Comparing occupational musculoskeletal exposures during common materials handling tasks between non-obese and obese adults

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 final revisions, as accepted by my examiners.

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Abstract

Higher body mass is associated with increased risk of musculoskeletal injury, a greater number of insurance claims, and higher direct and indirect costs due to decreased productivity during manual materials handling. Over one billion adults are overweight and at least 400 million are obese worldwide. Obese individuals may experience higher musculoskeletal exposures during work performance due to excess body mass. With greater segmental masses and higher distance of these masses from joint centers of rotation, larger joint moments could be generated for obese persons in similar postures to non-obese persons. This consequently would make tasks that require farther reaches relatively more demanding for obese persons. It is crucial to assess this potentially vulnerable cohort to reduce risk of musculoskeletal injuries during manual materials handling (MMH) tasks, particularly as many current workspace designs are based on normal weight anthropometric charateristics.

The purpose of this research was to determine differences in joint loading and modified motion patterns between non-obese (normal weight & overweight) and obese adults during common manual materials handling tasks. Thirty participants (15 male & 15 female) performed the following four manual materials handling tasks: load transfer (0.5kg, 1.5kg, 2.5kg), lift & lower (2.5kg, 5kg, 10kg), push (40N, 60N, 80N), and pull (40N, 60N, 80N). Upper extremity kinematics were collected during the four MMH tasks with 29 reflective markers. Joint kinematic profiles of amplitude probabilty distribution functions (APDF) were created for the low back, shoulder, and elbow, while joint moments of APDF were created for the low back, shoulder, elbow, and wrist. Isometric and maximal functional strength tests evaluated low back and shoulder strength. Worktables and handle heights were adjusted to each participant according to NIOSH and Liberty Mutual Table recommendations. Participants were categorized into two groups: those obese with BMI>30kg/m^2 or non-obese with BMI≤30kg/m^2. Body discomfort and exertion were recorded for each task combination. Statistical comparisons between the obese and non-obese individuals were performed for isometric and maximal functional strength tests, kinematic and kinetic profiles for APDFs.

Results showed that obese individuals have higher absolute strength unless normalized to body mass, and they experiece higher moments at the low back and shoulder for specific task parameters. On average, obese individuals had greater absolute strength for isometric tests, low back flexion (495N), low back extension (453N), shoulder flexion (86N), shoulder internal rotation (128N), and for maximal functional strength tests push (216N) and down (148N) exertions. Absolute isometric joint and maximal functional strength had positve corrleations with increases in BMI. When strenght tests were normalized to body mass, there was a negative correlation with increase in BMI. Interactions between distance and groups during the 90th percentile level of exposures resulted in increases to low back resultant moments by 39% at the 30cm reach, 31% at 50cm, and 21% at 70cm reach during the load transfer task compared to the non-obese group. Lift combinations from knuckle to shoulder (KS) resulted in higher low back moments with hand loads of 2.5kg and 10kg by 20%, 5kg and 10kg increased by 29%, and 2.5kg and 5kg increased by 43% for obese participants. Height combinations of floor to shoulder (FS) resulted in higher low back moments with hand loads of 2.5kg and 5kg by 25%, 5kg and 10kg by 27%, and 2.5kg and 5kg by 46% for obese participants when compared to the non-obese group. Interactions between distance and groups for shoulder moments were higher at exposure levels of 90th percentile where height combination of FK, KS and FS were greater by 30%, 19%, and

21% respectively, for obese participants when compared to the non-obese group. Obese individuals experienced more exertion when executing the push and pull tasks, but did not exemplify significant differences from the non-obese groups.

Future recommendations for manual materials handling tasks for obese individuals, particularly for the upper extremity during load transfer tasks, should consider closer work distances and lighter hand loads. This would minimize low back and shoulder moments as they were higher compared to non-obese individuals for all distance and load combinations. To minimize the amount of work performed, lifts requiring floor-to-shoulder heights should have lighter hand loads to minimize high exposures. Workspaces should allow individuals to move freely as movement compensations may occur to potentially avoid overload at certain joints or segments.

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I. Introduction

The prevalence of obesity continues to rise and is an epidemic concern not only within Canada but worldwide. The World Health Organization (WHO) estimated that more than 1 billion adults worldwide are overweight and at least 400 million adults are obese (2006). Since the early 1930s, life insurance companies began using height and weight charts to identify clients for increased risk of death (Caballero, 2007). Using body mass index (BMI) to calculate obesity provides a quick and easy method to classify adults as normal weight (18.5-24.9), overweight (25.0-29.9), obese class I (30.0-34.9), obese class II (35.0-39.9) or obese class III (≥40.0). The economic burden from the obese population cannot be ignored as the estimated costs to the Canadian economy were approximately $4.6 billion in 2008, up $735 million or about 19% from $3.9 billion in 2000 (Hodgson, 2011). According to the Public Health Agency of Canada, obesity is associated with increased numbers of absent workdays (2011), reduced productivity (2013), and higher numbers of compensation claims (Tunceli et al., 2006). In Canada, lost days and productivity due to obesity have an indirect cost of $4.3 billion per year and growing (Janssen, 2012).

Optimal and efficient movement is often compromised and can lead to performance deficits and higher injury prevalence in people with higher BMI. Individuals with higher BMIs have a reduction in work capacity which subsequently decreases spine flexibility and increases dorsal stiffness (Gilleard & Smith, 2007; Hue et al., 2007), limited range of motion in major joints (Xu et al., 2008), and potentially reduced muscle strength (Xu et al., 2008; Katzmarzyk et al., 2000). Higher body mass increases external joint moments, primarily in the back (Gilleard & Smith, 2007; Hue et al., 2007) and knees (Capodaglio et al., 2010). The shoulder joint is also at risk for injuries (Viikari-Juntura et al., 2008). Increased physical demands could cause damage or injuries to biological tissues. Biomechanical models of the musculoskeletal system indicate that obese individuals experience higher joint loading during lifting tasks (scaled to 10% and 25% of their capacity) than normal weight counterparts (Xu et al. 2008). As the mass of the torso creates greater moments about the lumbar spine, it requires more muscle force, which increases spinal loading for the same task in a heavier individual. With the assumption of higher mass per segment, increased forces and moments are required for movement. Movement compensations may occur to potentially avoid overload at certain joints or segments. Blue-collar workers in Canada (such as those who work in an industrial setting) were more likely to be obese than those who worked in white-collar type settings (Park, 2009; Statistics Canada, 2002). Their work performance could be hindered from having to experience higher moments or generating greater muscle contributions to accomplish the same task because of limitations to physical capabilities. This could ultimately lead to movement compensation from lack of range of motion at adjacent joints due to excess adipose tissue surrounding the joint.

The connection between higher BMI levels and movement strategies requires further investigation as altered movements can be adopted due to constraints from increases in body mass. Developing and implementing effective interventions requires better knowledge on what approaches work (and do not work) in different settings and with different populations (WHO, 2009). Reductions in physical capacities occur for occupational tasks due to abnormal mechanics or body movements (Capodaglio et al., 2010). Increased body mass is associated with elevated risk of musculoskeletal injuries (Janssen, 2011), particularly in the shoulders and back (Norman et al., 1998; Parkinson et al., 2009; Park et al., 2009; Xu et al., 2008). Obese individuals have reduced muscle strength when compared to normal-weight individuals, potentially due to lower physical activity levels, reduced muscle function, and reduced motor unit activation during exercise (Lafortuna et al., 2005). Occupational materials handling performance across different obese and non-obese adults lack robust evaluation. Obese workers may endure higher exposures when performing common manual materials handling tasks. Exploration of how obesity modifies work task performance is crucial as the number of workers in this population continues to increase. Therefore, the primary objective of this thesis is to examine the relationship between occupational exposures and body composition. It is hypothesized that obesity will alter work performance, which may potentially increase the risk of physical exposures to the shoulder and low back when performing tasks compared to non-obese individuals. This research provides context for obese individuals' capabilities and task exposures during common manual materials handling tasks.

1.1 Purpose

The purposes of this study are to: 1) examine the kinematic and kinetic outcomes at the shoulder and low back from four different manual materials handling (MMH) tasks between non-obese (normal & overweight) and obese adults, and 2) explore how obesity modifies work task performance. The tasks:

a) A static isometric one-handed forward push at 40N, 60N, 80N at three different recommended heights by National Institute for Occupational Safety and Health (NIOSH), in which the elbow is flexed to 90° with the hand in line with the acromion in the sagittal plane, and the two others achieved by raising and lowering by an equal distance to 25% of the recommended height.

b) A static isometric one-handed backwards pull at 40N, 60N, 80N at three different recommended heights by NIOSH, in which the elbow is flexed to 90° with the hand in line with the acromion in the sagittal plane, and the two others achieved by raising and lowering by an equal distance to 25% of the recommended height.

c) A dynamic load transfer task (0.5kg, 1.5kg, 2.kg) at reach distances of 30cm, 50cm, and 70cm.

d) A dynamic lift and lower task with weights of 2.5kg, 5kg, and 10kg for three different heights (floor to shoulder height (FS), knuckle to shoulder (KS) height, and floor to knuckle height (FK)).

1.2 Hypotheses

The aim was to identify differences in work task performance of the upper extremity in the shoulder, elbow, wrist, and low back joint during four manual materials handling tasks between non-obese and obese individuals. The non-obese group consisted of normal weight (BMI 18.5-24.9) and overweight (BMI 25.0-29.9) individuals, while the obese group consisted of obese class I (BMI 30.0-34.9), obese class II (BMI 35.0-39.9), and obese class III (BMI ≥40) individuals. The supporting hypotheses include:

1) *Obesity will influence kinematic outcome variables in all MMH tasks; there will be increases in arm elevation and decreases in trunk flexion for the obese group compared to the non-obese group.*

Movement compensations could potentially make up for lack of range of motion in adjacent joints, which may be less optimal as it reduces the number of kinematic redundancies available. The rate of musculoskeletal disorders in the shoulder region is higher in obese individuals and a possible source is postural compensation from the spine due to existing dorsal stiffness and to reduce loading and range of motion of the upper limb (elbow and wrist joints)

(Capodaglio, 2010). Arm elevation is expected due to dorsal stiffness from the spine, which could limit the amount of forward trunk flexion motion to complete dynamic tasks from a work bench. Larger amounts of adipose tissue reduce spine flexibility and increase spinal stiffness, which affects execution of job tasks involving the trunk (Gilleard & Smith, 2007; Hue et al., 2007). Obese persons perform lifting tasks with different back kinematics (Xu et al., 2008). Obesity is also a factor in postural stability (Corbeil & Simoneau, 2001) which is required for stability during dynamic movements. Obese individuals may be less efficient and more at risk of injuries than normal weight individuals in a large number of work tasks and daily activities requiring upper limb movements performed from an upright standing position (Berrigan, Simoneau, Tremblay, Hue, & Teasdale, 2006). Moreover, inter-segmental joint rotations, specifically shoulder extension and adduction, lumbar spine extension and lateral flexions, and knee flexions are reduced from adipose tissues around the joint (Chaffin, Anderson, & Martin, 2006).

2) *Joint moments of the wrist, elbow, shoulder, and low back will be higher for the obese group during MMH tasks when compared to the non-obese group*.

A variety of factors potentially affect low back and shoulder moments, including: different hand loads, work layouts, or work rates. The work tasks studied replicate common MMH tasks.

I hypothesized that there would be higher joint moments in the upper extremity for individuals who are obese when doing the same tasks. Musculoskeletal disorders in the shoulder region are higher for obese subjects, and a possible explanation is postural compensation in the spine (decreased flexibility) and upper limb (reduction of range of motion at the elbow and wrist)(Capodaglio et al., 2010). The shoulder will have to potentially compensate for the lack of range of motion at adjacent joints, such as at the low back to accomplish the same task due to obstruction of movement at associated joints from excessive adipose tissue or from adopting another strategy to reduce low back loading. Industrial and clerical workers with BMI over 28, who had a baseline complaint of a hand/wrist/finger problem, were associated with an increase in discomfort over time (Werner, Franzblau, Gell, Ulin, & Armstrong, 2005).

3) *Obese subjects will have greater circumferences in upper arm, upper leg, waist, and hip than the non-obese group.*

There is currently minimal anthropometric data for overweight or obese individuals. As a consequence, workspace designs do not conform to the needs of obese individuals, whose prevalence continues to increase, and could possibly hinder accomplishment of the job tasks, increasing the risk of work-related musculoskeletal disorders (WMSD) due to prolonged awkward postures (Capodaglio et al., 2010). Large amounts of adipose tissue reduce spine flexibility which negatively affects execution of job tasks involving the trunk (Gilleard & Smith, 2007; Hue et al., 2007). Waist-to-hip ratios (measurements of waist and hip circumferences) are suggested as an additional measure of body fat distribution (World Health Organization, 2008). Waist-to-hip ratio can be measured more precisely than skin folds, and provides an index of both subcutaneous and intra-abdominal adipose tissue (BjÖrntorp, 2006). This index better reflects current anthropometrics of the work force, which may improve our understanding on how future workspaces could be designed to accommodate for workers with different body compositions.

4) *Isometric muscular strength will be higher and functional strength will be lower in obese individuals when compared to non-obese individuals.*

I hypothesized that absolute isometric muscular strength will be greater in obese individuals than normal weight and overweight individuals. Isometric-joint strength is of interest for this thesis because it will help determine the capacity of the low back and shoulder by isolating these joints in static strength testing. Static strength testing can define the capacity to produce torque or force by a maximal voluntary isometric contraction and can be used to measure work capacity if an individual is able to perform a certain task (Chaffin &Park, 1973; Chaffin, Herrin, & Keyserling, 1978; Keyserling, Herrin, & Chaffin, 1980). Absolute isometric and isokinetic strength output was higher in obese individuals compared to lean counterparts (Hulens et al., 2001; Maffiuletti et al., 2007). Maximal functional strength represents the ability for the whole body to generate strength instead of only isolating it to one specific joint. By testing a worker’s strength, one can determine if the worker can physically perform the duties of a particular job based on its strength requirements (Lang, 2015). Maximal functional strength may be lower for individuals who are obese because they may be less efficient at generating forces with their whole body. Reduced muscle strength could stem from diminished muscle function, abnormal metabolism, and lower physical activity levels, also shown by reduced motor unit activation during exercise (Capodaglio et al., 2010). However, functional strength is reduced in individuals with sarcopenic obesity, as it increases the risk of disability (Roubenoff, 2000). Normalized muscle strength to body weight is possibly reduced for obese individuals as it could emerge from diminished muscle function, abnormal metabolism, and lower physical activity levels (Lafortuna et al., 2005).

