 hr day without straining themselves. This made the participants think about how they felt with the mass selected again evaluating how their joints, muscles and cardiovascular felt.

In examining repetitive lifting tasks, cardiovascular fitness plays a role in the amount that a person would choose to lift. After examining the heart rate at the end of each task it was found that there was no significant differences between the absolute heart rate of the older and younger workers; however, there were significant differences in the percentage of the age-adjusted maximum heart rate that the older workers and the younger workers reached by the end of each task (Table 3. 16). Rather than looking at the absolute heart rate of the participants, it is important to look at the percentage of their maximum heart rate that they were working at as the recommended maximum heart rate value decreases as a person gets older (85% of 220-age)(Centers for Disease Control and Prevention 2011). The older workers were closer to their age-adjusted maximum heart rate than the younger workers, reaching almost 90% of their maximum during the 1lift/9 s from floor-to-knuckle height, while the younger workers reached only 80% of their maximum. Looking at the percentage of the maximum heart rate, the tasks affected the older workers more cardiovascularly than the younger workers. In a previous study (Martin, Ogawa et al. 1991) it was found that in comparison to younger participants, diastolic blood pressure during submaximal exercise was higher in older participants. In addition to hypertension, it has been found that congestive heart failure and other forms of cardiovascular disease increase in prevalence with age due to impaired function of the capsular endothelium and a decrease in the peripheral vasodilatory capacity (Martin, Ogawa et al. 1991). Studies involving HR have shown that there is a decrease in the vagal modulation of HR at rest as a person ages (Lipsitz, Mietus et al. 1990). The influence of the cardiovascular system on MAWLs may differ across task demands. During the **strength** tasks (1 lift/2 min and 1 lift/8 hr) the participants were not close to their maximum heart rate suggesting that cardiovascular function was not likely a major factor in the *MAWL* selected for these low frequency tasks (section 3.4.1 and 3.4.6). Since both older and younger workers heart rates increased for the cardiovascular task (i.e. 1 lift/9 s) to a higher percentage of their maximum heart rate than during the strength task (Table 3. 16), it may have contributed to the fact that there were no significant differences between the older and younger *MAWL* value (approximately 1.5 kg difference). This is in agreement with several studies that have concluded that strains on the circulatory system are the limiting work factors when performing manual labour jobs (Asmussen, Klausen et al. 1960; Suggs and Splinter 1961; Suggs and Splinter 1961). Although it is important to examine the percentage of the workers' maximum heart rate reached, it is also instructive to look at absolute heart rates to allow comparisons with several previous studies (Morris and Chevalier 1961; Suggs and Splinter 1961). During the cardiovascular task, the younger workers reached heart rates higher than 130 bpm (~134 bpm), while during the strength tasks the heart rates were lower than 110 bpm. There are several suggestions for the maximum HR ranging from 110 beats per minute (bpm) to 130 bpm with the enhancing worker safety (Morris and Chevalier 1961; Suggs and Splinter 1961). According to guidelines that have been set by Astrand (1960), workers between the ages of 20-33 years old should not exceed 127 bpm, while workers from 50-59 years old should not exceed 98 bpm while on the job (Table 2.1). The cardiovascular task brought both age groups higher than the guidelines set by Astrand (1960); the strength tasks, however, kept the participants lower than the guidelines. This indicates that cardiovascular function may have played a role choosing a final *MAWL* in the cardiovascular task, but not the strength tasks.

Within the Snook and Ciriello (1991) tables there are numbers in which are italicized (Figure A 3). These italicized values are values which exceed physiological criteria. The values that the participants selected for each task (Figure 3. 5) did not exceed physiological criteria according to Snook and Ciriello (1991) (Figure A 3).

Overall, it was found that there were significant differences between older and younger workers in their *MAWL* for strength tasks, with the older workers choosing significantly lower loads than the younger workers. In contrast, there were no significant differences between older and younger workers in the *MAWL* for the cardiovascular task (although a trend of lower values for older workers was observed). Based on my secondary analyses, the significant differences in the *MAWL* chosen for the strength tasks was likely most related to the overall strength of the participants rather than their technique (as indicated by their maximum intersegmental sagittal plane angles) or cardiovascular function.

3.5.3 Limitations

There were several limitations associated with this investigation. Firstly, it was found that the adjustment time of 15 minutes did not allow for enough lifts for the participants to choose a *MAWL* value that was reproducible within the next 15 minute adjustment period for the 1 lift/2 min lifting task. This adjustment period was chosen based on a 20 minute adjustment period used in many studies (Kim and Fernandez 1993; Marley and Fernandez 1995) This indicates that a longer adjustment period is necessary for lifting frequencies of 1 lift/2 min or less. Accordingly, although I provided some commentary on comparisons with the Snook and Cirello (1991) data, we cannot directly compare our results to their values. Secondly, there were not enough participants in each age group to enhance our likelihood of observing significant correlations if they existed. However, when considering all participants as a single group, there were significant correlations between grip strength and *MAWL* values. Thirdly, ratings of fear avoidance, such as the 'Fear Avoidance Beliefs Questionnaire (FABQ)' (Williamson 2006), propensity were not collected. Accordingly, we have no insights into an important factor that had the potential to affect our MAWL results. Future studies might consider collecting fear avoidance ratings to gain additional insights into the potential factors that might underlie age-related changes in perceived MAWL values. Fourth, the conclusions of this study are limited to female workers as males were not recruited for the study. As an initial probe in determining if there is a difference between the younger and older working population, females were examined as they are the limiting population and there is limited data available about females in manual materials handling. Fifth, another limiting factor was that only lifting was examined in this study with a limited number of lifting conditions from the Snook and Ciriello

(1991) tables. Lowering, carrying, pushing and pulling as well as several other frequencies were not examined. Sixth, from the perspective of kinematics, only the maximum intersegmental sagittal plane angles of the right shoulder, left and right hip and knee were examined in this study. In future studies, looking at joint-specific kinetics (including peak and/or cumulative loading) might be a better indicator of differences between the older and younger working population. Although kinetics were not explicitly examined in this study, the postures in which maximum sagittal plane joint angles occurred at the right shoulder, left and right hip and knee for older workers, were input into 3DSSPP to provide some initial insights into the joint-specific loading that may be occurring (Appendix F). Lastly, a general limitation is that my results do not provided any direct insights into age-related differences in injury risk. There is little direct evidence that differences in psychophysical estimates of safe lifting loads correlate with age-related differences in injury risk. Future work is merited to assess the validity of using psychophysically derived variables as a metric of injury risk in both older and younger workers.

The anticipated increases in the aging population within the workforce needs to be addressed and examined to determine if the current guidelines in place allow older workers to work with the same productivity and safety as younger workers. Similarly to the recent Ciriello et al (2011) study, indicating that female workers were choosing loads that were 67% of the Snook and Ciriello (1999) values, my results also indicate that further investigations are required to determine whether the current guidelines need to be updated to accommodate older workers.

3.5.4 Conclusion

Although the workforce in developed countries is aging, the implications of this trend with regards to work efficiency, productivity, and health are unknown. There are differences between older and younger workers with regards to injury incidence and severity rates. In terms of injury rates, reports have found that adolescents and young adults (20-24 years old) have injury rates 1.4-4 times higher than males over 25 years old (Breslin, Koehoorn et al. 2003). Although adolescents are more frequently injured, injuries to older workers are more likely to result in permanent disability than injuries to younger workers regardless of the severity of the injury (Rossignaol, Lock & Burke, 1989). This thesis has provided an initial insight into the self-selected loads that older and younger workers believe they are capable of lifting safely without straining themselves. Specifically, I found that older workers selected loads approximately 24% lower than the younger workers across four lifting task scenarios. Not only were older workers selecting loads lower than the younger workers, they were also selecting loads lower than Snook and Ciriello's (1991) values that 75% of females should be capable of lifting for an 8 hr work day (numbers that are commonly used as guidelines for the design of manual materials handling tasks). Towards providing insights into the drivers of these age-related differences, I evaluated several secondary variables. It was also determined that older and younger workers generally have similar lifting strategies for the task conditions I studied. Since participants in this study were not working at a high percentage of their maximum heart rate during the strength tasks, had similar ratings of perceived exertion overall for each task, and as there was a correlation between the grip strength and final *MAWL* values, strength appears to be the factor most closely associated with *MAWL* in my study.

The results of this work suggest there is value in continued research probing whether current ergonomic and work design guidelines need to be updated to accommodate the aging working population. According to the results presented in this study, the current approaches often employed during the design of manual materials handling tasks (i.e. incorporating the loads that 75% of females could perform based on the Snook and Ciriello tables (1991)) may not be sufficiently protective for older female workers in the workplace.

Chapter 4

Thesis Synthesis and Conclusion

4.1 Novel Contributions

This thesis offers a novel contribution to the field of occupational biomechanics in that the participants used to conduct the experiment were older and younger females within the manual materials handling field. This was important as they were specifically recruited because they were experienced manual materials handlers (i.e. not students or just an 'active' population). Another novel contribution is that young and older workers were matched based on body mass (in efforts to reduce variability across groups). This is an improvement over previous studies as in previous studies the participants were not matched (Snook and Ciriello 1991; Wright and Mital 1999), and although the average *MAWL* of the older participants was approximately 13% lower than the average for the younger participants, the variability within each group was sufficiently high that significant across-group differences were not observed. Finally, this study extended beyond the existing work in the literature by making substantial efforts to assess factors that may have contributed to age-related differences in *MAWL* through the collection of kinematic, cardiovascular, and perceived exertion outcome variables.

4.2 Research Significance and Impact

The workforce within Canada, as well as many other countries', is continuing to age as the baby boomer generation (those born between 1946 and 1964) ages and are remaining in the workforce longer. The number of older workers is estimated to double within the next 10 years (Perry 2010). These baby boomers are either maintaining full-time work or finding part-time work, and the number of retirees re-entering the workforce is increasing (Finch and Robinson 2003). As a person grows older, there are several natural age-related physical changes that occur, having potential implications on functional abilities. Some of these physical changes are: muscle mass, neuronal changes, cardiovascular changes, and lung capacity changes. Some of the functional limitations due to aging include vision and hearing loss, arthritis, balance and gait problems, and loss of strength and stamina (refer to section 2.1.2). Despite all of these potential age-related changes, there is little available information in the literature regarding potential differences in injury risk for younger and older workers. Such data would be critical in developing potential age-specific or age-appropriate guidelines to encourage health and safety across the lifespan.