Summary:

There is a lack of quantitative evidence to determine whether obese individuals have an increased risk of physical exposure to shoulder and low back injuries in common industrial work. With increased risk of physical exposure due to body composition it could potentially constitute them as a vulnerable population. Quantifying the ways in which obese individuals perform tasks differently than normal weight individuals could provide guidance on how to alter work tasks to reduce physical exposures. Obesity could change musculoskeletal performance by reducing upper limb range of motion, reducing postural stability, and changing the proportions of lean and fat tissues. With the combinations of these conditions, optimal movement could be reduced as more work would need to be done to complete the same MMH tasks. Reductions to upper limb range of motion could lead to a cascade of changes to associated joints, as there would be less kinematic redundancies available. With less kinematic flexibility there may be increased loading on specific joints as individuals are constrained to fewer motion possibilities. There is suspicion of potential negative exposures and outcomes for obese compared with non-obese individuals. The proposed project will evaluate biomechanical exposures on this new vulnerable population through performing a series of MMH tasks to identify the role of body composition between obese and non-obese groups.

II. Review of Literature

2.1 Obesity

Obesity is a clinical condition characterized by the accumulation of an abnormal or excessive amount of body fat that may have negative health effects. Many factors drive the obesity epidemic such as genetics, environmental factors, and lack of physical activity (Karnik & Kanekar, 2012). Genetics play a crucial role in a child's susceptibility for becoming obese, as it influences the rate of metabolism during which body fat content is regulated by energy intake and expenditure. Hereditability of obesity could occur from parents as well (Karnik & Kanekar, 2012). Environment and behavioural factors could influence individuals and their eating habits. Constant advertisement of less healthy foods (Center for Disease Control and Prevention, 2011), limited access to affordable healthy foods (Larson, Story, & Nelson, 2009), greater availability of high-energy dense foods and sweetened beverages (Johnson, Mander, Jones, Emmett, & Jebb, 2008), and increased portion sizes (Benton, 2013; McConahy, Smiciklas-Wright, Mitchell, & Picciano, 2004) all promote overconsumption of less healthy foods. Further, obesity is correlated with reduced levels of physical activity (Capodaglio et al., 2010). The main cause of obesity is the ability to maintain equilibrium from poor energy intake or poor diet which could lead to difficulty in energy expenditure. A lack of physical activity or reduction in calorie use can therefore result in obesity (Karnik & Kanekar, 2012).

2.1.1 Prevalence of Obesity

Obesity is a growing concern because it imposes direct and indirect stress on the economic and health systems. A staggering number of 1.9 billion adults who are 18 years and older were overweight in 2014, and of those, over 600 million were obese worldwide (WHO, 2016). In 2014, Global Health Observatory (GHO) reported that 39% of adults aged 18 and over were overweight and 13% were obese globally. The estimated direct, indirect, and total health care costs of physical inactivity in Canada in 2009 were $2.4 billion, $4.3 billion, and $6.8 billion, respectively (Janssen, 2012). Between 2000 and 2011, the percentage of Canadians who were obese rose by 18% (Gotay et al., 2013)(Figure 1). Self-reported BMI is underestimated in height and weight by approximately 10% (Shields, Gorber, & Tremblay, 2008). This suggests that the estimates from Gotay et al (2013) are underrating the current widespread issue of obesity. BMIs have increased as well as waist circumferences between 1981 and 2009 (Table 1). Males' average waist circumference increased by 5 cm or more, and females', by 10 cm or more (Shield et al., 2010). Since 2005, more than two million employed Canadians aged 18 to 64 were obese according to Statistics Canada. As previously mentioned, blue-collar workers in Canada are more likely to be obese than white-collar workers. Nearly 1 in 10 blue collar workers sustain on-the-job injuries which is four times more likely than white-collar occupations (Statistics Canada, 2007). Arguably, blue-collar workers are more susceptible to becoming obese which could make them a vulnerable population for being at higher risk of work related musculoskeletal injuries.

Table 1: Comparisons of BMI and waist circumference measurements from 1981 and 2009. Mean and median values for selected fitness measures, by sex and age group, household population aged 20 to 69 years, Canada, 1981 and 2007-2009.

Fitness measure, sex, and survey year	**20 to 39 years**		**40 to 59 years**		**60 to 69 years**	
	Mean	**Median**	**Mean**	**Median**	**Mean**	**Median**
Body mass index (kg/m^2)						
Male						
1981	24.4	24.0	26.1	25.8	26.6	26.3
2007-2009	**26.5***	**25.7***	**28.3***	**27.9***	**28.5***	**28.0***
Female						
1981	22.5	21.8	25.0	24.3	25.8	25.4
2007-2009	**25.9***	**24.3***	**27.0***	**25.6***	**28.7***	**27.4***
Waist circumference (cm)						
Male						
1981	85	84	92	92	95	95
2007-2009	**91***	**89***	**99***	**98***	**103***	**102***
Female						
1981	72	70	78	76	82	80
2007-2009	**83***	**79***	**88***	**86***	**94***	**93***
*** significantly different from estimate for 1981 ($p < 0.05$)** **Source: 1981 Canada Fitness Survey; 2007-2009 Canadian Health Measures Survey.**						

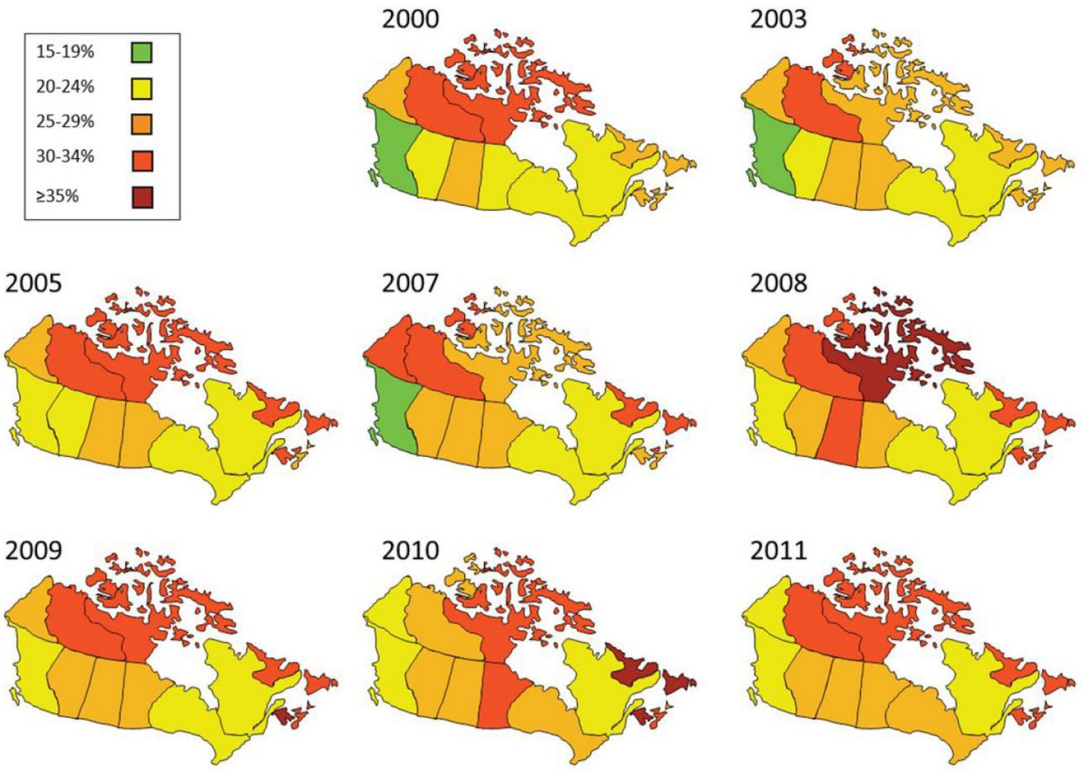

Figure 1: Estimated prevalence of obesity in Canadian adults by province from self-reported height and weight surveys conducted by the Canadian Community Health Survey (2000-2011).

2.1.2 Methods of Assessing of Obesity

Body mass index (BMI) has often been employed as a primary means to classify body composition. BMI is a rapid screening tool for excess body weight. BMI is calculated with a person’s weight (in kilograms) divided by the square of his or her height (in meters). BMI is a crude estimate for categorizing an individual into normal weight (BMI 18.5-24.9), overweight (BMI 25.0-29.9), obese I (BMI 30.0-34.9), obese II (BMI 35.0-39.9), and obese III (BMI ≥40) classifications. A high BMI value may occur due to either a high percentage of body fat or high muscularity (Gallagher et al., 1996). Misclassifying a person as obese by using BMI as a method of assessment could possibly be incorrect as that individual may have higher muscle mass versus fat mass which would skew the results. An accurate classification is enhanced by also considering waist circumference measurements. Currently there is no set of anthropometric data to represent overweight or obese individuals. Body segment parameters are often provided using cadavers (Braune & Fischer, 1889; Dempsters, 1955), methods of medical imaging on living subjects (Drillis & Contini, 1966), or predictive equations (Drillis & Contini, 1966; Young, Chandler & Snow, (1983).

Alternatively, measurement of waist circumferences or waist to hip ratio is often used in classifying body composition and obesity. Abdominal adiposity is the accumulation of fat around the waist, and increased abdominal adiposity is associated with long term health risk (Hu, 2007). The National Heart, Lung, and Blood Institute of the National Institutes of Health (NHLBI) recognizes that abdominal obesity assessed by waist circumference, when coupled with BMI, predicts health risk better than using BMI alone (Janssen et al., 2004). Following the NHLBI, waist circumferences of >102cm and >88cm for males and females respectively are categorized as abdominal obesity (Grundy et al., 2005). The International Diabetes Federation (2006) considers females with waist circumferences >80cm and males >90cm to have abdominal obesity, though different ethnic groups have slightly modified cut-off values. Waist-to-hip ratio is another metric for assessing possible health outcomes. Waist-to-hip ratios provide consolidation for abdominal obesity; the WHO (2011) considers females with >0.85 and males of >0.9 to have abdominal obesity. Waist-to-hip ratios are predictive of health outcomes including diseases and deaths; individuals with larger waists have higher risk of cardiovascular disease, while people with larger hips and thighs have increased their risk of type 2 diabetes (De Koning, Merchant, Pogue, & Anand, 2007). The interpretation of waist-to-hip ratio is complicated by variations in individual "shape". Individuals classified as apple (larger waist) or pear shaped (larger hips and thighs) have different ratio values, leading to difficult implications/assessments on their health status as well. Overall, both waist circumference and waist-to-hip ratios are methods for reinforcing predictions of health risks such as cardiovascular diseases (de Koning, Merchant , Pogue, 2007), type 2 diabetes (Vazquez, Duval, Jacobs, Silventoinen, 2007, Qiao, Nyamdorj, 2009), risk of death from heart disease, cancer, or any cause (Zhang, Rexrode, van Dam, Li, Hu, 2008).

Skinfold thickness measurements rapidly assess subcutaneous tissues, however they have reliability concerns depending on the investigator and population being measured. The method relies heavily on the accuracy of the calipers used to measure subcutaneous fat, and it is inherently more difficult to measure with larger amounts of adipose tissue in obese individuals (Carrero & Avesani, 2015; Gray et al., 1990). Skinfold thickness measurements are not as accurate or reproducible compared to the previously detailed methods due to a combination of intra and interrater errors (Carrero & Avesani, 2015). An underestimation of roughly 20 mm occurred when comparing student skinfold measurements to skilled technician measurements on a healthy population (Wells & Fewtrell, 2006). Various circumstances could explain why additional subcutaneous tissue could increase the variation in skinfold measurements due to poor accuracy and precision. The size of calipers may not accommodate for some skinfolds in very obese individuals, and the level of experience and training for skinfold measurements could differ between investigators (Carrero & Avesani, 2015). Factors that influence the validity and reliability of skinfold measurements include adiposity, age, sex, and hydration levels (Barreto Silva, Avesani, Vale, Lemos, & Bregman, 2008). Therefore, this method is difficult in determining whether an individual is obese and could be inaccurate as the calipers have a limit on skinfold measurements. Overweight and obese individuals are particularly difficult to measure because finding the correct regional area to measure subcutaneous fat is challenging. Hydration levels may affect the outcome of the measurements.

2.1.3 Health Risks Associated with Obesity

Obesity predicts various health outcomes; it is associated with chronic co-morbidities such as hypertension, osteoporosis, depression, heart ischemia and cerebral conditions, and several types of cancers (Orpana et al., 2007). Additionally, body composition is strongly correlated with type 2 diabetes, as females with BMI > 35 are 93 times more likely to develop diabetes compared to females with BMIs of < 22 (Colditz, Willett, Rotnitzky, & Manson, 2016). In conjunction, cardiovascular diseases such as coronary heart disease, stroke and cardiovascular death are affected by higher body composition classifications. Overweight persons have a 32% increased risk of developing coronary artery disease, and obese persons an 81% higher risk than normal weight individuals (Bogers et al., 2007). The specific links between obesity and various cancers are unclear. However, weight gain and abdominal obesity are associated with several cancers (American Institute for Cancer Research, 2007). Likewise, accumulation of excess fat can disrupt mechanical respiratory functions such as lung expansion, flexibility of the chest walls, and create narrow airways in the lungs (McClean, Kee, Young, & Elborn, 2008). Mortality rates increase in parallel with increased BMI levels (Orpana et al., 2010).

A higher BMI could make workers more vulnerable to injuries and illnesses and this could result in economic burdens through direct and indirect costs. The musculoskeletal system of an obese individual may experience higher exposures on bones, joints, and muscles.

Osteoarthritis of the knee and hips are prevalent and positivity associated with obesity as a third of all joint replacements operations are for obese individuals (Anandacoomarasamy, Caterson, Sambrook, Fransen, & March, 2008). Treatment costs for obesity related circumstances are often presented as direct or indirect costs. Direct costs are generalized as the result from outpatient and inpatient health services, laboratory and radiological tests, and drug therapy. Indirect costs are resources that have been used as a result of a health condition, such as lost work (missed days), insurance, and wages. The obesity epidemic is steadily rising and the direct and indirect costs accompany this trend. From 2000 to 2008, the annual economic burden from obesity increased by $735 million in Canada from $3.9 billion to $4.6 billion according to Public Health Agency of Canada. Obesity affects the control of balance and imposes constraints on goal-directed movements (Berrigan et al., 2006) which could also partly account for a higher incidence of musculoskeletal disorders. The emphasis on individuals with higher BMI is necessary, as they could be a new vulnerable population of workers.

2.1.4 Workspace Design

Workspaces vary throughout Canada, but ergonomics standards and guidelines are increasingly emphasized to provide workstation designs that decrease potential causes of work-related musculoskeletal disorders (WMSD). In Canada, musculoskeletal disorders account for the most lost time injuries, lost time claims, and lost-time workdays of any type of injury (Canadian Centre for Occupational Health & Safety, 2014). From 2003 to 2007, the Ontario’s worker compensation system approved 187,000 musculoskeletal claims resulting from lost-time workdays, and WMSD accounted for 43% of all lost-time claims (Ontario Ministry of Labour, 2009). Repetitiveness, a set pace, and awkward postures are all occupational contributors to discomfort and pain development. Most modern workspaces have been designed based on anthropometric data representing persons with normal body composition. This poses consistent difficulties for higher BMI classified individuals (Capodaglio et al., 2010). Workspaces should be adjustable and adaptable to fit individuals' anthropometrics to avoid potentially dangerous postures or movements. Obese individuals have a larger abdominal region, which influences body postures, as they must work at greater horizontal distances (Capodaglio et al., 2010). Increased fat deposits around the abdominal region also significantly limits the range of motion for lumbar extension with non-obese and obese groups having 24 ± 4° and 18.8 ± 6.4°, respectively ($p<0.0041$); the visceral fat increases abdominal pressure which interferes with the motion (Park, Ramachandran, Weisman, & Jung, 2010). Obese persons may use different strategies for completing tasks, but this lacks examination.

2.1.5 Effect of Obesity on the Upper Extremity

The upper extremity is challenged by accumulation of abnormal amounts of adipose surrounding associate joints, which could cause greater vulnerability to musculoskeletal injuries at the shoulders and low back. Previous literature suggests that obesity and overweight individuals have increased risk of occupational injuries (Kouvonen et al., 2013). A higher BMI is associated with more injuries and illnesses to the back and upper extremity (Figure 2) (Ostbye et al., 2007; Schmier et al., 2006), which includes rotator cuff tendinopathy (Wendelboe et al., 2004). WMSD involve muscles, tendons, and nerves. Work that requires repetitive or awkward postures increases the development for WMSDs. Gender is a risk factor for upper extremity nerve entrapments or tendonitis due to the physical demands in relationship with functional capacity (Werner et al., 2005). Obesity is a documented risk factor for carpal tunnel syndrome

(Kurt et al., 2008). The development of carpal tunnel syndrome is correlated with higher BMI in the industrial population (Nathan, Takigawa, Keniston, Meadows, & Lockwood, 1994) and is 2.5 times more likely in obese individuals (Werner, Albers, Franzblau, & Armstrong, 1994). Repetitive work often requires the arms and hands, which potentially puts the upper extremity at risk for injuries. Risk factors for WMSDs are movements that contain gripping, holding, reaching, straightening, and twisting (CCOHS, 2014). Obese workers are twice as likely to develop significant discomfort over time doing industrial and clerical work when compared to non-obese counterparts (Werner et al., 2005). Morbidly obese individuals with low back pain who have undergone bariatric surgery achieve less frequent low back pain and decreased functional disability from loss of weight (Anandacoomarasamy et al., 2008).

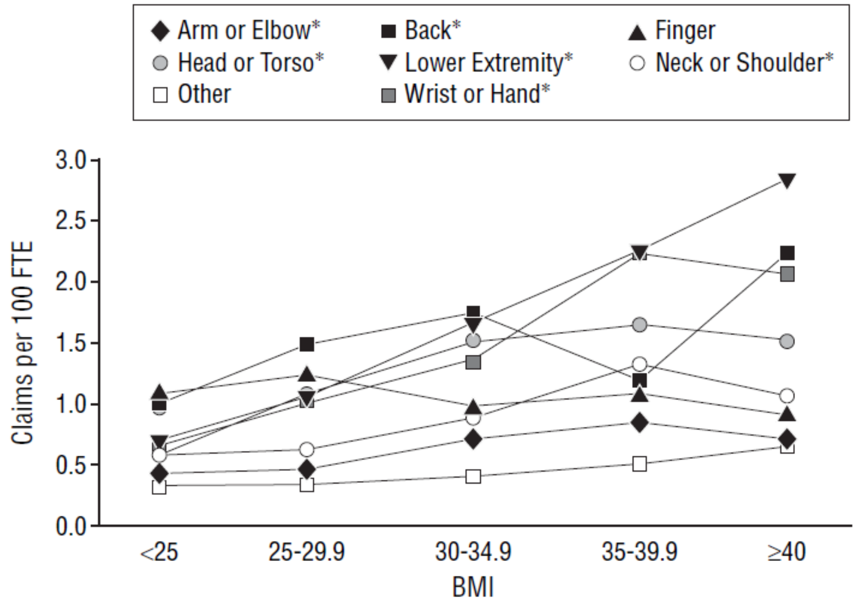

Figure 2: Claims per 100 full-time equivalents for specific affect body parts by body mass index (BMI) category. *p<0.01.

Higher fat mass and lower muscle mass create a progressively difficult situation, as motion patterns could be modified, increase in joint loading, and earlier onset of muscle fatigue. Inadequate muscular strength in the lower limbs can cause impair motor function which limits individuals to performing activities of daily living and predisposes them to greater risk of musculoskeletal fatigue and injury (Hills, Henning, Bryne, & Steele, 2003). Loss of muscle mass lowers the resting metabolic rate, which reinforces fat gain and can lead to sarcopenic obesity, thereby increasing disability (Roubenoff, 2000). Reduced relative skeletal muscle mass in older Americans is common and independently associated with functional impairment and disability, particularly in older women (Janssen, 2002). Elderly females with BMI higher than 30kg/m^2 were twice as likely to display functional limitations compared to normal-weight females (Zoico et al., 2004). Lack of efficiency in recovery and decreases in muscle mass with age pose an unfavorable circumstance for females. Both men and women with BMI > 40 had significantly increased risk of functional limitation (Friedmann, Elasy, & Jensen, 2001). Roughly 60% of obese individuals have less endurance than a non-obese group when performing hand-grip and shoulder flexion tasks, and reported rates of perceived discomfort (RPD) were 30% higher when performing these tasks (Cavuoto & Nussbaum, 2014). Obesity-associated postural changes may affect overall whole-body stability of obese workers and increase injury risk either directly (e.g. increased risk of a fall) (Gentier et al., 2013; Mignardot, Olivier, Promayon, & Nougier, 2010) or indirectly (e.g. decreased attention to task) (Berrigan et al., 2006). Physiological muscular changes that accompany obesity decreases muscle capillary and blood flow (Newcomer, Hunter, & Weinsier, 2001). Reduction in supply of blood flow to capillaries limits the amount of oxygen and energy sources, which alternatively decreases the size and amount of mitochondria necessary to produce energy (Cavuoto & Nussbaum, 2014). Under these circumstances, recovery performance is less efficient and may lead to more rapid fatigue.

Joint range of motion can be compromised by obesity. This is significant because joint range of motion affects an individual’s physical capabilities. Range of motion could be impeded by skeletal structures or connective tissues surrounding the joint (Park et al., 2010). Abnormally large amounts of adipose tissue found in obese persons may obstruct ordinary joint function, yielding altered movement adaptations within this particular group. Numerous kinematic redundancies allow flexibility in performing tasks requiring the shoulder. Adaptive altered movement patterns are generally less optimal for performance as they stem from constrained joint range of motion/goal directed movement from excess tissues and would likely lead to increased biomechanical stresses. Larger amounts of adipose tissues limit kinematic flexibility, creating constrained postures for obese individuals. As a result, obese individuals have reduced range of motion and restrictions of the number of possible postures or movements they can execute. Inter-segmental joint rotations are reduced from adipose tissues around the joint (Chaffin, Anderson, & Martin, 2006; Park et al., 2010), particularly shoulder extension and adduction, lumbar spine extension and lateral flexions and knee flexions (Park et al., 2010).

Low back pain is a common health problem where overweight and obese individuals have more of an increased risk. Overweight and obese individuals strongly associated with the action of seeking care for low back pain and chronic low back pain (Shiri, Karppinen, Leino-Arjas, Solovieva, & Viikari-Juntura, 2010). An estimated $6-12 billion is spent annually in Canada for low back pain and the additional costs associated with the impact on society due to loss of productivity and time off work (Bone and Joint Canada, 2013). Monthly prevalence of low back pain occurs for 30-40% of the general population, while annual low back pain occurs for 25-60%, and chronic low back pain occurs for 10-13% of the general population Inconsistences in research relating to low back pain in overweight or obese individuals exist because many studies have different because many studies have different BMI cutoffs for overweight and obese individuals. Thus, further research with standardized BMI cutoffs are needed to identify the possible relationship between low back pain and higher BMI. There is current evidence suggesting obese individuals have higher mechanical loads on the spine, which cause higher compressive and shear forces on the lumbar spine (Shiri et al., 2010). Abdominal obesity is related to generalized low back pain as there are decreases in both spinal mobility and disc degenerations from the excess body weight caused by a lack of nutrients to repair the disc (Han, Schouten, Lean, & Seidell, 1997; Liuke et al., 2005). Since low back pain is a common cause for work-related disabilities and absences, it ultimately creates an unfavourable situation for companies and their productivity. Pain and discomfort affects productivity at work and often result in claiming compensation for lower back pain (Anandacoomarasamy et al., 2008).

2.1.6 Manual Materials Handling (MMH)

A diverse range of manual materials handling tasks could be performed differently due to a variety of anthropometrics from non-obese and obese individuals. MMH refers to the manual handling of objects, by means of being lifted, lowered, carried, pushed or pulled (Snook et al., 1978). High levels of repetitive work, combined with lifting at or above the shoulder level, increases the risk of arm pain in workers (Andersen, Haahr, & Frost, 2007). However, a potential issue is that guidelines are often made without the consideration of excessive body weight or for individuals with higher BMI levels. The weight of an elevated upper limb alone can cause increases in shoulder load moment (Anthony and Keir, 2010). To address this gap of anthropometrics and physical exposures, obese and non-obese individuals will be quantified and evaluated for common MMH activities to create better work environments to decrease WMSD.

Strength testing can define the capacity to produce force or torque with a voluntary isometric contraction (Chaffin, 1975). The importance of conducting strength tests to relate them to a specific job requirement could be purposeful when the test posture closely mimics the posture used on the job (Stobbe, 1981; Stobbe & Plummber, 1984). The force vectors of the strength test should also be similar to the job in order to best replicate the job requirements. Isometric tests are also easy to implement in job settings and are relatively quick to avoid fatigue (Chaffin, 1975). Isometric strength tests can also predict risk of future injuries for individuals with physically demanding jobs (Chaffin et al., 1978; Keyserling et el., 1980). Maximal functional strength also relates to specific job requirements as these tasks are performed with fewer constraints. Testing functional strength, such as the ability to use the entire body to generate force can provide useful information of an individual’s ability to accomplish the demands of the industrial task. McDaniel (1983) has reported that these tests are predictive of performance on a wide range of dynamic tasks, including asymmetric carrying and pushing tasks. There is a consensus among researches that absolute strength is greater in the lower limbs for obese individuals, but strength is lower in the loaded musculature when normalized to total body mass (La Fortuna et al., 2005; Tomlinson et al. 2014; 2016; Blimkie et al. 1990; Maffiuletti et al. 2007; Hulen et al. 2001; 2002; Hilton et al. 2008). The importance of examining maximal isometric and functional strength in the upper limbs is that previous research focused predominantly on the lower limbs. The current study investigated the upper limbs with the intention of adding further context to differences in isometric-joint strength and maximal functional strength between obese and non-obese individuals. Normalizing the strength values with total body mass allows for an easier comparison across individuals. However, normalizing strength values to muscle mass would be more useful in evaluating how much muscle mass is contributing to the strength values as opposed to gravitational contributions from heavier body segments.

Commonly in the workplace, MMH often involves pushes and pulls at different heights, durations, loads, and frequencies. Pushing and pulling are defined as exerting a (hand) force on an object or another person, such that the direction of the largest component of the resultant force is horizontal (Hoozemans et al., 1998; Martin and Chaffin, 1972; Chow & Dickerson, 2015). Nearly half of all MMH consists of pushing and pulling (Baril-Gangras and Lortie, 1995). Due to the commonality of these tasks, it is critical to quantify the effects of the loads on the upper extremity for obese individuals as increases in hand load increases intramuscular pressures, which may significantly impair muscular blood flow and increase risk of muscular injury (Jarvholm et al., 1991). During a push, the (hand) force is directed away from the body, and in pulling, the force is directed towards the body (Hoozemans et al., 1998). Guidelines of maximum acceptable pushes and pulls have been established by Mital, Nicholson, & Ayoub, (1997) and further refined through psychophysical experiments by Snook & Ciriello (1991), but had no information on how obesity affects pushing and pulling. With excess body mass or additional loads in the hand (Palmerud et al., 2000), intramuscular pressures of infraspinatus and supraspinatus rose by 40 mmHg with elevated flexion and abduction angles – a pressure above would significantly impair muscular blood flow and follow with muscle injury (Jarvholm et al., 1991).

One-handed reaches to targets or performing load transfers within the reach envelope are common manufacturing tasks. However, there is a lack of research on the influence of body composition during this task. Females tend to report higher perception of exertion levels than males for similar load transfer tasks (Han Kim et al. 2004). When aiming for a target as fast as possible, speed and accuracy are two constraints often used to define motor performance. The relationship between these two variables has been formalized as Fitts' law (Fitts, 1954). When more time is needed to reach a target, it could be partially explained by the mechanical consequences of greater inertial load if that arm or forearm has more mass for heavier individuals. Thus, moving heavier segments requires more force and potentially more time to generate the correct amount of force to perform the task. Normal weight individuals reached targets with shoulder flexion and elbow extension, whereas obese individuals moved their whole body forward while aiming for the target. This might be less efficient in a large number of work tasks or daily activities (Berrigan et al., 2006). Gilleard and Smith (2007) showed that obese individuals adopt different work postures during a standing grasp task as they stood further back from the work bench creating a more flexed trunk posture and increased hip joint moment and hip-to-bench work distance compared to non-obese individuals. Further investigation is required to understand this potential vulnerable population and how they perform in workspaces that are designed from anthropometric guidelines that do not represent them. With adoptions of different work postures at a workbench from excess body mass, work capabilities may change and additional effort may be required to complete the task. Alterations of shoulder, lumbar, and knee joint range of motion occurred with additional body mass (Park et al., 2009). With less possible kinematic redundancies from possible obstruction of excess adipose tissue, dynamic load transferring tasks could increase the risk of musculoskeletal injuries.