My thesis is significant as it provides insights into the aging population within the workforce as well as the direction in the abilities of the workforce in the future. On the basis of this study, there is an indication that the guidelines for safe load limits of lifting that are currently in place are significantly higher than what older females workers (50+ years old) think they can lift safely for an 8 hour work day. Therefore, the guidelines that are currently used for safe load limits of lifting may need to be decreased to accommodate older female workers within the workforce.

4.3 Future Research

In order to determine if the existing tables used for the design of MMH (Snook and Ciriello 1991) need to be updated or if a discount factor shoulder be applied in order to accommodate, the aging workforce (in addition to overall secular changes to the working population) need to be investigated further. Also, additional investigations for other tasks including lowering, carrying, pushing, pulling, etc., should be conducted in order to determine if the guidelines currently in place for these tasks are suitable for the aging workforce. Towards providing insights into potential mechanisms underlying age-related differences, comprehensive assessment approaches should be employed. For example, in addition to the kinematics, heart rate, and strength measured in the current study, future research should consider adding elements such as kinetics, range of motion and fear avoidance questionnaires. Such information may provide important information regarding not only the loads that workers select, but also the reason as to why people choose the loads that they do.

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Appendix A

Example Resources Used in the Planning and Execution of the Thesis

Physical Activity Readiness
Questionnaire - PAR-Q
(revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO		
☐	☐	1.	**Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?**
☐	☐	2.	**Do you feel pain in your chest when you do physical activity?**
☐	☐	3.	**In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	4.	**Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	5.	**Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	6.	**Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	7.	**Do you know of any other reason why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME ____

SIGNATURE ____ DATE ____________________________

SIGNATURE OF PARENT ______________________________ WITNESS __________________________
or GUARDIAN (for participants under the age of majority)

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

CSEP | SCPE

Figure A 1: PAR Q & YOU form filled out by participants prior to coming into the laboratory to ensure they were eligible for the protocol.

Borg's CR10 Scale Instructions

Basic instruction: 10, "Extremely strong—Max P," is the main anchor. It is the strongest perception (P) you have ever experienced. It may be possible, however, to experience or to imagine something even stronger. Therefore, "Absolute maximum" is placed somewhat further down the scale without a fixed number and marked with a dot "•". If you perceive an intensity stronger than 10, you may use a higher number.

Start with a *verbal expression* and then choose a *number*. If your perception is "Very weak," say 1; if "Moderate," say 3; and so on. You are welcome to use half values (such as 1.5, or 3.5 or decimals, for example, 0.3, 0.8, or 2.3). It is very important that you answer what *you* perceive and not what you believe you ought to answer. Be as honest as possible and try not to overestimate or underestimate the intensities.

Scaling perceived exertion: We want you to rate your perceived (P) exertion, that is, how heavy and strenuous the exercise feels to you. This depends mainly on the strain and fatigue in your muscles and on your feeling of breathlessness or aches in the chest. But you must only attend to your subjective feelings and not to the physiological cues or what the actual physical load is.

- 1 is "very light" like walking slowly at your own pace for several minutes.
- 3 is not especially hard; it feels fine, and it is no problem to continue.
- 5 you are tired, but you don't have any great difficulties
- 7 you can still go on but have to push yourself very much. You are very tired.
- 10 This is as hard as most people have ever experienced before in their lives.
- • This is "Absolute maximum," for example, 11 or 12 or higher

Scaling pain: What are your worst experiences of pain? If you use 1o as the strongest exertion you have ever experienced or can think of, how strong would you say that your three worst pain experiences have been?

- 10 "Extremely strong—Max P" is your main point of reference. It is anchored in your previously experienced worst pain, which you just described, the "Max P".
- • Your worst pain experienced, the "Max P," may not be the highest possible level. There may be pain that is still worst. If that feeling is somewhat stronger, you will say 11 or 12. If it is much stronger, 1.5 times "Max P," you will say 15!

Figure A 2: Borg's CR10 Scale Instructions - these instructions were read to participants and available to them each time they performed a rating of perceived exertion (RPE) (Borg 1990)

Table 3. Maximum acceptable weight of lift for females (kg).

Width‡	Distance§	Percent¶	Floor level to knuckle height One lift every								Knuckle height to shoulder height One lift every								Shoulder height to arm reach One lift every							
			5 s	9 s	14 s	1 min	2 min	5 min	30 min	8 h	5 s	9 s	14 s	1 min	2 min	5 min	30 min	8 h	5 s	9 s	14 s	1 min	2 min	5 min	30 min	8 h
		90	5	6	7	7	8	8	9	12	5	6	7	9	9	9	10	12	4	5	5	6	7	7	7	8
		75	7	8	9	9	10	10	11	14	6	7	8	10	11	11	12	14	5	6	6	7	8	8	8	10
	76	50	8	10	10	11	12	12	13	17	7	8	9	11	12	12	13	16	6	7	7	8	9	9	10	11
		25	9	11	12	13	14	14	15	21	8	9	10	13	14	14	15	18	7	7	8	9	10	10	11	13
		10	11	13	14	14	15	16	17	23	9	10	11	14	15	15	17	20	7	8	9	10	11	11	12	14
		90	6	7	8	8	9	9	10	14	6	7	8	9	10	10	11	13	5	6	7	7	7	7	8	9
		75	7	9	9	10	11	11	13	17	7	8	9	11	12	12	13	15	6	7	8	8	9	9	9	11
75	51	50	9	10	11	12	13	14	15	21	9	9	11	13	14	14	15	17	7	8	9	9	10	10	11	13
		25	10	12	13	15	16	16	18	24	10	11	12	14	16	16	17	20	8	9	10	10	11	11	12	14
		10	11	14	15	17	18	18	20	27	11	12	14	16	17	17	19	22	9	10	11	12	13	13	14	16
		90	6	8	8	9	9	9	11	14	6	7	8	10	11	11	12	14	5	6	7	8	8	8	9	10
		75	8	10	11	11	12	12	13	18	7	8	9	12	13	13	14	17	6	7	8	9	9	9	10	12
	25	50	10	12	13	13	14	14	16	21	9	10	11	14	15	15	16	19	7	8	9	10	11	11	12	14
		25	11	14	15	15	16	17	19	25	10	11	12	16	17	17	19	22	8	9	10	12	12	12	14	16
		10	13	16	17	17	19	19	21	29	11	12	14	18	19	19	21	24	9	10	11	13	14	14	15	17
		90	5	6	7	8	8	8	9	13	5	6	7	9	9	9	10	12	4	5	5	7	7	7	8	9
		75	7	8	9	10	10	10	12	16	6	7	8	10	11	11	12	14	5	6	6	8	8	8	9	11
	76	50	8	10	10	12	12	13	14	19	7	8	9	11	12	12	13	16	6	7	7	9	10	10	11	12
		25	9	11	12	14	15	15	17	22	8	9	10	13	14	14	15	18	7	7	8	10	11	11	12	14
		10	11	13	14	15	17	17	19	25	9	10	11	14	15	15	17	20	7	8	9	11	12	12	13	15
		90	6	7	8	9	10	10	11	15	6	7	8	9	10	10	11	13	5	6	7	7	8	8	9	10
		75	7	9	9	11	12	12	14	18	7	8	9	11	12	12	13	15	6	7	8	9	9	9	10	12
49	51	50	9	10	11	13	15	15	16	22	9	9	11	13	14	14	15	17	7	8	9	10	11	11	12	14
		25	10	12	13	16	17	17	19	26	10	11	12	14	16	16	17	20	8	9	10	11	12	12	13	15
		10	11	14	15	18	19	20	22	30	11	12	14	16	17	17	19	22	9	10	11	13	14	14	15	17
		90	6	8	8	9	10	10	11	15	6	7	8	10	11	11	12	14	5	6	7	8	9	9	10	11
		75	8	10	11	12	12	13	14	19	7	8	9	12	13	13	14	17	6	7	8	9	10	10	11	13
	25	50	10	12	13	14	15	15	17	23	9	10	11	14	15	15	16	19	7	8	9	11	12	12	13	15
		25	11	14	15	16	18	18	20	27	10	11	12	16	17	17	19	22	8	9	10	12	13	13	15	17
		10	13	16	17	19	20	21	23	31	11	12	14	18	19	19	21	24	9	10	11	14	15	15	16	19
		90	7	8	9	9	10	10	11	15	6	7	8	9	10	10	11	13	5	6	7	8	9	9	10	11
		75	8	10	11	12	13	13	14	19	7	8	9	11	12	12	13	15	6	7	8	9	10	10	11	13
	76	50	10	12	13	14	15	16	17	23	9	9	11	13	14	14	15	17	7	8	9	11	12	12	13	15
		25	12	14	15	17	18	18	20	27	10	11	12	14	16	16	17	20	8	9	10	12	13	13	15	17
		10	13	16	18	19	20	21	23	31	11	12	13	16	17	17	19	22	9	10	11	14	15	15	16	19
		90	7	9	9	11	12	12	13	18	8	8	9	10	11	11	12	14	7	7	8	9	10	10	11	12
		75	9	11	12	14	15	15	16	22	9	10	11	12	13	13	14	17	8	8	9	11	11	11	12	14
34	51	50	11	13	14	16	18	18	20	27	10	11	13	14	15	15	17	19	9	10	11	12	13	13	14	17
		25	13	15	17	19	21	21	24	32	12	13	14	16	17	17	19	22	10	11	12	14	15	15	16	19
		10	14	18	19	22	24	24	27	36	13	14	16	18	19	19	21	24	11	12	14	15	16	16	18	21
		90	8	10	11	11	12	12	14	19	8	8	9	12	12	12	14	16	7	7	8	10	11	11	12	14
		75	10	12	13	14	15	15	17	23	9	10	11	13	14	14	16	18	8	8	9	12	12	12	14	16
	25	50	12	15	16	17	18	19	21	28	10	11	13	16	17	17	18	21	9	10	11	13	14	14	16	18
		25	14	17	19	20	22	22	24	33	12	13	14	18	19	19	21	24	10	11	12	15	16	16	18	21
		10	16	20	21	23	25	25	28	38	13	14	16	19	21	21	23	27	11	12	14	17	18	18	20	23

‡ Box width (the dimension away from the body) (cm).
§ Vertical distance of lift (cm).
¶ Percentage of industrial population.
Italicized values exceed 8 h physiological criteria (see text).