Obese individuals may adopt unconventional lifting and lowering strategies. Lifting overhead is definable as any lift above shoulder height. A widely accepted definition of overhead is defined as where hands reach a point above the height of the acromion and above the line of vision (Bjelle, Hagberg, & Michaelson, 1981). The risk of shoulder injury subsequently increases when the hands reach shoulder level and therefore may increase further with lifting overhead. The shoulder flexion required for overhead work is a risk factor for shoulder pain and rotator cuff injuries in particular. (Roquelaure et al., 2009). Since increased shoulder flexion and lumbar spine extension are necessary to lift an object overhead, the biomechanical demands of the overhead lift could contribute to the increased risk of injury when lifting. Industrial workers exposed to increased peak and cumulative loading and flexion of the spine during the performance of MMH tasks are 1.4-2.4 times more likely to report low back pain (Norman et al., 1998). Musculoskeletal injury risk for obese workers may be higher as traditional workspaces are designed based on working populations from decades ago and without the accommodation of increase body composition. With additional mass for obese individuals, it may result in unhealthy movement mechanics (Capodaglio et al., 2010). With greater abdominal region due to adipose tissue, it yields greater horizontal distance of the worker’s spine and shoulders from a workstation that modifies reaching distances and available joint range of motion (Capodaglio et al., 2010). Ultimately, further understanding of lifting and lowering tasks for obese individuals is required to change workstation designs to provide better guidelines for these workers to avoid postural stresses or difficulties when reaches are required to complete tasks.

2.1.7 Summary from Literature Review

A consistent rise in obese individuals over the past few decades has created a new vulnerable population susceptible to physical exposures and escalating the development for WMSD. The current underestimation of the economic burden does not account for the increasing proportion of the working population within higher BMI classifications. WMSD are amplified in occupations involving manual materials handling. Scarce knowledge exists on the influence of obesity during MMH on shoulder and low back exposures. Musculoskeletal injuries to the upper extremity and back are common among workers with incidences increasing in terms of obesity. Current ergonomic guidelines do not incorporate a wide range of body compositions like overweight and obese individuals who are a considerable proportion of the workforce. Therefore, it is crucial to consider this growing population who are more prone to WMSD. This research will be widely applicable to helping many work sectors involving MMH by identifying hazardous physical exposures that may generate WMSD for this vulnerable population.

III. Methods

3.1 Participants

Participants between the ages of 18 and 65 were recruited because this age range represents the majority of the working population. Exclusion criteria for all participants included: a history of shoulder or low back injury in the past 6 months, any physical conditions that may be exacerbated by the testing protocol (i.e., cannot hold both arms out for 45 seconds), and allergies to latex or adhesive tape. Out of thirty participants (15 males, 15 females), three people from each sex group were recruited for each of the five BMI classifications defined by WHO: Normal weight (BMI 18.5-24.9), Overweight (BMI 25.0-29.9), Obese class I (BMI 30.0-34.9), Obese class II (BMI 35.0-39.9), and Obese class III (BMI ≥40) from a convenience sample. Participants were then categorized into two separate groups of non-obese (BMI 18.0 – 29.9) (n=12) and obese (BMI ≥30) (n=18). Participants were not height- or age-matched. Both sexes were recruited to increase the application of findings to work populations.

3.2 Instrumentation

3.2.1 Motion Capture

Three-dimensional motion was tracked using a seven-camera VICON MX20 system (Vicon, Oxford, UK) at 50Hz. The volume of the experiment was calibrated prior to each participant's arrival using a 5-marker calibration wand until the tracking system had a root mean square marker position error of less than 0.30mm. The origin and axes of the global coordinate system was defined with X-axis directed anteriorly, the Y-axis directed superiorly, and the Z-axis directed laterally to the right (Wu and Cavanaugh, 1995). Twenty-nine individual reflective markers were placed according to recommendations from the International Society of

Biomechanics (Wu et al., 2002; Wu et al., 2005) on the upper body; bilaterally (Table 2). Five rigid clusters with three reflective markers were placed on monitored segments (Table 3).

Table 2: Reflective markers on the upper extremity and thorax used to calculate local coordinate systems based on ISB recommendations (Wu et al., 2002; Wu et al., 2005).

Segment	**Marker Placement**
Head*	Central Zero (central region and midline of "central lobe")
	Zygomatic arch (on the Frankfort line) *
Thorax	Spinous process of 8th thoracic vertebrae (T8)
	Spinous process of 5th lumbar vertebrae (L5)
	Incisura Jugularis (suprasternal notch) (IJ)
	Processus Xiphoideus (PX)
Clavicle†	Acromioclavicular Joint (AC)
Pelvis†	Iliac crest (IC)
	Anterior superior iliac spine (ASIS)
	Posterior superior iliac spine (PSIS)
Femur†	Greater trochanter of the femur (GT)
Humerus†	Lateral humeral epicondyle (LE)
	Medial humeral epicondyle (ME)
Forearm†	Radial styloid processes (RS)
	Ulnar styloid processes (US)
Hand†	Second metacarpophalangeal joints (MCP2)
	Fifth metacarpophalangeal joints (MCP5)

* Based on (Edmondston et al., 2007) recommendation † indicates bilateral placement

Table 3: Cluster markers on the upper extremity to calculate local coordinate systems.

Segment	Marker Placement
Thorax	Spinous process of 7th cervical vertebrae (C71), (C72), (C73), (C74)
Humerus†	Upper arm triad, half way between AC and LE markers (UA1), (UA2), (UA3)
Forearm†	Lower arm triad half way between LE and US markers (LA1), (LA2), (LA3)

† indicates bilateral placement

3.2.2. Force Measurement

Participants completed six maximal isometric-joint strength tests. Each test was performed once against a 6 degrees of freedom (DOF) force transducer (MC3A, Advanced Medical Technology Inc., Watertown, MA, USA) which was interposed between a D-shaped cylindrical handle and a fixed metal beam. All force data was collected at 1500Hz. The analog signal from the force transducer was amplified using a MSA-6 Miniamp (Advanced Medical Technology Inc., Watertown, MA, USA). The force, in the primary axis of exertion, was calculated based on the conversion of voltage output to Newtons from the calibration matrices provided by the manufacturer. The force transducers were turned on half an hour prior to the collection to limit the amount of voltage error caused by drift and then zeroed immediately prior to the start of the first trial. Low back flexion/extension strength tests had a similar set-up to Biering-Sorensen, (1984) and Kumar, Dufresne, & Van Schoor, (1995) where participants stood upright with their arms crossed across their chest (Figure 3). A strap was placed around the thighs, which was fixed to rigid supports to constrain movement of the torso during testing. A padded roll was placed in front of the hip joints to provide pelvic fixation and to prevent rotation at the hip joints (Demoulin, 2012). A harness was worn and attached via a chain to the 6 DOF force transducer (MC3A, Advanced Medical Technology Inc., Watertown, MA, USA) which was fixed between a D-shaped cylindrical handle and mounted to a fixed metal beam. Participants exerted maximal forward force for flexion, then were turned 180° and exerted a backwards force for extension.

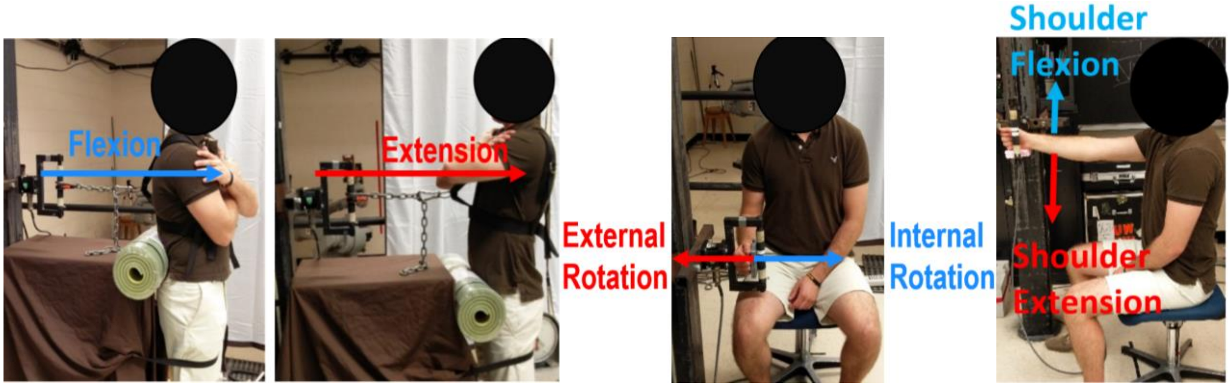

Figure 3: Pictorial representation of isometric strength tests done with dominant hand. From left to right: Low back flexion, low back extension, Shoulder external rotation, shoulder internal rotation, shoulder flexion, shoulder extension.

Participants performed five maximal functional strength tests while in a standing upright posture with a similar set-up to isometric strength tests (Figure 4). All measured force data was collected at 1500Hz. The analog signal from the force transducer was amplified (MSA-6 Miniamp, Advanced Medical Technology Inc., Watertown, MA, USA). Maximal functional lifting strength was assessed by having the participant pull upward bimanually on a horizontal bar handle attached to a digital force gauge (Chatillon Ametek, DFGS-R-200, AMETEK Measurement & Calibration Technologies, Largo, FL, USA) and chained to the ground. The digital force gauge was zeroed with the weight of the chain and handle before the start of each maximal lifting trial.

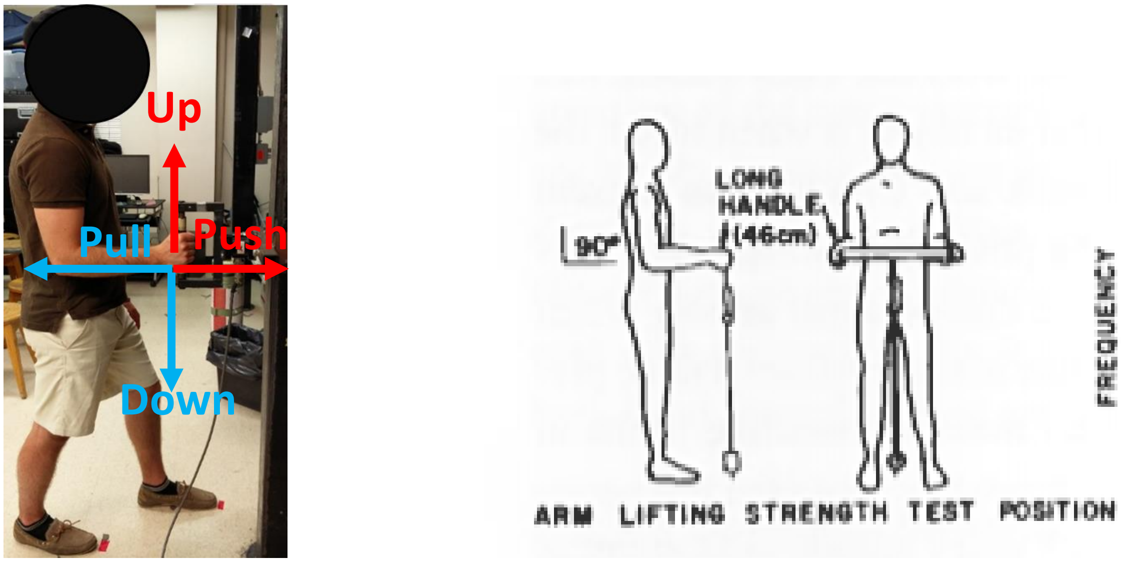

Figure 4: Pictorial representation of maximal functional strength tests, Directional exertions of one-handed upward, downward, pull, and push were completed, as well as a two-handed lift (Chaffin, Anderson, & Martin, 2006).

3.2.3. Ratings of Perceived Discomfort

Ratings of perceived discomfort (RPD) were recorded before the start of the experimental protocol and after the completion of each experimental task. Perceived discomfort was recorded to determine the subjective level of discomfort the participant experienced for each task. Regional discomfort of the participant’s body was assessed with a continuous visual analog scale (VAS). A VAS of 100mm in length was anchored on a scale of 0mm (least discomfort) to 100mm (worst discomfort) for their RPD. Participants indicated their discomfort for each region by dragging the cursors on a tablet to the location that best represented their current state of discomfort in the Electronic-mail Visual Analog Scale (Appendix A). To calibrate participants to the RPD scale, the anchor of 0mm was no discomfort and 100 mm was the worst imaginable discomfort.

3.2.4. Ratings of Perceived Exertion

Ratings of Perceived Exertion (RPE) were recorded before and after the start of each testing protocol. Perceived exertion was used to determine the subjective level of exertion the participant performed for each task. A verbal statement of their RPE was stated based on the Borg's Perceived Rating of Exertion 1-10 modified ratio scale (Borg, 1990) (Appendix B). The RPE scales from 0 (nothing at all) to 10 (maximal effort). To calibrate participants to a RPE of 10 (maximal exertion), we related it to the maximal functional lifting test. Participants provided any score on the 1-10 continuum.

3.2.5. Photographs and Video Recording

After receiving consent from the participant, photographs and video recordings were taken during the study for future scientific presentation or publication. Photographs and videos were taken to focus on the upper limb and torso during each manual material-handling task. Any facial features were obscured to maintain participant confidentiality.

3.3 Testing Protocol

3.3.1 Overview

Upon arrival, the participant provided informed consent. Next, anthropometric measurements were taken. Maximal isometric-joint strength test and functional-strength tests were performed in a randomized order. The participant was then fitted with passive reflective motion capture markers. A five-second calibration trial of the participant with all the reflective markers was recorded. The RPD and RPE baselines were recorded prior to the start of the MMH tasks. The order of the MMH tasks was block randomized and randomized within each task based on heights, weights, and workspace distances. RPD and RPE was recorded at the beginning and end of each task as well. The following figure shows the order of operations for this study (Figure 5). The description of each component of the study follows.

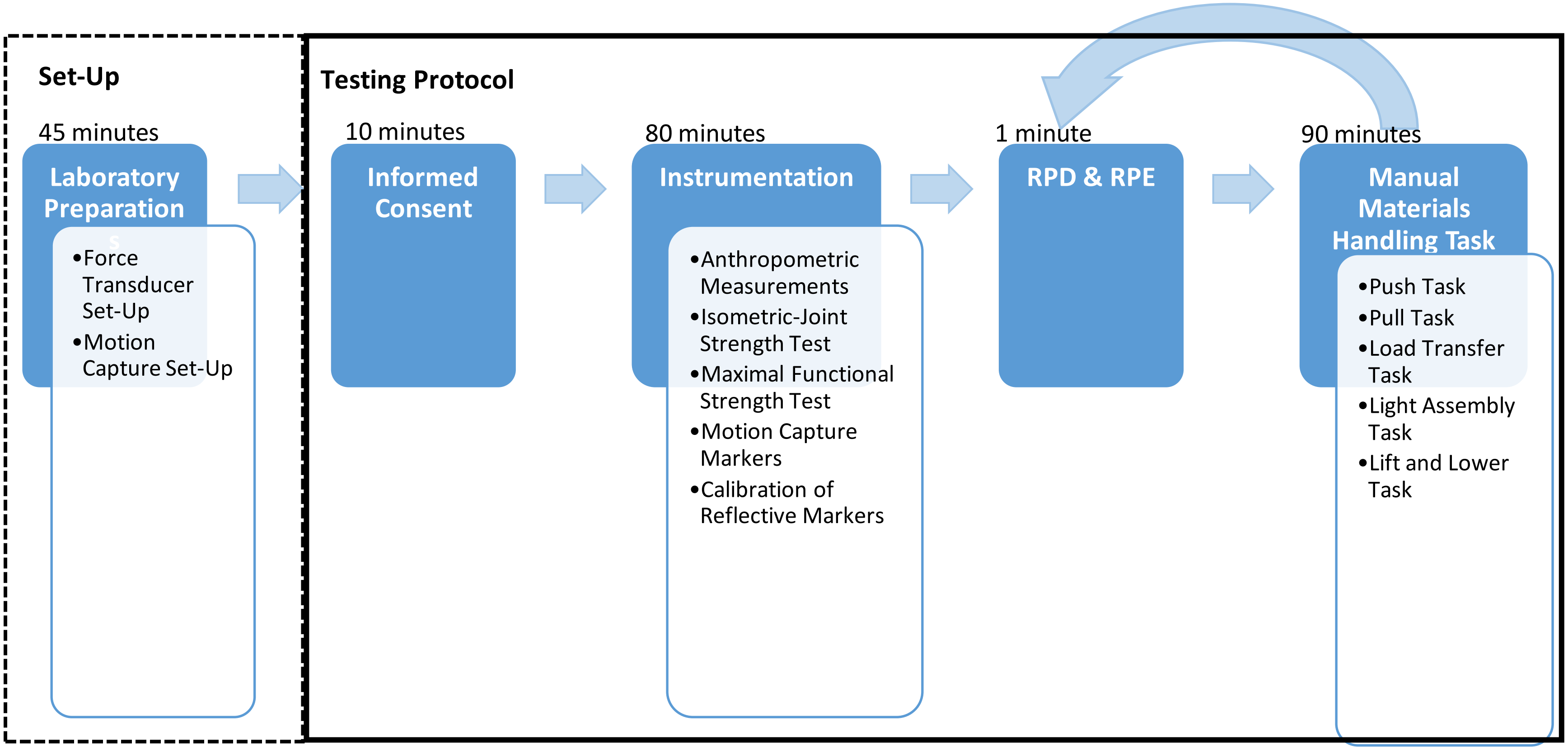

Figure 5: Outline of experimental protocol: After the preparation of the laboratory, informed consent was obtained prior to beginning the session. Anthropometrics was measured, and the randomization of the various isometric-joint strength tests and maximal functional strength tests were done. Next, the kinematic reflective markers were placed on anatomical bony landmarks, and a calibration of all markers was taken prior to the MMH tasks. RPD and RPE were recorded before and after every trial that was completed. The MMH was block randomized (push task, pull task, load transfer task, and lift & lower task), and randomized within each task depending on the work height, weight, or workspace.

3.3.2 Anthropometric Measurements

Participants' anthropometrics were compared between obese and non-obese adults. Participant's mass and height were measured with a balance scale and stadiometer. Segment lengths were measured bilaterally for the upper arms, forearms, and hands with a soft measuring tape following National Aeronautics and Space Administration (1995), and Dempsters (1955) guidelines. Central adiposity was recorded by measuring the circumferences of the waist and hip, which was then used to calculate waist-to-hip ratios. Waist circumferences was measured at the midway between the iliac crest and lower rib using a soft measurement tape (Janssen et al., 2004; Price et al., 2006); and hip circumferences was measured at the widest circumference over the buttocks and below the iliac crest (Janssen et al., 2004; Price et al., 2006). The circumference of the arm and thigh at distances of 25%, 50%, and 75% of the length of each segment was also recorded from proximal to distal (Table 4). The participants self-identified their dominant hand. Participants performed all tasks wearing their preferred shoes.

Table 4: Body Segment Parameters: Description of segment length measurements

Body Segment Parameters	**Description**
Upper Arm Length †	Shoulder Plane to Elbow Plane: plane originating at the acromion landmark to plane originating at the olecranon landmark
Upper Arm Circumference †	Proximal to distal segment length of 25%, 50%, 75%
Forearm Length †	Elbow Plane to Wrist Plane: plane originating at the olecranon landmark to plane originating at the ulnar and radial styloid landmarks
Hand Length †	Wrist Plant to 3rd distal phalange: plane originating at the ulnar and radial styloid landmarks to 3rd distal phalange
Upper Leg Length †	Thigh Plane to Knee Plane: plane originating at the greater trochanter landmark to plane originating at the lateral femoral epicondyle
Upper Leg Circumference †	Proximal to distal segment length of 25%, 50%, 75%
Lower Leg Length †	Knee Plane to Ankle Plane: plane originating at the lateral femoral epicondyle to plane originating at the sphyrion landmark
Waist Circumference	Midway between the iliac crest and lower rib
Hip Circumference	The widest circumference over the buttocks and below the iliac crest

† indicates bilateral placement

3.3.3 Isometric Joint-Strength & Functional Strength Tests

Force measurements were recorded during maximal isometric joint-strength and functional-strength tests. Hand forces (from isometric and maximal functional strength test and the weight of the materials in the dynamic tasks) were used in a top-down quasi-static model, which calculated the low back, shoulder, elbow, and wrist joint moments occurring for each trial and at each time point. Participants exerted a maximum force with a closed fist against the handle. The handle of the transducer was positioned in the same sagittal plane as the acromion (Figure 5).). Maximal voluntary exertions were performed for one trial with each lasting 7-seconds (an initial 3 seconds to ramp-up and the remaining 4 seconds to maintain a static maximum) for each strength assessment to improve reliability of the results (Fischer et al, 2010) with a minimum of two minutes' rest between maximal exertions (Chaffin, 1975). Push and pull forces exerted were perpendicular to the handle, allowing maximal force exertion without a friction limitation at the grip (Seo, 2010). However, exertions in the up and downward exertions were in line with the orientation of gravity.

Participants performed maximal isometric joint-strength exertions for shoulder flexion, shoulder extension, shoulder internal rotation, shoulder external rotation, low back flexion, and low back extension (Figure 3). All isometric arm joint-strength tests were performed in a seated position to isolate upper extremity contributions and to limit the use of the torso and lower limbs. For shoulder flexion/extension, participants sat with their arm forward flexed to 90° in the sagittal plane with the elbow fully extended and the forearm in a neutral rotation, where the thumb was pointed toward the ceiling. Participants exerted upward on the handle for flexion tests and downward for extension tests. For internal/external rotation, participants abducted the arm to

90° in the frontal plane, bent elbow at 90° so the palm faces forward and the fingers pointed toward the ceiling. To test internal rotation, the participant exerted their arm forward against the handle. The participant pulled against the handle for external rotation.

Functional strength tests for the dominant arm consisted of unilateral forward push, backwards pull, upward and downward exertions, and a bilateral lift was performed (Figure 4). All maximal functional strength tests were performed in a standing position while using a power grip. Participants stood with their arm in neutral forward flexion, with the elbow flexed to 90°. The participant's stance was constrained to having their feet shoulder-width apart, with half a step in front of the opposite foot of their dominant arm and half a step behind with the other foot.

3.3.4. Preparation for motion capture

Palpation of bony landmarks for all marker placements were securely positioned over each landmark with double-sided carpet tape (Indoor Carpet Tape, Scotch, St. Paul MN, USA) and securely fastened with surgical tape (3M Transpore Surgical Tape, 3M, London ON, Canada) to prevent motion of the markers on the participant's skin. Participants were instructed to quietly stand in the workspace in the anatomical position for five seconds as a static calibration trial. This calibration procedure was used to define each joint when constructing the rigid link model to calculate joint angles and moments.

3.3.5. Manual Materials Handling (MMH) Tasks

Four MMH tasks (push task, pull task, load transfer task, and lift and lower task) were evaluated in a standing configuration. These tasks were selected due to their broad applicability across work sectors. Task parameters were varied within each task by modifying workspace dimensions and/or load. Load transfer, lift and lower, push, and pull tasks were completed once. One minute of rest occurred between successive trials before the next task. The order of the four tasks was block randomized, and the loads and heights of workstations were randomized individually within each block.

3.3.5.1. Push Task

Participants pushed against a 6 DOF force sensor (FS6, Advanced Medical Technology Inc., Watertown, MA, USA) which was attached to a MOTOMAN HP-50 robotic arm (Motoman Robotics Division, Yaskawa America, USA), with their dominant arm with a power grip for 7 seconds. The push was in a horizontal direction in line with the handle and their acromion. The handle was set to three different heights as participants exerted an isometric push while maintaining an upright posture. The postures chosen were recommended by NIOSH, as participants had their elbow flexed at 90° with their acromion in line with the handle (Figure 6). The handle was lifted and lowered to 25% of the recommended height for a handle for a push exertion. Loads for the push tasks were based on the maximum acceptable load for a sustained push for a 75th percentile female according to Liberty Mutual Tables (2012). One trial of the push task was done for each of the three different forces (40N, 60N, and 80N). Participants received visual feedback on their force production, which indicated the force outputs.

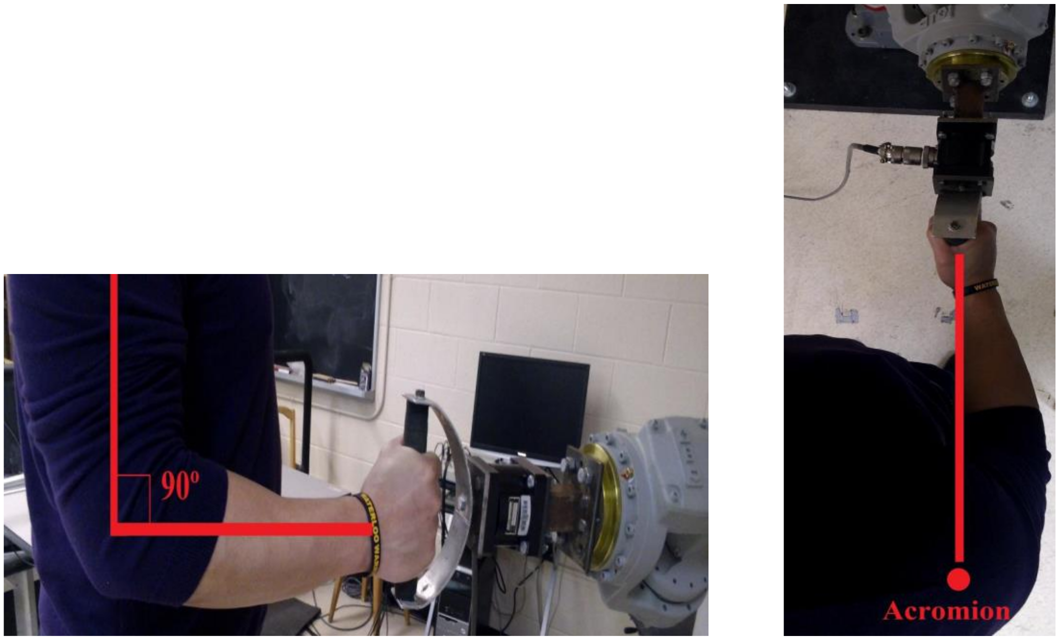

Figure 6: One-handed power grip during push and pull task with elbows flexed at 90°.

3.3.5.2. Pull Task

For the pull task, all parameters matched the pushing task except forces were produced posteriorly. The pull was in a posterior horizontal direction in line with the handle and their acromion. The handle was set to three different heights as participants exerted an isometric pull while maintaining an upright posture. The postures chosen were recommended by NIOSH, as participants had their elbow flexed at 90° with their acromion in line with the handle (Figure 6). The handle was lifted and lowered to 25% of the recommended height for a handle for a pull exertion. One trial of the pull task was done for three different heights and for three different forces. The pulling loads performed were 40N, 60N, and 80N. These loads were based on the maximum acceptable load for a sustained pull for a 75th percentile female according to Liberty Mutual Tables (2012). Participants received live visual feedback on their force production from another monitor that indicated their force production.

3.3.5.3. Load Transfer Task

Participants were asked to transfer an opaque bottle, weighted with lead shot, from an origin point to five pre-determined locations in a semi-circle on a table (Figure 7). During this task, participants stood upright working at a table level that was normalized to their elbows flexed at 90°, which were working height recommendations from NIOSH (1997). Transfer of the lead shot bottle with weights of 0.5kg, 1.0 kg, and 2.5kg were synchronized with a metronome set to 60 beats per minute. The predetermined locations of all 5 locations were set at three reach zones; primary (30cm), secondary (50cm), and tertiary (70cm) from the origin point placed at 45° from one another along azimuths from left to right (Figure 7). The weights of the bottle were unknown to the participant. The bottle was transferred from the origin point, out to one of the five predetermined locations then back to the origin with the bottle in a clockwise then counter clockwise manner. The bottle was transferred from the origin to the next predetermined location in a clockwise direction and once the 5th location is reached, the transferring of the bottle was reversed in going in a counter-clockwise direction. These transfers occurred for 3 cycles, where 1 cycle is a total of 10 transfers (clockwise then counter-clockwise).