Figure A 3: Snook and Ciriello (1991) lifting guidelines for females with the initial mass of the box for each task outlined in red

Appendix B
Kinematic data for frontal and transverse planes

Presented below are the maximum frontal plane joint angles for each task. There were significant differences between the older and younger workers for the maximum frontal plane flexion angles at the shoulder, hip and knee (all joints examined in this study). There were interactions for all of the joints except for the left hip (Table B 1). Post-hoc tests were run where interactions were present. There were significant differences between the older and younger workers at the shoulder during the strength tasks, but not the cardiovascular task. There were significant differences between the older and younger workers at the right hip and knee for all of the tasks, while there were only significant differences for the older and younger workers at the left knee during both the floor-to-knuckle height lifting task and the knuckle-to-shoulder height lifting task at a frequency of 1 lift/2 min (Table B 2). Participants were abducting their upper arms in order to pick up the boxes for the floor-to-knuckle height lifting tasks. Compared to the younger workers, older participants adducted their upper arms (kept their upper arms closer to the sides of their body) during the knuckle-to-shoulder height lifting tasks, while the younger participants continued to abduct their upper arms (held their arms further away from the side of their body) (Table B 3). In comparison to anatomical position, older workers adducted their legs (brought them closer together) while lifting the box; however, younger workers abducted their legs (spread their legs further apart producing a wider stance).

Table B 1: F-ratio (p-value) from the repeated measures ANOVA tests on maximum frontal plane joint angles

	ANOVA		
Joint Angle	Age	Task	Interaction
Shoulder (°)	18.801 (<0.001)*	11.263 (0.001)*	17.977 (<0.001)*
Right Hip (°)	14.751 (0.001)*	0.490 (0.642)	4.584 (0.012)*
Left Hip (°)	14.388 (0.001)*	1.150 (0.336)	2.191 (0.098)
Right Knee (°)	12.630 (0.002)*	3.640 (0.051)*	4.630 (0.027)*
Left Knee (°)	8.916 (0.007)*	2.389 (0.078)	4.757 (0.005)*

Table B 2: T-test t(p) values for older and younger workers' maximum joint angles in the frontal plane

Joint	Task	t(p)
Shoulder	Floor-to-knuckle (1 lift/9 s)	-1.737 (0.096)
	Floor-to-knuckle (1 lift/2 min)	4.366 (0.001)*
	Knuckle-to-shoulder (1 lift/2 min)	5.086 (<0.001)*
	Knuckle-to-shoulder (1 lift/8 hr)	4.113 (0.002)*
Right Hip	Floor-to-knuckle (1 lift/9 s)	4.139 (0.001)*
	Floor-to-knuckle (1 lift/2 min)	4.015 (0.001)*
	Knuckle-to-shoulder (1 lift/2 min)	3.354 (0.003)*
	Knuckle-to-shoulder (1 lift/8 hr)	3.220 (0.008)*
Right Knee	Floor-to-knuckle (1 lift/9 s)	4.280 (0.001)*
	Floor-to-knuckle (1 lift/2 min)	3.243 (0.008)*
	Knuckle-to-shoulder (1 lift/2 min)	3.342 (0.005)*
	Knuckle-to-shoulder (1 lift/8 hr)	3.282 (0.006)*
Left Knee	Floor-to-knuckle (1 lift/9 s)	3.564 (0.002)*
	Floor-to-knuckle (1 lift/2 min)	3.378 (0.005)*
	Knuckle-to-shoulder (1 lift/2 min)	2.637 (0.019)*
	Knuckle-to-shoulder (1 lift/8 hr)	2.005 (0.059)

Table B 3: Average (SD) older and younger worker maximum joint angles (°) in the frontal plane of the shoulder, hip and knee for each task. (Positive indicates adduction)

	Age Group	Shoulder	Right Hip	Left Hip	Right Knee	Left Knee
Floor-to-Knuckle (1 lift/9 s)	Older	-51.0 (4.78)	34.6 (7.25)	30.7 (7.50)	26.0 (6.69)	24.8 (8.33)
	Younger	-40.8 (4.58)	-4.0 (6.94)	-11.0 (7.18)	-8.9 (6.10)	-11.8 (7.60)
Floor-to-Knuckle (1 lift/2 min)	Older	20.6 (11.01)	36.9 (7.90)	24.8 (7.70)	40.9 (12.08)	36.7 (9.60)
	Younger	-41.3 (10.54)	-3.9 (7.56)	-9.8 (7.37)	-9.3 (11.03)	-4.5 (8.76)
Knuckle-to-Shoulder (1 lift/2 min)	Older	24.0 (12.29)	25.3 (4.97)	22.0 (6.06)	13.7 (5.01)	19.8 (5.81)
	Younger	-57.1 (11.77)	2.8 (4.76)	-7.3 (8.80)	-6.4 (4.61)	1.1 (5.31)
Knuckle-to-Shoulder (1 lift/8 hr)	Older	23.4 (12.19)	30.8 (5.83)	21.1 (6.32)	13.6 (5.18)	22.5 (7.67)
	Younger	-49.0 (11.67)	3.8 (5.58)	-10.8 (6.05)	-8.9 (4.73)	1.7 (7.00)

The maximum transverse plane angles during the lifting tasks for the older and younger workers were calculated and it was found that there were significant differences between older and younger participants at the shoulder, right hip, and left knee, while there was no significant difference between older and younger works at the left hip or right knee (Table B 4). There were no interaction effects (Table B 4). Participants externally rotated their arm during the lift cycle for all tasks. Older workers internally rotated their legs (compared to anatomical position) while lifting during all tasks, while younger participants slightly externally rotated their legs while lifting (Table B 5).

Table B 4: F-ratio (p-value) from the repeated measures ANOVA tests on maximum transverse plane joint angles

	ANOVA		
Joint Angle	Age	Task	Interaction
Shoulder (°)	6.127 (0.022)*	0.735 (0.486)	1.912 (0.160)
Right Hip (°)	11.846 (0.002)*	2.380 (0.104)	2.607 (0.138)
Left Hip (°)	3.472 (0.076)	1.204 (0.304)	0.286 (0.702)
Right Knee (°)	3.829 (0.065)	0.367 (0.678)	1.020 (0.365)
Left Knee (°)	12.83 (0.002)*	0.812 (0.492)	2.324 (0.084)

Table B 5: Average (SD) older and younger worker maximum joint angles (°) in the transverse plane of the shoulder, hip and knee for each task. (Positive indicates internal rotation)

	Age Group	**Shoulder**	**Right Hip**	**Left Hip**	**Right Knee**	**Left Knee**
Floor-to-Knuckle (1 lift/9 s)	Older	69.3 (7.8)	40.9 (13.0)	21.5 (18.1)	5.3 (8.1)	21.7 (5.8)
	Younger	57.7 (7.5)	-19.8 (12.6)	-10.9 (17.3)	-9.5 (7.4)	1.4 (5.3)
Floor-to-Knuckle (1 lift/2 min)	Older	63.6 (6.7)	44.2 (12.9)	25.6 (17.7)	17.6 (11.2)	39.1 (7.6)
	Younger	62.3 (6.4)	-17.8 (12.4)	-4.8 (16.9)	-17.6 (10.6)	-2.1 (6.9)
Knuckle-to-Shoulder (1 lift/2 min)	Older	68.5 (8.6)	34.0 (12.6)	33.9 (9.8)	7.0 (6.3)	19.2 (4.8)
	Younger	48.4 (8.2)	-17.3 (12.1)	-2.5 (9.4)	-6.3 (6.1)	-5.2 (4.4)
Knuckle-to-Shoulder (1 lift/8 hr)	Older	69.3 (10.1)	40.9 (9.1)	38.5 (13.0)	12.1 (12.3)	21.9 (9.1)
	Younger	45.3 (9.6)	-7.3 (8.7)	-3.8 (12.5)	-1.1 (11.2)	-0.3 (8.3)

Below are the frontal plane angles at the shoulder, right and left hip and knee when the maximum sagittal plane joint angles occur. The only significant difference between older and younger workers was at the right knee (Table B 6). There were also significant differences across tasks for the shoulder and right knee as well as an interaction effect for the right knee (Table B 6). After conducting a post hoc test on the right knee, there was only a significant difference between the older and younger workers right knee joint angle during the knuckle-to-shoulder height at 1 lift/8 hr (Table B 7). The older workers adducted their legs (brought their legs closer together),while the younger workers abducted their legs (spread their legs further apart) from anatomical position while lifting the box (Table B 8). Both older and younger workers abducted their shoulders while lifting the box.