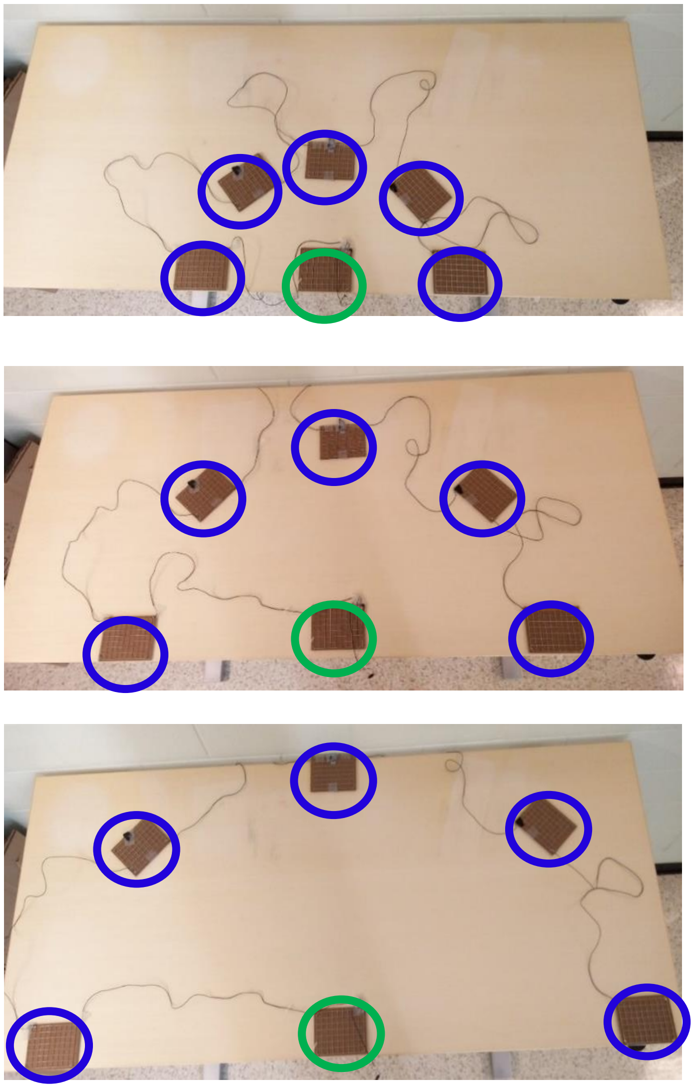

Figure 7: Load Transfer Task Set-up: The predetermined locations of all 5 locations of where the bottle was placed (circled in blue) at the primary (30cm), secondary (50cm), and tertiary (70cm) zones are listed from top to bottom respectively. The origin point circled in green.

3.3.5.4. Two-handed Lift and Lower Task

Participants stood in front of an adjustable shelf that was normalized to each participant's shoulder and knuckle heights. They lifted a weighted crate from the origin to a designated shelf, and then returned the crate to the origin. The participants were instructed to lift and lower the weighted crate as quickly and as safely as possible for three repetitions, with no further instructions provided regarding lifting/lowering technique. The crate measured 34cm x 34cm x 34cm with handles analogous to previous recommendations. The crate had lead shot weights to change the weight of the crate to 2.5 kg, 5.0 kg, and 10.0 kg corresponding to Liberty Mutual Tables (2012) for a 75th percentile female lifting an identical box once from the floor every 9 seconds. A combination of three lifts occurred for three repetitions from heights of: floor to knuckle height (FK), floor to shoulder height (FS), and knuckle to shoulder height (KS).

3.4 Data Analysis

Kinematic marker data was reconstructed using Vicon Nexus software (version 1.8.5), and further processed using a custom MATLAB® code. All raw data was low pass Butterworth filtered with a 6Hz cut-off frequency (Winter, 2009). Processed marker location data was used to calculate local joint center locations for the upper limbs, thorax, and spine as recommended by the International Society of Biomechanics (Wu et al., 2005). The static calibration trials performed before the testing protocol were used to determine the relative position of the markers and allowed for any necessary reconstruction in subsequent frames. The glenohumeral joint was calculated from the acromion marker which was in the Y vector and 60mm below the acromion marker (Nussbaum & Zhang, 2000). These were used to calculate joint angles, local joint coordinates, and external joint moments. For each frame, the angle of each joint and task was calculated by using dot products to calculate segmental angles relative to the gravity vector running through the joint centre for that particular joint. Segmental vectors were created for the torso, bilateral upper arm, and bilateral forearm. The long axis is in respect with gravity and poses as one of the two segmental vectors used to calculate a dot product. Next, the length of each vector was determined before the dot product was done. Segmental angles were then derived using trigonometry to solve for the relate angle from the vertical, which was assumed to be in line with gravity. The mean resultant angles for the load transfer and lift & lower tasks were analyzed through a kinematic time-series and amplitude probability distribution functions (APDFs). The APDF of the 10th percentile of work was an estimate of the lower magnitude for angles observed for the majority of the trial (i.e. static), 50th was the median angles throughout the trial, and 90th is the peak angles observed during the trials. Taking the 10th and 90th, rather than actual min and max, protects against potential transient artifacts that may not be a true indication of the sustained exposure levels. Measurements of weights, stature, limb lengths, and hand forces (from isometric and maximal functional strength test and the weight of the materials in the dynamic tasks) were used in a top-down quasi-static model. The top-down quasi-static model solved for the moments occurring at each time point during each trial. Seven segments were incorporated in the model: trunk, bilateral upper arms, bilateral forearms, and bilateral hands. Joint centres of the low back, glenohumeral, and elbow were estimated using the kinematic data. Masses for each segment were estimated in percentage of body weight using Occupational Biomechanics, 4th Ed. (2006). Equations for external joint forces for each segment in three axes is to follow:

$$\sum \mathrm{F_x} = \mathrm{F_{UAx}} + \mathrm{W_{UAx}} + \mathrm{R_{Sx}} = 0 \tag{2}$$

$$\sum \mathrm{F_y} = \mathrm{F_{UAy}} + \mathrm{W_{UAy}} + \mathrm{R_{Sy}} = 0 \tag{3}$$

$$\sum \mathrm{F_z} = \mathrm{F_{UAz}} + \mathrm{W_{UAz}} + \mathrm{R_{Sz}} = 0 \tag{4}$$

Where F = force at the upperarm, W = weight of upperarm (UA), R = reaction force at the shoulder (S). Once the forces in all three planes were calculated, they were substituted into the sums of moments for the shoulder, elbow, and low back. The following equation were used for calculating sums of the moment at the hand:

$$\sum \mathrm{M} = 0$$

$$\sum 0 = \mathrm{r}_{\mathrm{WUA}} \times \mathrm{F}_{\mathrm{H}} + \mathrm{r}_{\mathrm{CM}_{\mathrm{UA}}} \times \mathrm{W}_{\mathrm{UA}} + \mathrm{M}_{\mathrm{S}} \qquad (5)$$

Where M = moment, r = distance, CM = center of mass, UA= Upper arm, WUA = weight of upperarm.

Force data from the transducer were filtered with a recursive 2nd order Butterworth low pass filter with a cut-off frequency of 6 Hz. External joint moments were calculated using hand forces produced during each strength test and moment arms were solved for using the landmarks of reflective markers collected during kinematics (perpendicular distance from the force to the associated joint center).

Each RPD score measured from the 19 regional locations on the body were recorded on the 100-mm visual-analogue scale to the closest mm. The baseline score RPD for each body location was removed from the start of each task during the testing protocol. This allowed for comparisons of each subsequent RPD score to the baseline.

3.5 Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics 24 (IBM Corporation, NY, USA). Independent t-tests were used to determine differences for descriptive variables between the non-obese and obese groups at a significance level of α=0.05. Means and standard deviations of anthropometric measures were determined for the non-obese and obese group (Table 5).

Independent t-tests were performed to determine significance for isometric and maximal functional strength tests. Mean and standard deviations were calculated for mechanical outcomes of absolute and normalized maximal strength tests (isometric-joint strength and functional strength) (Table 5). Pearson's correlation coefficients, r, were performed for increasing BMI and absolute strength values as well as for increasing BMI and normalized strength values. The strength of the correlations between the two variables were categorized as small when coefficient r = 0.1 to 0.3 or -0.1 to-0.3, medium strength r = 0.3 to 0.5 or -0.3 to -0.5, large strength in r = 0.5 to 1.0 and -0.5 to -1.0 (Lund Research Ltd, 2013). Due to uneven distribution of participants in each group, a Bonferroni correction was done to correct for family wise errors. Independent t-tests were performed to determine significance between RPD and RPE values between the non-obese and obese groups during the four MMH tasks. The minimum clinically significant difference in VAS pain scores is 9mm (Kelly, 1998).

Three-way ANOVAs evaluated the between-subject factor of group (non-obese/obese participants) and within-subject factors of distance/heights (3 levels) and load (3 levels). Individual ANOVAs were performed on 10th, 50th and 90th percentile APDF values for load transfer and lift and lower tasks, and means of push and pull tasks (Table 6). Effect sizes were used to determine the importance of significance. Machly's Test of Sphericity was used to determine if sphericity was violated. If sphericity was violated the Greenhouse-Geisser adjusted p-value was used to determine significance. If a difference was found, a Tukey HSD post-hoc test was performed to identify the factor levels which were different between groups in joint angles or moments for each task.

Table 5: Baseline variables of participants which were analyzed by independent t-tests for hypothesis 3.

Descriptive Variables	
Anthropometrics	Mechanical Outcomes
• Mass (kg) • Height (m) • BMI (kg/m^2) • Upper arm circumferences (m) • Waist circumferences (m) • Hip circumferences (m) • Thigh circumferences (m)	• Isometric-Joint Strength • Maximal Functional Strength

Ratings of perceived discomfort and exertions were analyzed for each separate body section. Independent t-test were performed to determine significance for rating of perceived discomfort and exertion. Mean and standard deviations were established for each task. Significance level was set at $\alpha=0.05$ between the non-obese and obese groups.

Table 6: Variables analyzed between non-obese and obese and across MMH tasks for hypothesis 1 and 2.

	Load Transfer	
	Variables	
Joints	**Kinematic**	**Kinetic**
Elbow	90th%ile Angle 50th%ile Angle 10th%ile Angle	90th%ile Moment 50th%ile Moment 10th%ile Moment Moment Range
Shoulder	90th%ile Angle 50th%ile Angle 10th%ile Angle	90th%ile Moment 50th%ile Moment 10th%ile Moment
Low Back	90th%ile Angle 50th%ile Angle 10th%ile Angle	90th%ile Moment 50th%ile Moment 10th%ile Moment

	Lift & Lower	
	Variables	
Joints	**Kinematic**	**Kinetic**
Elbow	90th%ile Angle 50th%ile Angle 10th%ile Angle	90th%ile Moment 50th%ile Moment 10th%ile Moment
Shoulder	90th%ile Angle 50th%ile Angle 10th%ile Angle	90th%ile Moment 50th%ile Moment 10th%ile Moment
Low Back	90th%ile Angle 50th%ile Angle 10th%ile Angle	90th%ile Moment 50th%ile Moment 10th%ile Moment

	Push & Pull	
	Variables	
Joints	**Kinematic**	**Kinetic**
Elbow	Mean	Mean
Shoulder	Mean	Mean
Low Back	Mean	Mean

IV. Results

The following results are divided into five major sections: descriptive variables, isometric and functional strength, joint moments, joint angles, and rating of perceived discomfort and exertion. First, differences in anthropometrics where all participants were categorized into the two groups of non-obese (BMI 18.0 to 29.9) and obese (BMI ≥30) are presented. Strength analyses are then presented as absolute forces and external joint moments and both were normalized to body mass. One male participant was excluded from the strength analyses as he was an outlier and was unable to finish certain strength tests. Joint angles were reported as ADPF values at the static (10th percentile), median (50th percentile), and peak (90th percentile) exposure levels. The moments at the low back, shoulder, elbow, and wrist were reported as APDF values at the static, median, and peak exposure levels. Lastly, rating of perceived discomfort and exertions were presented between each group and task throughout the study.

4.1 Descriptive Variables

4.1.1 Anthropometrics

Group differences existed for weight, BMI, waist circumference, hip circumference, and wasit:hip ratio (Table 7), for all circumference measurements (Table 8), and for all limb lengths except for the left upper leg and right forearm (Table 9). Significance for p-values and effect sizes are denoted with an asterisk, *, and bolded for all tables.

Table 7: Anthropometric means and standard deviations (SD) for non-obese and obese groups. Significance is denoted with an asterisk, *, at α <0.05.

	Non-Obese		**Obese**				
	Mean	**SD**	**Mean**	**SD**	**Mean Difference**	**p-value**	**Effect Size (ω^2)**
Age (years)	27	5.74	30.94	14.59	-3.94	**<0.01***	0.2%
Height (m)	1.69	0.08	1.72	0.11	-0.03	0.19	-0.6%
Weight (kg)	69.37	9.69	112.24	23.73	-42.87	**<0.01***	**60.5%***
BMI (kg/m^2)	24.3	2.47	37.6	5.44	-13.3	**0.01***	**73.0%***
Waist Circumference (m)	0.78	0.07	1.07	0.12	-0.29	0.06	**66.0%***
Hip Circumference (m)	0.97	0.1	1.24	0.12	-0.27	0.33	**57.7%***
Waist : Hip	0.81	0.06	0.87	0.06	-0.06	0.88	**13.4%***

Table 8: Means and standard deviations (SD) for both participant groups for anthropometrics of circumferences for segments. Circumferences (m) of the arm and thigh were collected at distances corresponding to 25%, 50%, and 75% of the length of each segment, from proximal to distal. Significance is denoted with an asterisk, *, at α <0.05.

			Non-Obese		**Obese**				
Circumference		**Distance from Proximal (%)**	**Mean**	**SD**	**Mean**	**SD**	**Mean Difference**	**p-value**	**Effect Size (ω^2)**
Upper Arm	**Left**	0.25	0.31	0.10	0.43	0.05	-0.12	**<0.01***	**39.8%***
		0.5	0.3	0.04	0.38	0.04	-0.08	**<0.01***	**48.8%***
		0.75	0.28	0.04	0.34	0.03	-0.06	**<0.01***	**39.5%***
	Right	0.25	0.33	0.04	0.44	0.05	-0.1	**<0.0***	**54.1%***
		0.5	0.31	0.03	0.39	0.05	-0.09	**<0.01***	**48.1%***
		0.75	0.28	0.03	0.35	0.04	-0.07	**<0.01***	**48.7%***
Upper Leg	**Left**	0.25	0.61	0.08	0.76	0.11	-0.15	**<0.01***	**35.6%***
		0.5	0.54	0.05	0.67	0.09	-0.13	**<0.01***	**46.7%***
		0.75	0.44	0.05	0.55	0.07	-0.11	**<0.01***	**39.7%***
	Right	0.25	0.61	0.07	0.77	0.11	-0.16	**<0.01***	**41.8%***
		0.5	0.54	0.05	0.67	0.10	-0.13	**<0.01***	**42.0%***
		0.75	0.43	0.05	0.55	0.08	-0.12	**<0.01***	**38.0%***

Table 9: Means and standard deviations (SD) for both participant groups for anthropometrics of limb lengths (m). Significance is denoted with an asterisk, *, at $\alpha < 0.05$.

		Non-Obese		Obese				
Lengths (m)		**Mean**	**SD**	**Mean**	**SD**	**Mean Difference**	**p-value**	**Effect Size (ω^2)**
Left	**Upper arm**	0.28	0.02	0.29	0.03	-0.02	0.05	**9.5%***
	Forearm	0.25	0.02	0.27	0.02	-0.01	0.15	**3.8%***
	Hand	0.18	0.02	0.19	0.02	-0.01	0.24	**1.5%***
	Upper Leg	0.45	0.03	0.45	0.03	-0.01	0.45	-1.4%
	Lower Leg	0.38	0.05	0.41	0.03	-0.01	0.10	**6.1%***
Right	**Upper arm**	0.28	0.02	0.29	0.02	-0.01	0.11	**5.3%***
	Forearm	0.26	0.02	0.27	0.02	-0.01	0.55	-2.2%
	Hand	0.18	0.01	0.19	0.03	-0.01	0.25	**1.3%***
	Upper Leg	0.44	0.03	0.46	0.03	-0.03	0.08	**7.2%***
	Lower Leg	0.38	0.05	0.41	0.03	-0.03	0.06	**8.3%***

4.1.2 Isometric and Functional Strength Outcomes

Independent t-tests were performed to determine differences between the non-obese and obese groups for isometric joint strength and maximal functional strength tests. One male participant was excluded from statistical analysis due to his inability to complete all strength tests. Effect size (ω^2 **)** calculations were performed to report the relative magnitude of the effect. As statistical power was generally low, an ω^2 >1% can be an indicator of the strength of a difference.

Significance for p-values where $p<0.05$ and effect sizes that were greater than 1% were denoted with an asterisk, *, and bolded (Table 10 & Table 11

Table 11). This indicates potential for these isometric and functional maximal strength tests to have reached significance if more statistical power was available. For absolute strength results, only shoulder internal rotation moments were significant with p-value = 0.03. Absolute strength tests of LB flexion (Figure B.1) and extension (Figure B.2), shoulder flexion (Figure B.3), internal rotation (Figure B.5), push (Figure B.7), and down exertions (Figure B.10) all have ω^2 >1%, suggest these assessments may reach significance with an increase in sample size. All absolute strength tests showed a positive trend;, there was an increase in production of absolute strength with an increasing BMI.

Strength tests normalized to body mass that were significant included isometric shoulder extension (p-value = 0.03; Figure B.14); functional downward exertion (p-value = 0.05; Figure B.21); and lifting (p-value = 0.04; Figure B.22). All normalized strength tests had a negative trend, where with increasing BMI there was a decrease in production of strength.

Table 10: Means, standard deviations (S.D.), and effect size from independent t-test for both participant groups for absolute isometric joint strength tests and maximal functional strength tests. Significance is denoted with an asterisk,*, at $p<0.05$.

	Non-Obese		**Obese**			
	Means	**S.D.**	**Means**	**S.D.**	**p-value**	**Effect Size (ω^2 (%))**
LB Flexion Moment (Nm)	86	52	136	77	0.08	**6.9***
LB Extension Moment (Nm)	79	37	127	98	0.09	**6.1***
Shoulder Flexion Moment (Nm)	38	22	56	33	0.13	**4.5***
Shoulder Extension (Nm)	56	29	73	41	0.34	-0.2
Internal Rotation Moment (Nm)	28	14	46	27	**0.03***	**12.3***
External Rotation Moment (Nm)	22	11	31	23	0.29	0.5
Push (N)	161	66	216	92	0.08	**7.2***
Pull (N)	109	85	138	146	0.54	-2.0
Up (N)	137	104	146	160	0.87	-3.2
Down (N)	126	57	148	38	0.21	**2.1***
Lifting (N)	274	127	306	69	0.41	-0.9

Table 11: Means, standard deviations (S.D.), and effect size from independent t-test for both participant groups normalized isometric joint strength tests and maximal functional strength tests. Significance is denoted with an asterisk,*, at p<0.05.

	Non-Obese		**Obese**			
	Means	**S.D.**	**Means**	**S.D.**	**p-value**	**Effect Size (ω^2(%))**
LB Flexion Moment (Norm)	1.19	0.59	1.13	0.48	0.75	-3.0
LB Extension Moment (Norm)	1.10	0.42	1.11	0.71	0.52	-1.9
Shoulder Flexion Moment (Norm)	0.52	0.25	0.49	0.22	0.31	0.2
Shoulder Extension (Norm)	0.79	0.31	0.64	0.25	**0.03***	**12.0***
Internal Rotation Moment (Norm)	0.40	0.17	0.41	0.18	0.64	-2.6
External Rotation Moment (Norm)	0.32	0.13	0.27	0.15	0.08	**7.4***
Push (Norm)	2.30	0.89	1.96	0.72	0.25	**1.1***
Pull (Norm)	1.55	1.18	1.37	1.15	0.67	-2.7
Up (Norm)	1.94	1.41	1.47	1.26	0.34	-0.2
Down (Norm)	1.78	0.64	1.37	0.32	0.05	**10.3***
Lifting (Norm)	3.86	1.44	2.89	0.77	**0.04***	**11.3***

Correlations were examined across the different BMI levels for all participants. All absolute strength tests had moderately strong correlations to increase in BMI except for shoulder extension = 0.299. Negative correlations existed between BMI and strength for normalized maximal functional and isometric joint strength tests (Table 12 & 13). All normalized isometric joint strength tests had a negative trend with only shoulder extension having a medium strength in terms of correlation with r = -0.351. Medium strength correlations were present for maximal functional strength tests where participants exerted force downward, upward, and lifted, with r = -0.448, -0.391, -0.532, respectively. Positive correlations generally existed for absolute strength of maximal functional and isometric strength tests with individuals with higher BMI. Obese individuals were perceived as stronger based on the absolute strength values, but once we normalized those absolute strength values to body mass, they were lower.

Table 12: Correlations for isometric joint strength tests across BMI levels

	Absolute (Nm)	**Normalized**
Low Back Flexion	0.409	-0.047
Low Back Extension	0.373	-0.081
Shoulder Flexion	0.377	-0.189
Shoulder Extension	0.299	-0.351
Internal Rotation	0.472	-0.128
External Rotation	0.350	-0.300

Table 13: Correlations for maximal functional strength tests across BMI levels

	Absolute (N)	**Normalized**
Push	0.445	-0.187
Pull	-0.056	-0.269
Up	-0.184	-0.391
Down	0.286	-0.448
Lifting	0.153	-0.532

4.2 Joint Moments

4.2.1 Resultant Moment

Load Transfer - Low Back

An interaction effect existed for the static level (10th percentile) for distance and groups (p-value = 0.04; Figure 8). There was an interaction effect with distance and the obese group, where decrease in low back moments for the obese group with increased in distance, while non-obese group had relatively no change with increase in distance. Obese individuals experienced less low back moments with further reach distances because for the majority of the time, both non-obese and obese individuals were likely in upright stance during the static exposure level. Low back resultant moments were 43% higher at the 30cm reach, 36% higher at 50cm, and 30% height at 70cm reach, occurring at the low back of the obese group during the load transfer task in comparison to the non-obese group. The main effect of load was significantly higher at the static exposure level as loads increased (p-value < 0.01; Figure C.1).

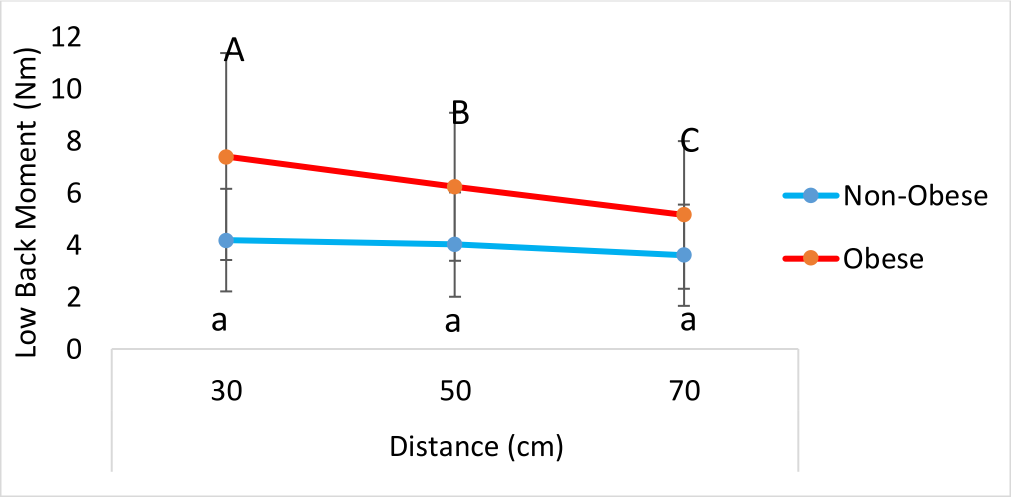

Figure 8: Low Back Moment at the static level (10th percentile) comparing non-obese and obese groups during load transfer task at three different distances. Uppercase letters indicate significantly differences between the reach distances for the obese group. Lowercase letters indicate significant differences between the reach distances for the non-obese group.

An interaction effect existed for the median level (50th percentile) for distance and group (p-value = 0.04; Figure 9). There is an upward trend in the non-obese group with further distances while the obese group remained relatively the same with increase in distance. The obese group may have adopted a similar work posture throughout the task during the median and peak exposure levels with a more upright posture. The non-obese group had a more flexed posture that increased the low back moments. However, the low back moment values continued to be lower than the obese group for both median and peak exposure levels. This suggests that even with a more flexed posture for the non-obese group, they experienced lower moments which could be attributed to less mass at the torso in comparison to the obese group. The obese group had less arm elevation during this task compared to the non-obese group suggesting that the obese group had an upright posture and more arm elevation to complete the task. Meanwhile, the non-obese group had a more flexed trunk and less arm elevation. Distance had an interaction effect with the non-obese group, where further distance meant more low back moments were produced. Low back resultant moments were 42% higher at the 30cm reach, 34% higher at 50cm, and 24% higher at 70cm reach for the obese group during the load transfer task compared to the non-obese group. A main effect of load was higher at 50th percentile with p-value < 0.01 as load increased (Figure C.2).

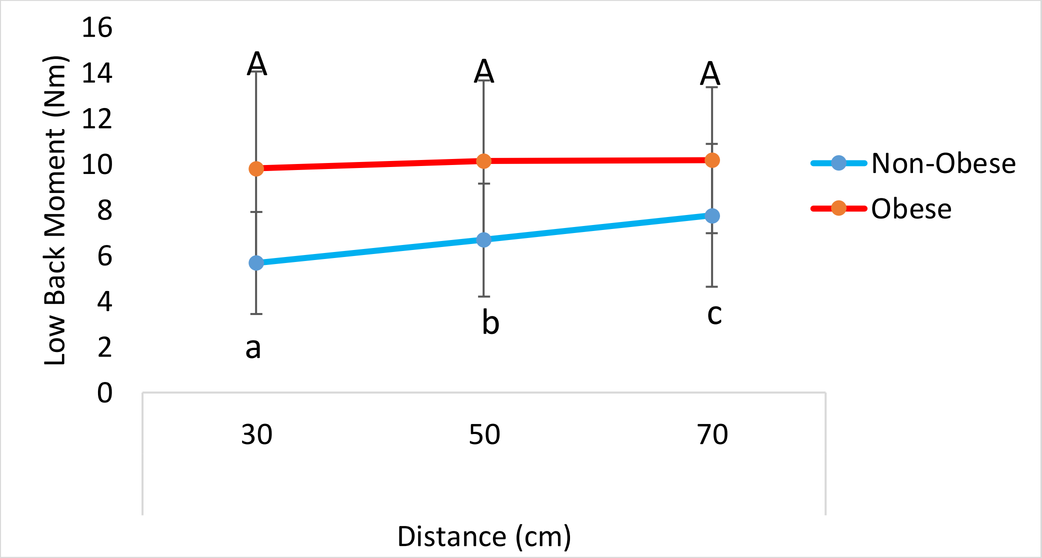

Figure 9: Low Back Moment at median level (50th percentile) comparing non-obese and obese groups during load transfer task at three different distances. Uppercase letters indicate significantly differences between the reach distances for the obese group. Lowercase letters indicate significantly differences between the reach distances for the non-obese group.

An interaction effect existed for the peak level (90th percentile) for distance and group (p-value=0.03; Figure 10). The non-obese group had increased in low back moments with distance, while the obese group leveled out after the 50cm reach. Similar to the static exposure level, this suggests that the obese group maintained their posture throughout the three different distances while the non-obese group changed their posture with farther reaches. Although the non-obese group had increases to low back moments, they were overall less than the obese groups. During the median exposure level, the obese group used a more consistent back strategy of non-leaning while the non-obese were leaning. At 30cm reach, 39% higher moments occurred at the low back; at 50cm reach, the obese group produced 31% higher than the non-obese group; and at 70cm, 21% higher low back moments. Overall, the non-obese group experienced lower low back moments regardless of their more flexed posture with farther reaches when compared to the obese group who had an upright posture.

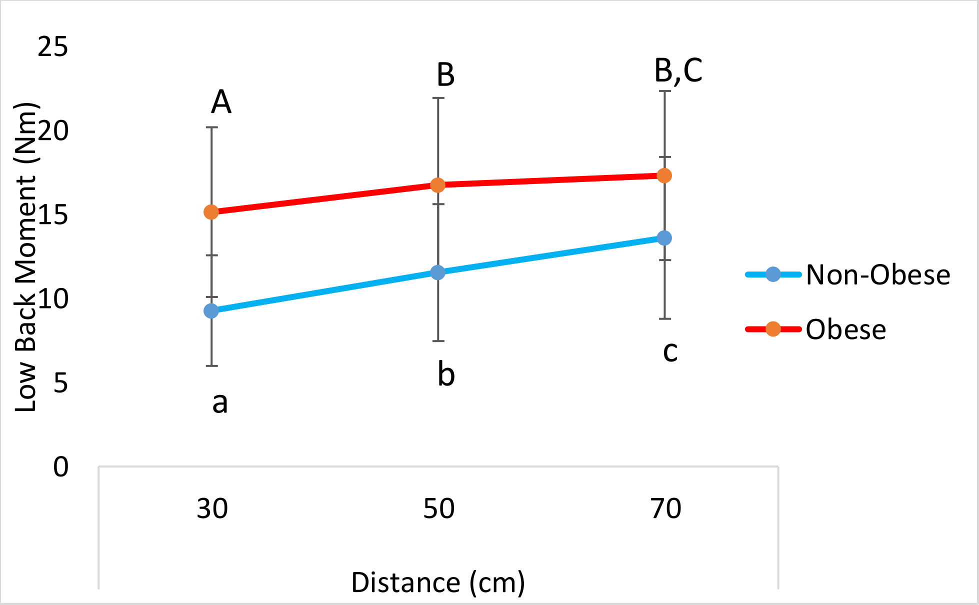

Figure 10: Low back and peak (90th percentile) comparing non-obese and obese groups during load transfer task at three different distances. Uppercase letters indicate significant differences between the reach distances for the obese group. Lowercase letters indicate significant differences between the reach distances for the non-obese group.