Table B 6: F-ratio (p-value) from the repeated measures ANOVA tests on frontal plane joint angles during maximum sagittal plane joint angles

	ANOVA		
Joint Angle	Age	Task	Interaction
Shoulder (°)	2.316 (0.143)	8.998 (<0.001)*	0.409 (0.692)
Right Hip (°)	0.014 (0.905)	0.202 (0.880)	1.278 (0.290)
Left Hip (°)	0.422 (0.523)	1.843 (0.157)	1.781 (0.168)
Right Knee (°)	9.914 (0.005)*	4.006 (0.018)*	3.287 (0.036)*
Left Knee (°)	4.082 (0.057)	1.467 (0.232)	2.633 (0.058)

Table B 7: T-test t(p) values for older and younger workers' right knee angle in the frontal plane during maximum sagittal plane right knee angle

Joint	**Task**	**t(p)**
Right Knee	Floor-to-knuckle (1 lift/9 s)	1.611 (0.130)
	Floor-to-knuckle (1 lift/2 min)	2.080 (0.057)
	Knuckle-to-shoulder (1 lift/2 min)	0.799 (0.440)
	Knuckle-to-shoulder (1 lift/8 hr)	2.773 (0.018)*

Table B 8: Average (SD) Participant Joint Angle (°) in the Frontal Plane during Maximum Sagittal Plane Joint Angle. (Positive indicates adduction)

	Age Group	Shoulder	Right Hip	Left Hip	Right Knee	Left Knee
Floor-to-Knuckle (1 lift/9 s)	Older	-15.6 (6.7)	5.9 (5.9)	10.5 (6.2)	22.9 (7.3)	16.8 (7.9)
	Younger	-29.3 (6.5)	-3.9 (5.7)	-0.1 (5.9)	-3.14 (6.7)	-8.0 (7.2)
Floor-to-Knuckle (1 lift/2 min)	Older	-14.6 (7.4)	0.4 (6.5)	6.7 (6.0)	31.3 (7.9)	22.6 (8.5)
	Younger	-29.3 (7.1)	-5.0 (6.3)	-0.0 (5.7)	-2.8 (7.2)	-1.4 (7.7)
Knuckle-to-Shoulder (1 lift/2 min)	Older	-28.1 (8.8)	4.4 (3.4)	10.9 (3.9)	9.0 (4.1)	16.7 (5.1)
	Younger	-47.9 (8.4)	3.9 (3.2)	-3.8 (3.8)	-3.1 (3.8)	5.4 (4.6)
Knuckle-to-Shoulder (1 lift/8 hr)	Older	-31.0 (8.5)	0.9 (6.4)	3.8 (4.8)	12.4 (4.7)	14.8 (6.3)
	Younger	-42.0 (8.2)	-3.8 (6.1)	-7.4 (4.6)	-4.9 (4.3)	7.1 (5.7)

Transverse plane joint angles during the maximum sagittal plane joint angles were determined and it was found that there were no significant differences between the older and younger workers at the shoulder or right and left hip and knees (Table B 9). There was an interaction effect for the right hip (Table B 9). A post-hoc analysis was performed on the right hip data and it was found that there was a significant difference between the older and younger workers at the right hip during the 1 lift/2 min from knuckle-to-shoulder height lifting task (Table B 10). All participants internally rotated their arms when lifting the box (Table B 11). Younger workers externally rotated their legs for all tasks, while older workers only externally rotated their legs for the cardiovascular task (Table B 11).

Table B 9: F-ratio (p-value) from the repeated measures ANOVA tests on transverse plane joint angles during maximum sagittal plane joint angles

	ANOVA		
Joint Angle	Age	Task	Interaction
Shoulder (°)	3.931 (0.061)	7.031 (<0.001)*	0.114 (0.946)
Right Hip (°)	1.613 (0.218)	1.537 (0.229)	4.093 (0.030)*
Left Hip (°)	0.609 (0.444)	5.939 (0.005)*	19.000 (0.191)
Right Knee (°)	2.404 (0.137)	0.504 (0.618)	0.779 (0.472)
Left Knee (°)	3.211 (0.088)	1.451 (0.245)	1.209 (0.311)

Table B 10: T-test of the right hip between older and younger workers for the right hip transverse plane joint angle during the right hip maximum sagittal plane joint angle

Joint	Task	t(p)
Right Hip	**Floor-to-knuckle (1 lift/9 s)**	-0.308 (0.716)
	Floor-to-knuckle (1 lift/2 min)	0.816 (0.423)
	Knuckle-to-shoulder (1 lift/2 min)	2.415 (0.024)*
	Knuckle-to-shoulder (1 lift/8 hr)	1.367 (0.186)

Table B 11: Average (SD) Participant Joint Angle (°) in the Transverse Plane during Maximum Sagittal Plane Joint Angle (Positive indicates internal rotation)

	Age Group	Shoulder	Right Hip	Left Hip	Right Knee	Left Knee
Floor-to-Knuckle (1 lift/9 s)	Older	39.0 (8.9)	-9.3 (11.6)	-33.5 (17.7)	3.4 (14.9)	0.1 (27.1)
	Younger	55.9 (8.5)	-4.9 (11.1)	-4.0 (17.0)	1.0 (13.6)	-19.9 (24.7)
Floor-to-Knuckle (1 lift/2 min)	Older	41.7 (7.4)	5.2 (9.9)	-20.7 (17.9)	13.6 (13.4)	1.8 (25.1)
	Younger	59.6 (7.1)	-3.7 (9.4)	10.8 (17.1)	-6.2 (12.258)	-9.3 (12.1)
Knuckle-to-Shoulder (1 lift/2 min)	Older	33.3 (4.8)	27.3 (12.6)	8.5 (17.3)	16.0 (12.798)	-8.4 (27.4)
	Younger	47.0 (4.6)	-14.5 (12.1)	14.9 (16.5)	1.0 (11.683)	-10.1 (7.7)
Knuckle-to-Shoulder (1 lift/8 hr)	Older	25.3 (5.8)	15.5 (11.4)	2.7 (16.908)	18.8 (17.304)	-5.5 (24.9)
	Younger	42.7 (5.6)	-6.1 (10.9)	5.0 (16.188)	4.8 (15.796)	-6.5 (3.4)

Significant differences were evident for the hip_{max} and $knee_{max}$ sagittal plane joint angles ($p<0.001$) for the floor-to-knuckle height and knuckle-to-shoulder height lifting tasks (Table B 12). When comparing the 1 lift/9 s and 1 lift/2 min from floor-to-knuckle height, the joint angles of the $shoulder_{max}$, hip_{max} and $knee_{max}$ were not significantly different ($shoulder_{max}$: t=-0.358 p= 0.722;hip_{max}: t=0.365 p=0.717; $knee_{max}$: t=-0.042 p=0.967) (Table B 12). Similarly, the sagittal plane joint angles of the hip_{max} and $knee_{max}$ for the two knuckle-to-shoulder height lifting tasks were not significantly different (right hip_{max}: t=-0.919 p=0.363; $knee_{max}$: t=0.647 p=0.495) (Table B 12). Therefore, there were significant differences for participants across all tasks, but when comparing similar task heights, there were no significant differences in maximum sagittal plane joint angles.

Table B 12: Statistical (F(p) values) and from the repeated measures ANOVA tests and p-values from paired t-tests. Average (SD) maximum sagittal plane shoulder, hip and knee joint angles (°) for each task for participants.

Joint	ANOVA		A priori pairwise comparisons					
	F Value	P Value	Floor-to-Knuckle (1Lift/9s)	Floor-to-Knuckle (1Lift/2 min)	t(p) Value	Knuckle-to-Shoulder (1Lift/2min)	Knuckle-to-Shoulder (1Lift/8hr)	t(p) Value
Shoulder	1.879	0.169	89.2 (6.9)	93.6 (6.9)	-0.358 (0.722)	87.9 (9.0)	75.9 (9.7)	1.140 (0.260)
Right Hip	13.034	<0.001 *	127.3 (7.6)	125.8 (7.8)	0.365 (0.717)	155.7 (4.0)	157.4 (3.0)	-0.919 (0.363)
Left Hip	8.854	<0.001 *	126.4 (8.3)	128.6 (6.5)	0.377 (0.708)	158.6 (3.0)	149.1 (5.7)	0.480 (0.411)
Right Knee	35.020	<0.001 *	83.9 (6.9)	76.8 (6.8)	-0.042 (0.967)	143.3 (6.3)	147.9 (4.8)	0.647 (0.495)
Left Knee	12.358	<0.001 *	125.4 (7.9)	124.1 (7.2)	0.100 (0.921)	151.9 (3.8)	153.6 (4.0)	0.468 (0.442)

Appendix C

Lift Time for each Task

Table C 1: F-ratio (p-value) from the repeated measures ANOVA tests on lift time for tasks

	ANOVA		
Lift Time	Age	Task	Interaction
Time (s)	0.478 (0.497)	16.747 (<0.001)*	1.82 (0.152)

Table C 2: Lift times (s) of older and younger workers for each lifting task

Task	**Older (s)**	**Younger (s)**	**Average (s)**
Floor-to-Knuckle (1 lift/9 s)	1.9 (0.15)	2.2 (0.13)	2.1 (0.09)
Floor-to-Knuckle (1 lift/ 2 min)	2.5 (0.15)	2.6 (0.14)	2.5 (0.10)
Knuckle-to-Shoulder (1 lift/ 2 min)	2.3 (0.12)	2.7 (0.11)	2.5 (0.08)
Knuckle-to-Shoulder (1 lift/ 8 hr)	2.9 (0.21)	2.8 (0.19)	2.9 (0.14)

No significant differences (F=0.478; p=0.497) were found between lift time for older and younger workers (Table C 1). Significant differences (p<0.001) were found between the amounts of time it took to lift the box between tasks. Pairwise comparisons showed significant differences between the various frequencies (1 lift/9 s, 1 lift/2 min and 1 lift/8 hr) (p<0.01). Both tasks at 1 lift/2 min were not significantly different (p=0.674).

Appendix D

Qualitative Notes from Interactions with Participants

Participant G1-01

1. How many years have you worked in within the manual materials handling field? *6 years*
2. In your past jobs, what have been your responsibilities? *Cleared chrome parts for the front of BBQs and "light line assembly" (placing parts in a box). The light line assembly was placing different parts or cardboard in a box to help with shipping. She also was responsible for putting screws and bolts in each panel for each box/bbq. She was required to stand all day for these jobs.*
3. Are you willing to continue working within the manual materials handling field/perform the same type of job today? If not, what type of job would you prefer? *No, she would prefer a desk job as she does not like to do physical work.*
4. Comment on the tasks performed today: *She said that she tries to avoid jobs that involve overhead work and repetitive lifting. She said that if she had to do any jobs with repetitive lifting, she would not return to work. G1-01 felt that the shoulder height was too high and would have preferred a height that was a couple inches shorter. During the cardiovascular task she felt that the box was too heavy and a good weight would have been if it was cut in half (2.6 kg).*

Additional Comments: *After several lifts in the lab, the participant claimed that she had low blood pressure and she thought there was something wrong with her heart, but her doctor could never find anything wrong. The participant tends to lean to her right side as her other job involves carrying trays since she works for a catering company as well.*

The participant has fatigue syndrome in her left forearm. She also complained that she did not like bending all of the time and would prefer to do desk work (no physical work). She said that she hasn't been able to find a desk job since she has done so much temporary work. She is currently trying to find a job as a legal aid.

Participant G1-02

1. How many years have you worked in within the manual materials handling field? *4 years*
2. In your past jobs, what have been your responsibilities? *Moving boxes, stocking and re-stocking as well as cashier.*

3. Are you willing to continue working within the manual materials handling field/perform the same type of job today? If not, what type of job would you prefer? *Only if it was a part time job, but not full time.*
4. Comment on the tasks performed today: *She preferred lifting from knuckle-to-shoulder height as she did not like bending over for the floor-to-knuckle height lifting tasks.*

Additional Comments: *The participant started out her career working for the city of Waterloo doing desk work, but stopped after many years because she wanted a job with more variety. She currently works for Toyota in the cafeteria and will not continue in the New Year because of the current commuting costs. The only problem she has working here is the commute. Prior to working here, the participant worked at the Superstore, but found that it involved too much heavy lifting. She said that she had performed a similar task to the floor to knuckle height when she worked for Grand River Foods and was moving boxes there.*

She is very open to doing any type of job in the New Year and says that she is planning to work through temporary agencies until she is 64.

Participant G1-03

1. How many years have you worked in within the manual materials handling field? *7 years*
2. In your past jobs, what have been your responsibilities? *Opening boxes, packing skids, putting materials on carts and shelves. Her current jobs requires her to work in refrigerated conditions where she wears 2 layers of gloves.*
3. Are you willing to continue working within the manual materials handling field/perform the same type of job today? If not, what type of job would you prefer? *Yes*
4. Comment on the tasks performed today: *She does not like the cardiovascular task (1 lift/9 s from floor-to-knuckle height) as she does not like any jobs that increase her heart rate. She said that it wasn't the mass of the box that she was having difficulty with, but the constant bending.*

Additional Comments: *The participant has worked at Schneider's for the past five months. Her job involves packing and moving boxes at approximately 10 minute intervals for one day a week, while the other four days she is doing fine tasks with sorting. The boxes that she moves are quite heavy at ~20 lbs and if she cannot lift it, she will try to roll them to the destination. Her current job involves her working in refrigerated conditions, but she has no problem with the temperature and wears 2 layers of latex gloves. She would not want to do a job like the experimental tasks for an 8 hour day (especially Task 1 – 1lift/9s). The participant said that she hasn't come across any jobs that require lifting at a pace of 1 lift/9 s. She* *also claimed that she had never had a job that involved lifting knuckle-to-shoulder height, but at her current job did tasks that involved floor-to-knuckle height lifting tasks.*

Since the participant has come in on her 5th day of work this week she feels as though she's finding it more tiring that if she had come in on the first or second day of her work week. She also found that the arm strap on the right upper arm may have been causing her discomfort (as indicated in the RPE scores). Her chin also continued to touch the shelf as she was going down to get the box from the floor.

Participant G1-04

1. How many years have you worked in within the manual materials handling field? *7 years*
2. In your past jobs, what have been your responsibilities? *Inspected and packed plastic parts, quality control, and lead operator.*
3. Are you willing to continue working within the manual materials handling field/perform the same type of job today? If not, what type of job would you prefer? *Yes*
4. Comment on the tasks performed today: *She does not like the cardiovascular task (1 lift/9 s from floor-to-knuckle height). She feels that both of the floor-to-knuckle height lifting tasks would hurt her back after a long time. Although she does not like lifting, she prefers the knuckle-to-shoulder height lifting tasks.*

Additional Comments: *The participant would like to find a full time job, but hasn't been able to find one. Currently, she can only find work through Work-Pro at DC Foods packaging meat. She said that she did not like the working environment. It is too cold working in the freezer. She was told that the freezer was kept 10 degrees colder than that temperature outside (she started working there in the winter).*

The participant didn't feel that Task 1 was representative of any jobs in factories.

Participant G1-05

1. How many years have you worked in within the manual materials handling field? 4 *years*
2. In your past jobs, what have been your responsibilities? *Order picker and customer service.*
3. Are you willing to continue working within the manual materials handling field/perform the same type of job today? If not, what type of job would you prefer? *Yes*
4. Comment on the tasks performed today: *Participant did not provide feedback for this question.*

Additional Comments: *The participant worked at NRC in Waterloo doing shipping and cycle counting for 28 years before the company went out of business. During her time there, she prepared package kits for shipment throughout North America. She was also responsible for tracking shipments and communicating* *with the buyers. The participant said that working there got better as the company started to make the work stations adjustable to the worker.*

Until now, the participant has worked as a parts and order picker and is currently employed by WorkPro. She has had a hard time finding work lately and has found that she can't keep up with the younger workers when working on a line. She finds that the younger workers have an easier time doing fine tasks. She has also found that she is sore after a day of work where she has been standing all day and doing repetitive movements without any job rotations.

Participant G1-06

1. How many years have you worked in within the manual materials handling field? *23 years*
2. In your past jobs, what have been your responsibilities? *Packing boxes*
3. Are you willing to continue working within the manual materials handling field/perform the same type of job today? If not, what type of job would you prefer? *Yes*
4. Comment on the tasks performed today: *The participant found that the box itself was very heavy and that she prefers a lighter weight when lifting once every 2 minutes because the rest periods make her not want to lift the box again. She prefers that one lift every 9 seconds as there isn't time to think about being tired. The repetitiveness of the lifting doesn't bother her, it was the weight of the box that bothered her.*

Additional Comments: *The participant stared doing manual labour jobs when she was 15 years old and continues to do them today. She specifically prefers jobs that involve lifting. In the past she has completed jobs that have involved lifting and steaming. One of the jobs in which she had to lift was when she was working for a car seat manufacturer and had to lift the seat cushions onto piles. Barb would like to continue to work, but finds that it is difficult as she finds that manual labour is taking a toll on her body and is becoming difficult to continue. The participant says that she has always been a lifter, lifting a variety of objects (boxes, seat cushion). She would not like to have a job that involves bending as it hurts her back to be bending and lifting.*

The participant would not want to continue lifting boxes for her job and would prefer a job that involves cleaning (e.g. retirement homes) or working in the kitchen in a retirement home until she is 65 years old.

Participant G1-07

1. How many years have you worked in within the manual materials handling field? *9 years*
2. In your past jobs, what have been your responsibilities? *Load empty plastic bottles onto a conveyer belt, observe automated liquid fill, place cap on filled bottles and tighten by hand,*

packed and labeled bottles into shipping boxes. Most of the jobs that she has had, has involved taking boxes off of a skid and putting them up on a shelf. The last job she had required her to unpack and pack blackberries into boxes.

3. Are you willing to continue working within the manual materials handling field/perform the same type of job today? If not, what type of job would you prefer? *Yes, if there were no other jobs available. She would prefer an administrative, less physically demanding job.*
4. Comment on the tasks performed today: *Participant did not provide feedback to this question.*

Additional Comments: *The participant has been doing factory work for a very long time. When applying to temporary agencies she was requesting light industrial work, but now would like an office job. The longest job that she has had consisted of filling boxes with shampoo/soap bottles. She said that this job was very tiring on her back from bending over all of the time. At this job, when everything was moving at maximum speed she would be responsible for packing 80 000 bottles/hr (40 boxes/hr). She recently turned down a job due to the blisters that she was getting on her feet as well as the chemical that the company was putting on the objects that she had to lift, which caused the skin on her hands to crack. The participant says that to lift boxes again, she just has to get back into it, which would probably take a couple weeks and she would be fine getting used to the weight that is given to her.*

Participant G1-08

1. How many years have you worked in within the manual materials handling field? *14 years*
2. In your past jobs, what have been your responsibilities? *Lifting totes off of a conveyor, take products off of a skid and pile them up to about waist height*
3. Are you willing to continue working within the manual materials handling field/perform the same type of job today? If not, what type of job would you prefer? *For a short time.*
4. Comment on the tasks performed today: *While doing the task, the participant continued to increase the weight and said that she likes to push herself. During Task 1, the weight that she had chosen had to be lowered since her heart rate was too high (was going over her max – 145 bpm). She said that if the pace wasn't so quick and increasing her heart rate, she would lift more. It wasn't the weight that was taxing, it was the pace.*

Additional Comments: *The participant is from Toronto and moved to Cambridge one year ago. While in Toronto, she had as office job for 14 years. After being laid off, she and her husband moved to Cambridge. Currently the participant is looking for an office job. She has previously worked at Pillar's in the factory and has also worked in shipping. She hasn't worked since the beginning of January, so she* *has been hired through a temporary agency and continues to look online for work. Her husband is a truck driver. She has no children, but has a cat and a dog. The participant had swollen ankles upon arriving to the laboratory and said that it was common.*

Participant G1-09

1. How many years have you worked in within the manual materials handling field? *10 years (in Canada)*
2. In your past jobs, what have been your responsibilities? *Lifting gear parts for inspection continuously and place the parts back into an empty box.*
3. Are you willing to continue working within the manual materials handling field/perform the same type of job today? If not, what type of job would you prefer? *Yes.*
4. Comment on the tasks performed today: *During the familiarization period, the participant found that the 1lift/9s was a good pace, but when doing the actual task, she found that it was too quick and her heart rate increased fairly fast. The participant's heart rate increased quickly (up to 150 bpm, her maximum was calculated to be 137.7 bpm) and due to this, she was asked to decrease the weight of the box. Also, during this task, she felt the need to take a break (for 5 min) at 12 minutes as she said that she felt very tired. Eugenie found that the 1 lift/2 min was a more realistic task. She preferred the knuckle to shoulder height lifting task as she did not have to bend over. She found the bending over awkward and hard on her body.*

Additional Comments: *The participant says that she has worked in factories all of her life. While in Kitchener, she has worked at DC Foods and has found that the climate is too cold. She has been having a hard time finding work. While in the factories, she said that most of her jobs have been doing fine tasks and that the men do to the heavy lifting. When she does have to lift, she is usually lifting off conveyor belts or skids to various heights. The participant says that the population in factories is mostly young people (20-30 years old) and they are VERY lazy. She said that the older workers (40+ years old) are much better to work with as they do not treat work like social time as the younger workers do.*

Participant G1-10

1. How many years have you worked in within the manual materials handling field? *6 years*
2. In your past jobs, what have been your responsibilities? *Packing blackberries (phones) in boxes on an assembly line.*
3. Are you willing to continue working within the manual materials handling field/perform the same type of job today? If not, what type of job would you prefer? *Yes.*
4. Comment on the tasks performed today: *Initially, the participant found it difficult to do the knuckle to shoulder height lifting task as she said that it hurt her shoulder. So, she said that she preferred the floor to knuckle height lifting task as she was used to lifting at that height. After performing all of the tasks, the participant said that she preferred the knuckle to shoulder height lifting task as it did not hurt her lower back like the floor to knuckle height lifting task. She also preferred the 1 lift/2 min task as she was able to get a break in between the lifting. The 1 lift/9 s task was making the participant very tired. She also said that the box handles hurt her hands. After the first floor to knuckle height lifting task, the participant said that she could feel it in her thighs.*

Additional Comments: *The participant is from New Delhi, India. She moved to Canada 8 years ago. While in India, she was a high school teacher. After moving to Canada, she was unable to find a job as a teacher and therefore, worked as a superintendent managing 6 buildings. After this, she got a job at RIM in the factory on a line where she inspected blackberries and put parts into them. When she did do lifting on the line, it was up to 10 kg. The participant described working at RIM like being in a five-star hotel. She lives with her old friend in Kitchener, whom is a doctor at Grand River Hospital. Currently the participant works as a supply teacher at an elementary school. Since there have been cut backs at the school board, she is again looking for more factory work. She still visits India as well as England as she has family there.*

Participant G1-11

1. How many years have you worked in within the manual materials handling field? *25 years*
2. In your past jobs, what have been your responsibilities? *Sort letter mail, flat mail, parcels, prepare and deliver to customers, load and unload corporate vehicles, pick up heavy outgoing items to mail, empty street letter and super-mail boxes to collect outgoing mail.*
3. Are you willing to continue working within the manual materials handling field/perform the same type of job today? If not, what type of job would you prefer? *Yes.*

4. Comment on the tasks performed today: *The participant preferred lifting once every two minutes and found she could lift the weight that was added at the half-way mark. For the max lift, the participant thought that she could lift the weight once she loaded the box, but once she tried, she found it very difficult to lift the weight she had chosen up, but was fine with it at lower levels. It took her several tries to settle on a weight that she was comfortable with lifting.*

Additional Comments: *The participant currently works at Winners in the change room section. She is responsible for letting people into the change rooms and putting the clothing back. The participant worked at with the Postal Service for many years sorting the mail and as a letter carrier. She recently signed up with Work Pro and has been getting several jobs from them. She also is starting this weekend working at a factory in Guelph which is responsible for building the heating and cooling systems for Toyota vehicles. She worked at this factory last year. She will be working weekends at Toyota until the end of August. She is hoping to get a full-time job from it.*

Participant G1-12

1. How many years have you worked in within the manual materials handling field? *11 years*
2. In your past jobs, what have been your responsibilities? *Transfer cakes of an oven and transfers them onto racks. Moves pails of banana peels (approximately 24lbs) onto skids. Once the skid is full, she gets a pump truck and wheels the skid to the dumpster. All of the bags are put into the dumpster (~35 bags/day).*
3. Are you willing to continue working within the manual materials handling field/perform the same type of job today? If not, what type of job would you prefer? *Yes.*
4. Comment on the tasks performed today: *She said that she did more knuckle to shoulder height lifting than floor to knuckle height lifting tasks. The participant would rather do the 1 lift/ 9s seconds as she is able to keep a rhythm instead of starting and stopping like during the 1lift/2min task. During the 1 lift/2 min task, she had to keep her legs moving so that they didn't hurt from standing still. 1 lift/2 min task would be easier if she had another task to do while she was waiting to do the lifts.*

Additional Comments: *The participant went to Conestoga College for Industrial Maintenance Mechanic in 1987 for the one year program. She later went to Laurier for Business Administration, but stopped as she had to look after her children. She has worked various jobs such as press operator, machine operator, and as a kitchen and baker assistant. While working in factories, the participant has had some lift training (lift with your knees). She has also been instructed by her physiotherapist to warm up before* *her 10 hour work days so that she does not get injured. At one of the places she worked 6 years ago, she was lifting 40 lb boxes once every 3 minutes. She is currently working in the bakery at Schaaf Foods where she does a lot of lifting of trays with baked goods as well as disposing of boxes banana peels in the garbage. While at the bakery the participant is responsible for lifting 480 cakes into and out of the ovens. She prefers lifting to doing swirls on the cakes as she hurt her back when doing swirls. While at work, the participant tries to maximize her work out by doing far, quick movements.*

Prior to doing the study, the participant had a high resting heart rate while she was talking ~114bpm, once she was asked to not speak, her heart rate went down to ~70 bpm. Her heart rate would increase quickly whenever she started to speak again.

Participant G2-01

1. How many years have you worked in within the manual materials handling field? *4 years*
2. In your past jobs, what have been your responsibilities? *Organize, receive and ship needed products into and out of distribution warehouse. Ensure quality by quickly and accurately checking products for defects.*
3. Are you willing to continue working within the manual materials handling field/perform the same type of job today? If not, what type of job would you prefer? *Yes.*
4. Comment on the tasks performed today: *During the familiarization period, the participant found that the lifting frequencies seemed to be very realistic with the type of factory work that she has had. She found the floor to knuckle height lifting a good height. While she was lifting she found herself thinking a lot about the weight and what she is comfortable lifting.*

Additional Comments: *The participant is from the GTA and moved to Kitchener when she was 13 years old. She graduated from Laurier in religion and culture. The year after, she completed her TESL from Conestoga College. The participant spent 6 months in Turkey teaching English abroad and returned to Kitchener in January. Since then, she has been looking for factory work. If Schnieder's was not closing down, that is where she would be continuing to work. She has worked every summer for 5 years at Schnieder's on the production line and later moved to shipping and receiving. Here she learned how to operate several lifting tools and received her license to operate them. She currently hasn't been able to find a job. She has had placements at a car manufacturing company moving parts of ~60lbs every 10 minutes, which she finds to be heavy and awkward to move. The participant is waiting to hear back from several schools which she applied to do a Master's degree in Linguistics.*

Participant G2-02

1. How many years have you worked in within the manual materials handling field? *2.3 years*
2. In your past jobs, what have been your responsibilities? *Assisted lifting an older lady out of a wheelchair into and out of a bed. Lifted packages at UPS.*
3. Are you willing to continue working within the manual materials handling field/perform the same type of job today? If not, what type of job would you prefer? *Yes.*
4. Comment on the tasks performed today: *The participant thinks that she was having a harder time lifting at the faster pace as she is a smoker.*

Additional Comments: *The participant grew up living with her family in Kitchener. While in high school, the participant was on the swim team. After high school, the participant went to the University of Waterloo on and off for 3 years. She would take time off in order to work to pay for school. She was in an arts program and did not enjoy it. After 3 years, the participant decided to no longer attend university. After no longer attending university, the participant started to work as a personal support worker for a lady that she met at a bus stop. The lady was in a wheel chair and required help in the mornings and evenings. The lady owned an electric wheel chair, so she did not require help during the day. The participant was later let go after 2 years as another person with a personal support worker diploma was employed. The participant would like to attend Conestoga college in order to become a PSW. She enjoys helping people. Currently, the participant works at UPS (for the past 4 months) and is responsible for lifting packages up to 40 or 50 lbs.*

Participant G2-03

1. How many years have you worked in within the manual materials handling field? *7 years*
2. In your past jobs, what have been your responsibilities? *Loading and unloading luggage.*
3. Are you willing to continue working within the manual materials handling field/perform the same type of job today? If not, what type of job would you prefer? *Yes.*
4. Comment on the tasks performed today: *The values chosen from knuckle to shoulder height lifting tasks are similar to the weights that she uses at the gym when she works out. She had no problems with either pace. While lifting the box onto the shoulder height shelf, the participant held the box by the handles, but at a different positioning than the previous participants. Her palms were not resting against the top. She had the box handles resting on her palms and finger.*

Additional Comments: *The participant grew up in Kitchener and later moved to Calgary for university. She decided that she didn't enjoy it and went to college for travel and tourism at Conestoga College. She* *got a job in Calgary at a travel agency which ended up going bankrupt two weeks into her starting there. She decided to stay in Calgary and try to find another job. Her dream job was to become a flight attendant. Since the participant has a shunt (to drain the fluid from her brain into her stomach) she can't work as a flight attendant since she gets dizzy easily. The participant had a seizure almost 2 years ago while she was at the hospital in ICU. This seizure was discovered to be due to a condition called hydrocephalus. When she was in Calgary she discovered that she wanted to work with trains. Thus, she went to train conductor school. The participant was offered a job to work at an American company to drive freight trains, but she's waiting on the paperwork to go through. While she is waiting she has been doing manual labour jobs. She currently has been doing manual labour work at a car plant since January 2012. Since her surgery (2 years ago), she has been getting stronger. As a train conductor, if something happens to the train she'll have to be able to lift 83lbs from the ground to her chest and carry it approximately one mile.*

Participant G2-04

1. How many years have you worked in within the manual materials handling field? *7 years*
2. In your past jobs, what have been your responsibilities? *General labourer at a meat packing plant and other factories working on an assembly line, maintained lawns, worked in kitchens, repaired floors*
3. Are you willing to continue working within the manual materials handling field/perform the same type of job today? If not, what type of job would you prefer? *Yes.*
4. Comment on the tasks performed today: *Participant did not comment on tasks performed today.*

Additional Comments: *The participant is from Kitchener, Ontario. She went to the University of Ottawa, and then decided that she no longer wanted to be in the arts program anymore. Once she stopped going to school, the participant started working in factories. She worked at a meat packing plant in Guelph for a year as well as a cargo plant. She also worked at a processing plant near Conestoga Mall through Work Pro. She signed up at Work-Pro recently. The participant worked at a landscaping company in Fergus a couple years ago. She will be going to school in September for culinary management. During high school, she played ringette. From experience on assembly lines, the participant is used to have to keep going when the package arrives on the line and not being the one waiting.*

Participant G2-05

1. How many years have you worked in within the manual materials handling field? *1 year*
2. In your past jobs, what have been your responsibilities? *Lifting her child, server, hostess, assisting nurses at a hospital*
3. Are you willing to continue working within the manual materials handling field/perform the same type of job today? If not, what type of job would you prefer? *Yes.*
4. Comment on the tasks performed today: *The participant started to get very tired by the end of the 4 hours*

Additional Comments: *The participant is from Kitchener and has moved around throughout high school. She moved back to Kitchener a couple years ago. The participant is currently a stay at home mother for her 3 year old daughter. She occasionally works when she can. She started working through Work Pro recently. In the past she has had jobs in factories. One of which was in a bath soap factory. These soaps were made for hotels. She had to stop working here once she passed out (after two weeks) due to being pregnant. She does well in school and completed paralegal assistant studies while she was pregnant. The participant is currently completing schooling to be a personal support worker, but does not want to pursue this field after completing an internship. She has been accepted to a police foundations school in North Bay and will be starting in September. The participant would eventually like to be a lawyer. The participant currently smokes.*

The participant wanted to have energy left for the rest of the day since she had to look after her child. Her 3 year old has ADD and Victoria finds it hard to keep up with her.

Participant G2-06

1. How many years have you worked in within the manual materials handling field? *2 years*
2. In your past jobs, what have been your responsibilities? *Weighed and wrapped slices of meat, stocking shelves with products off of pallets, assembly line sorting products to be shipped, machine operator*
3. Are you willing to continue working within the manual materials handling field/perform the same type of job today? If not, what type of job would you prefer? *Yes.*
4. Comment on the tasks performed today: *The participant prefers the once every 2 minutes and the floor-to-knuckle height lifting task. She has worked where she has had to load every 1.5 minutes and enjoys the break. While at work the participant constantly thinks about how much she can lift.*

Additional Comments: *The participant has done both factory and secretarial work. She is thinking about going back to school as she cannot find any permanent work. The participant has signed up as many temporary agencies in the area as possible within the area). Dropped out of high school and then returned a year later to finish. In the past the participant has worked a lot with plastic and had to wear gloves with the carving and the heat. She has also worked at the Toyota plant.*

Participant G2-07

1. How many years have you worked in within the manual materials handling field? *8 years*
2. In your past jobs, what have been your responsibilities? *The participant has worked in factories and in greenhouses. She prefers jobs where she is moving and not sitting at a desk all day. She currently works at a movie theater part time where she lifts boxes in order to re-stock the inventory. When she worked at a factory, she worked on a line, but it did not involve lifting. When she worked at a greenhouse, she had to lift a lot of weight, especially if the plants had been watered.*
3. Are you willing to continue working within the manual materials handling field/perform the same type of job today? If not, what type of job would you prefer? *Yes.*
4. Comment on the tasks performed today: *During the lifting task, the participant seemed to be able to judge what she was able to lift, but when the mass was perturbed she didn't end up changing the weight back. Only during the floor-to-knuckle height lifting task at once every nine seconds did she lower the weight after it was perturbed. This was because she rated the task overall a 7 on the BORG CR-10 scale and was asked to lower the weight. The participant preferred the floor-to-knuckle height as the knuckle-to-shoulder height made her shoulders tired. She also preferred the once every nine seconds as it kept her moving rather than having to wait for the next lift like in the once every 2 minute tasks.*

Additional Comments: *The participant grew up on a farm and currently lives in grandfather's old house, just down the street from where she grew up. Temperatures within the greenhouse would reach up to 118 degrees Fahrenheit. While working there, she lost 30 lbs due to the lifting and temperature. She is currently looking for a full time job so that she'll be able to purchase a house in 10 years.*

Participant G2-08

1. How many years have you worked in within the manual materials handling field? *0.2 years*
2. In your past jobs, what have been your responsibilities? *Other jobs that she has that involved lifting are her ones at Cineplex (previously) and Pita Shack (currently). While working at these two jobs, the particpant was responsible for stocking the inventory.*
3. Are you willing to continue working within the manual materials handling field/perform the same type of job today? If not, what type of job would you prefer? *Yes.*
4. Comment on the tasks performed today: *During the lifting task, the participant preferred the lifting once every 2 minutes from floor to knuckle height. She feels like her arms are shorter, making moving things to shoulder height more difficult.*

Additional Comments: *The participant is currently in her second year doing her undergraduate degree at Laurier in psychology. She is planning to work with Work Pro throughout the summer in Brampton. While at university the participant involves herself in extracurricular activities such as her University Radio show called "the basement". She does not play any sports outside of school as she does not have very good hand-eye coordination.*

Participant G2-09

1. How many years have you worked in within the manual materials handling field? *1 year*
2. In your past jobs, what have been your responsibilities? *Minced meat and incorporated ingredients into meat in a bag, stocked fridges at a restaurant, lift boxes filled with frozen products*
3. Are you willing to continue working within the manual materials handling field/perform the same type of job today? If not, what type of job would you prefer? *Yes.*
4. Comment on the tasks performed today: *The participant was having a hard time with the 1 lift/9s as she found the bending very hard on her legs. She found the repetition the problem more so than the weight of the box. She preferred the 1lift/2min. She had to reduce the weight during the 1 lift/9s due to her heart rate being high and her RPE score of 7 each time.*

Additional Comments: *The participant is from Kitchener and went to Conestoga College for one year doing Human Services Foundations. She is starting school at Fanshaw in September to become a Child and Youth Program Worker. She has worked at DC Foods with Work Pro where she was responsible for. She requested not to get anymore shifts there as she found it monotonous. She is looking for a full-time* *job for the summer. Prior to signing up with Work Pro, the participant worked at a retirement home as a dietary aid for 2.5 months before she was let go.*

Participant G2-10

1. How many years have you worked in within the manual materials handling field? *1 year*
2. In your past jobs, what have been your responsibilities? *Server, cleaning lady, has worked at factories on the and transport machine parts (approximately 15 lbs)*
3. Are you willing to continue working within the manual materials handling field/perform the same type of job today? If not, what type of job would you prefer? *Yes.*
4. Comment on the tasks performed today: *The participant was asked to decrease the weight for task 1 at 10 and 20 minutes because her RPE was 6 at 10 minutes and her heart rate was at 167 bpm and RPE at 6 at 20 minutes.*

Additional Comments: *The participant goes to the University of Ottawa for social sciences. She just finished her 1st year and will be starting her 2nd in September. The participant worked as a bartender in England for 3 months and traveled to various countries after that. She is currently looking for summer jobs and has applied to a lot of temporary agencies and factories. She has worked in factories before such as Toyota and other ones that manufacture parts for cars. The participant took time off after high school and worked.*

Participant G2-11

1. How many years have you worked in within the manual materials handling field? *2 years*
2. In your past jobs, what have been your responsibilities? *Machine operator removing parts from mold and cutting runners off, server carrying large trays for catering*
3. Are you willing to continue working within the manual materials handling field/perform the same type of job today? If not, what type of job would you prefer? *Yes.*
4. Comment on the tasks performed today: *The participant preferred the floor to knuckle height lifting task and the once every 2 minute task. She felt that she was too short for the knuckle to shoulder height lifting task.*

Additional Comments: *The participant has been with Work Pro for several months and has been given jobs every week from them. The past couple weeks, the participant was working at Bingeman's in the catering department (in the kitchen). She has also worked in several factories through Work Pro. Prior to signing up with Work Pro, the participant was working doing injection molding in a factory. She was* *responsible for pushing the buttons to inject the material into the mold. Kim is currently looking for a full-time factory job.*

Participant G2-12

1. How many years have you worked in within the manual materials handling field? *0.3 year*
2. In your past jobs, what have been your responsibilities? *Took boxes from stock and to customers (~15 kg)*
3. Are you willing to continue working within the manual materials handling field/perform the same type of job today? If not, what type of job would you prefer? *Yes.*
4. Comment on the tasks performed today: *The participant preferred the floor to knuckle height lifting task and the once every 2 minute task. She felt that she was too short for the knuckle to shoulder height lifting task.*

Additional Comments: *The participant is looking for full time work for the summer. She just finished her first year at the University of Waterloo in legal studies. She has worked as a cashier and as a door to door salesman. She has worked at a store keeper, opening the business as well as cleaning the store.*

Appendix E

Times at which Participants Were Required to Reduce Mass due to HR or RPE

Table E. 1: Decreases to load due to participant reaching age-adjusted maximum acceptable heart rate

Participant Group	Participant Code	Age-Adjusted Maximum Heart Rate (bpm)	Task	Heart Rate (bpm)	Time (min)	Load Prior to Decrease (kg)	Load After Decrease (kg)
Older	G1-08	144	Floor-to-Knuckle (1 lift/9 s)	146	7:00	15.5	11.0
				150	14:00	11.0	8.6
				150	17:00	7.8	7.3
	G1-09	138	Floor-to-Knuckle	140	9:00	8.0	7.1

Table E. 2: Decreases to load due to participant reaching an overall RPE greater than 6 at 10 or 20 minutes into lifting task

Participant Group	Participant Code	Task	Overall RPE	Time (min)	Load Prior to Decrease (kg)	Load After Decrease (kg)
Older	G1-01	Knuckle-to-Shoulder (1 lift/2 min)	7	10	7.4	5.4
			7	20	5.3	5.3*
	G1-03	Floor-to-Knuckle (1 lift/9 s)	7	10	7.8	7.1
	G1-04	Floor-to-Knuckle (1 lift/9 s)	7	20	9.3	7.7
	G1-06	Floor-to-Knuckle (1 lift/9 s)	7	20	6.1	5.4
		Floor-to-Knuckle (1 lift/2 min)	7	10	5.8	5.2
			7	20	8.2	6.1
	G1-07	Floor-to-Knuckle (1 lift/9 s)	7	20	9.2	7.8
	G1-10	Floor-to-Knuckle (1 lift/ 9 s)	7	10	6.7	6.4
			7	20	6.3	5.9
Younger	G2-06	Floor-to-Knuckle (1 lift/9 s)	7	20	14.3	11.9
	G2-07	Floor-to-Knuckle (1 lift/9 s)	7	20	13.6	12.2
	G2-09	Floor-to-Knuckle (1 lift/9 s)	7	10	8.0	7.2
			7	20	9.7	7.7

*could not decrease load any more

Appendix F

Initial Insights into Loading during Maximum Intersegmental Sagittal Plane Flexion Angles for Older Workers

During the 1 lift/9 s floor-to-knuckle height lifting task, the older participants had a low back compression of 2961 N (Figure F. 1). The strength percent capable was within the “green zone” in 3DSSPP for the wrist, elbow, shoulder, torso, knee and ankle (Figure F. 1). The only joint in the “yellow zone” was the hip. Similar results were shown for the 1 lift/2 min floor-to-knuckle height lifting task, however the low back compression was higher at 3629 N and was in the “yellow zone” (Figure F. 2).

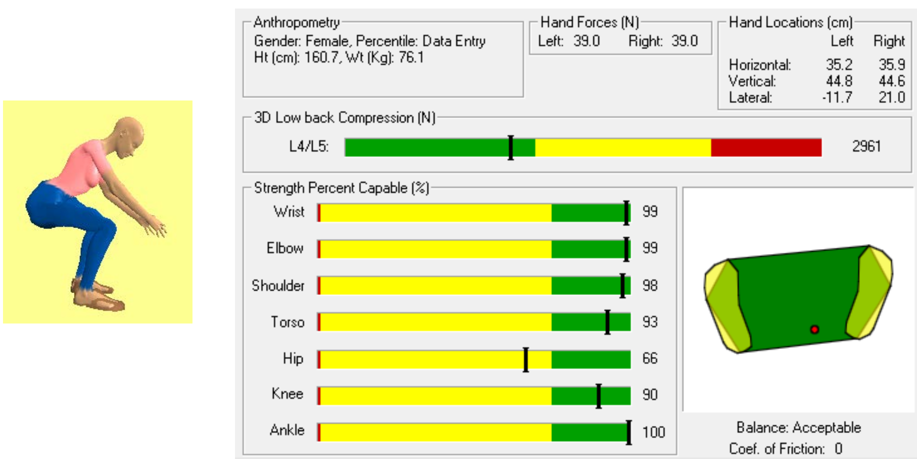

Figure F. 1: Maximum flexion of the right shoulder, right and left hip and knee position during floor-to-knuckle height lifting at 1 lift/9 s (left) and 3DSSPP output of low back compression and strength percent capable (%) at the wrist, elbow, shoulder, torso, hip, knee and ankle

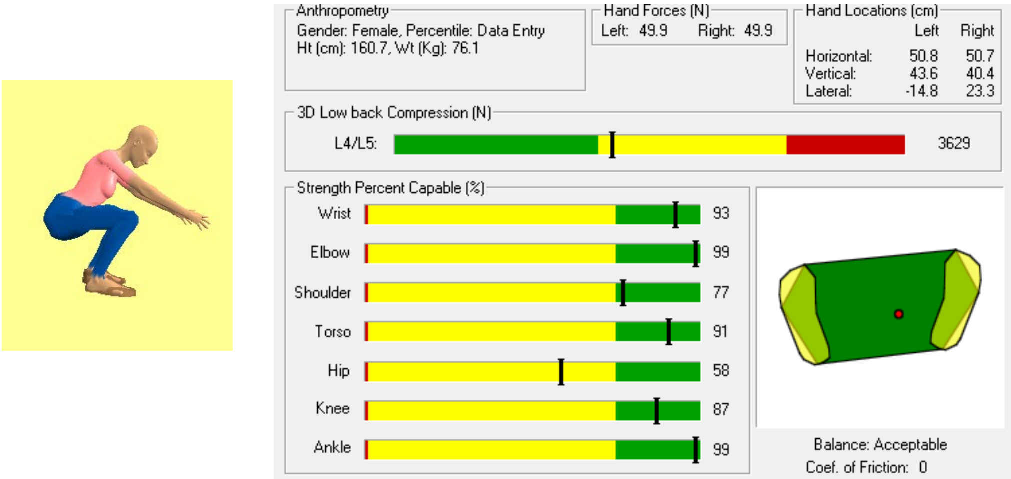

Figure F. 2: Maximum flexion of the right shoulder, right and left hip and knee position during floor-to-knuckle height lifting at 1 lift/2 min (left) and 3DSSPP output of low back compression and strength percent capable (%) at the wrist, elbow, shoulder, torso, hip, knee and ankle

During the 1 lift/9 s floor-to-knuckle height lifting task, the older participants had a low back compression of 2145 N (Figure F. 3). The strength percent capable was within the “green zone” in 3DSSPP for the wrist, elbow, torso, hip, knee and ankle (Figure F. 3). The only joint in the “yellow zone” was the shoulder. Similar results were shown for the 1 lift/2 min floor-to-knuckle height lifting task, however the low back compression was higher at 2263 N (Figure F. 4).

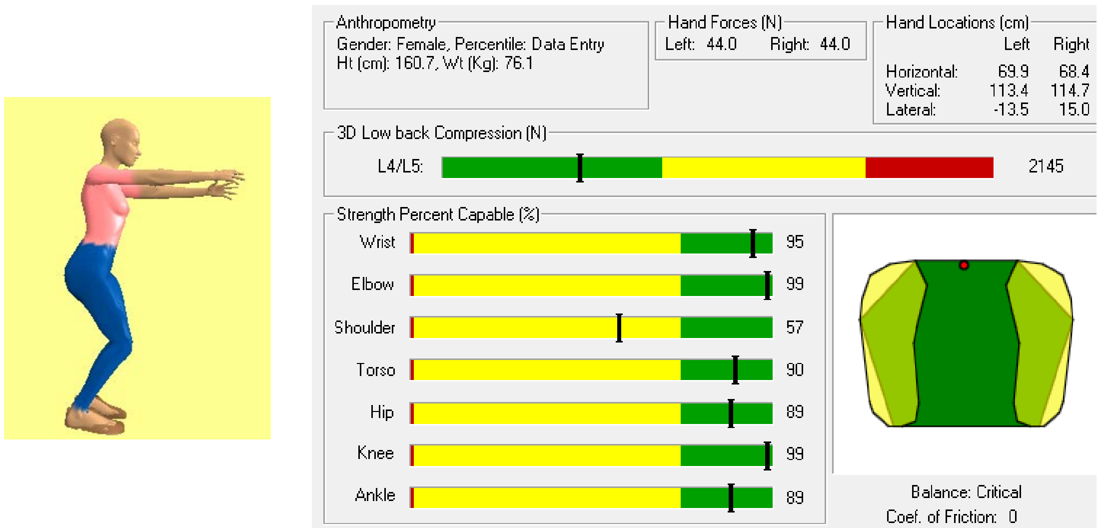

Figure F. 3: Maximum flexion of the right shoulder, right and left hip and knee position during knuckle-to-shoulder height lifting at 1 lift/2 min (left) and 3DSSPP output of low back compression and strength percent capable (%) at the wrist, elbow, shoulder, torso, hip, knee and ankle

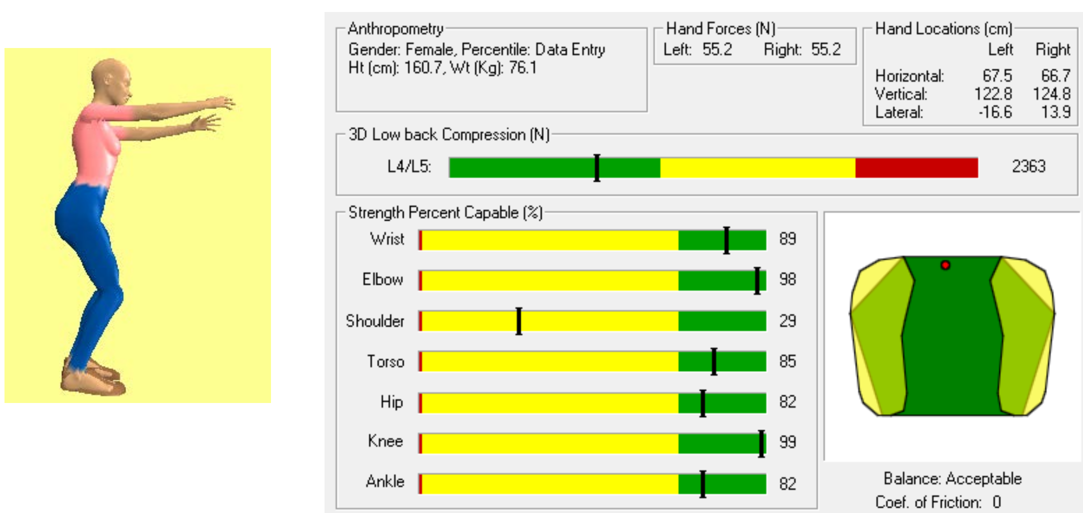

Figure F. 4: Maximum flexion of the right shoulder, right and left hip and knee position during knuckle-to-shoulder height lifting at 1 lift/8 hr (left) and 3DSSPP output of low back compression and strength percent capable (%) at the wrist, elbow, shoulder, torso, hip, knee and ankle