Load Transfer – Shoulder

During the static exposure level, the obese group had higher shoulder moments (7Nm) than the non-obese group (4Nm) during the load transfer task. Significant main effects occurred for the group with p-value<0.01 (Figure 11) in which the difference of percent shoulder moments created from the obese group was 43% more than the non-obese group. At the median exposure level, the obese group had significantly higher shoulder moments than the non-obese groups with p-value<0.01 (Figure 11**Error! Reference source not found.**) where there was a 35% increase in shoulder moments for the obese group. A main effect occurred for group with p-value < 0.01 (Figure 11), where the difference between shoulder moments was 31% greater for the obese group at the peak exposure level.

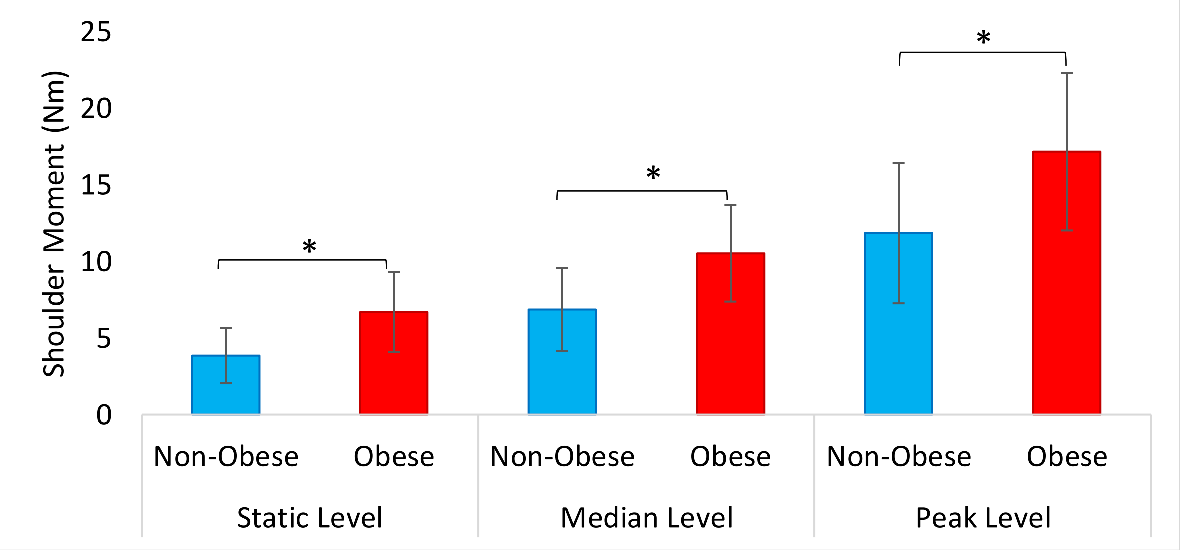

Figure 11: Shoulder Moment at the static level, median, and peak (10th, 50th, 90th percentile) comparing non-obese and obese groups during load transfer task. Asterisks(*) indicate significant differences between non-obese and obese.

Load Transfer – Elbow

A main effect occurred for the static, median, and peak levels for elbow moments with p-value < 0.00 for group, where the obese group experienced higher elbow moments. At the static level, there were significantly greater elbow moments between the groups with 25%, the 50th percentile of 22%, and at the peak level with 21% higher compared to the non-obese group (Figure 12). Elbow moments with the factor distance was not significantly different for the load transfer task.

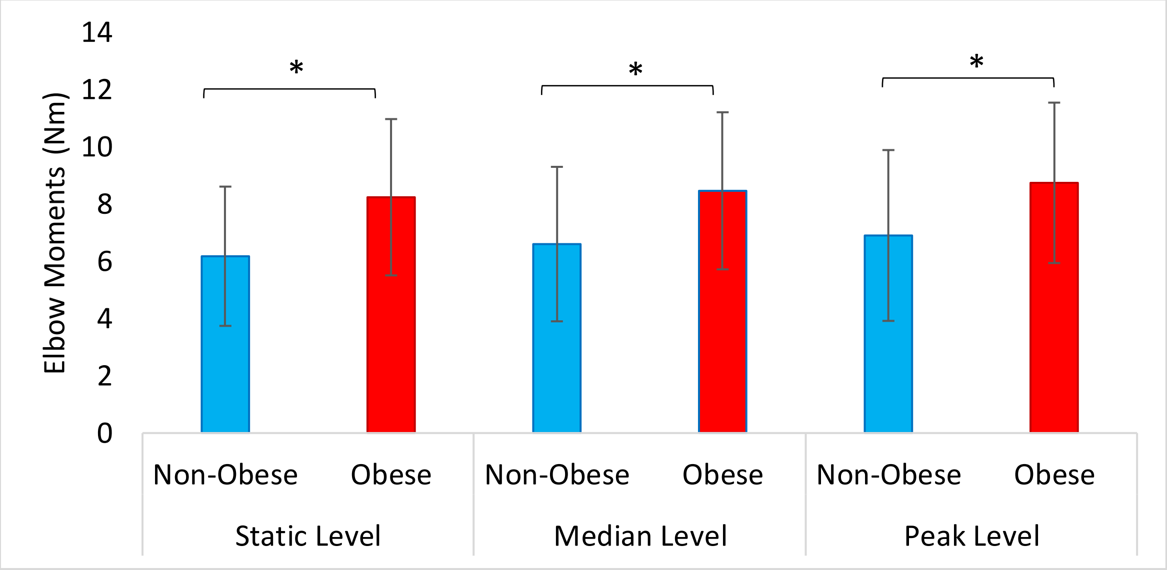

Figure 12: Elbow Moment static, median, and peak levels (10th, 50th, 90th percentile) comparing non-obese and obese groups during load transfer task. Asterisks (*) indicate significant differences between non-obese and obese within each exposure level.

Load Transfer - Wrist

Main effect of group occurred at the static level with p-value < 0.01, there was a 15% increase in wrist moments for the obese group (Figure 13). There was no significant difference for distance at the static, median, and peak levels. There was no significance between groups at the median and peak levels for the wrist during load transfer tasks.

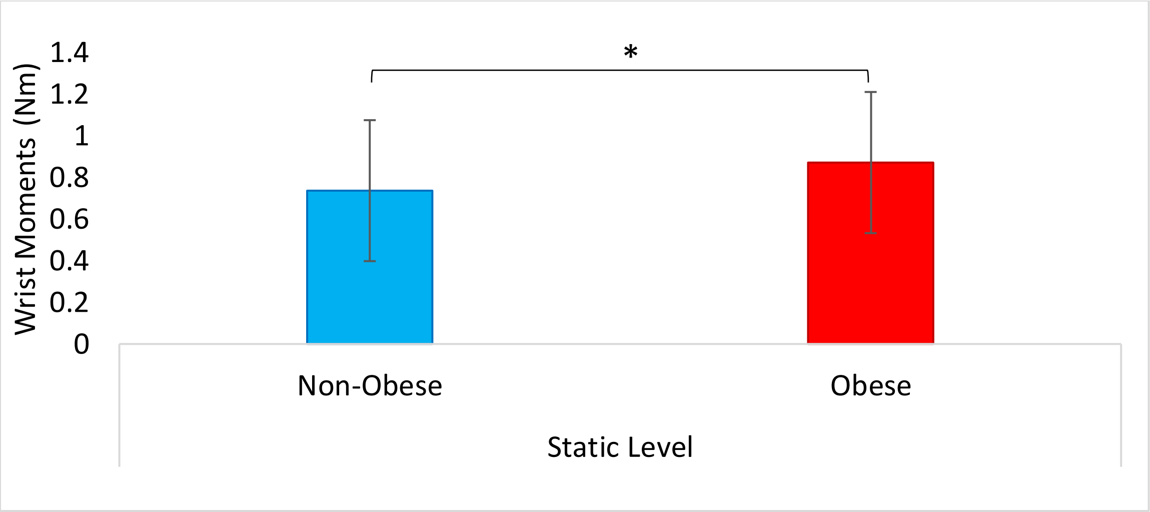

Figure 13: Wrist Moment at peak level (90th percentile) comparing non-obese and obese groups during load transfer task. Asterisks (*) indicate significant differences between non-obese and obese.

Lift and Lower - Low Back

During lift and lower, there was a significant interaction effect for lift combinations and group (p-value = 0.02; Figure 14) for the static exposure level. The average low back moments experienced by the non-obese group was 19Nm for FS, 6Nm for KS, and 4 Nm for FK. For the obese group, the average low back moments experienced for FS was 29Nm, and 9Nm for both KS and FK lifts at the static exposure level. The interactions from the obese and non-obese groups with the lift heights occurred for only the knuckle-to-shoulder and floor-to-shoulder lifts. With the knuckle-to-shoulder height lifts, higher low back moments were experienced by both groups due to the increase in trunk flexion at the static exposure level. With the floor-to-shoulder height lifts, the low back moments were higher as there was a greater vertical distance that both groups had to overcome before completing the task.

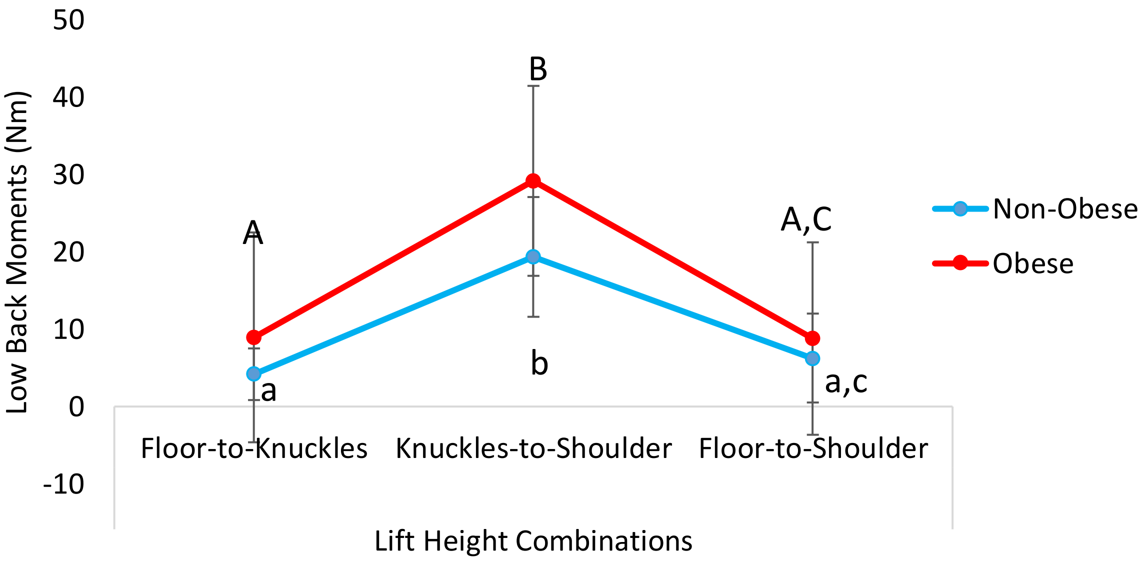

Figure 14: Low Back Moment at static level (10th percentile) comparing between non-obese and obese group during lift and lowering task. Uppercase letters indicate significantly differences between the reach distances for the obese group. Lowercase letters indicate significantly differences between the reach distances for the non-obese group.

Significant interaction effect for height and group (p-value = 0.01; Figure 15) occurred for lift combinations of FK (40% increase in low back moments), KS (25% increase in low back moments) and FS (26% increase in low back moments) for obese groups at the peak exposure level during lift & lowering tasks. There was a more pronounced increase in low back moments for the obese and non-obese group from the lift combination when comparing FK to KS and FK to FS. Both groups had gradual increases to low back moments with lifts involving shoulder height. The average low back moments experienced by the non-obese group was 32Nm for FS, 42 Nm for KS, and 44 Nm for FK. For the obese group the average low back moments experienced was 52 Nm for FS, 56 Nm for KS, and 59 Nm for FK at the peak exposure level.

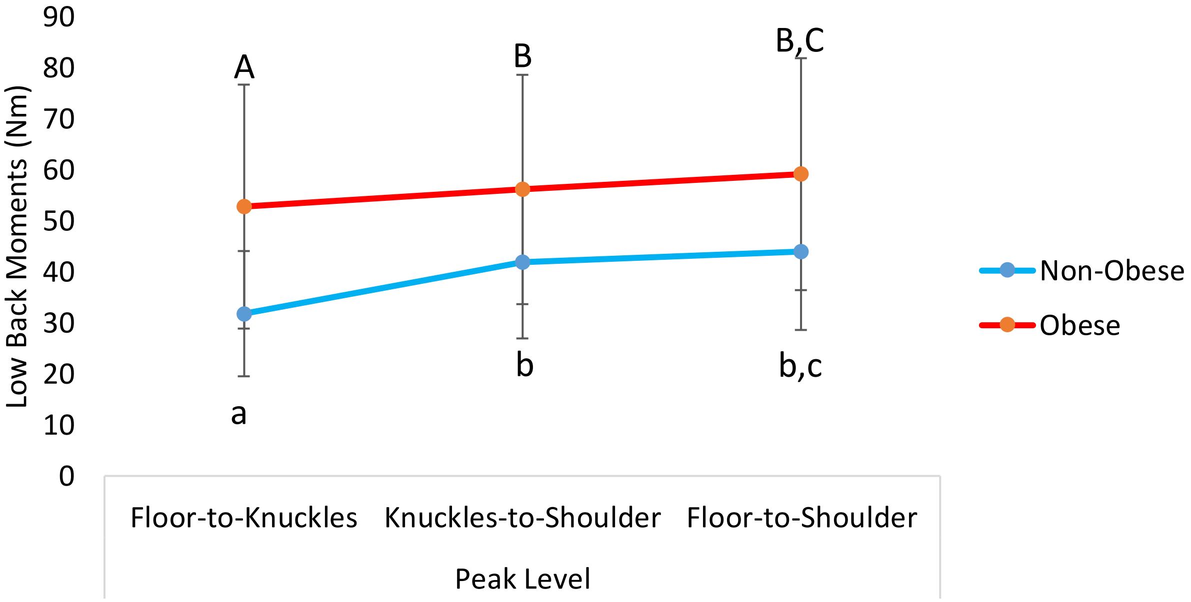

Figure 15: Low Back Moments at peak level (90th percentile) comparing between non-obese and obese group during lift and lowering task. Uppercase letters indicate significantly differences between the reach distances for the obese group. Lowercase letters indicate significantly differences between the reach distances for the non-obese group.

Lift and Lower – Shoulder

At the static level, lift combinations and group had a significant interaction effect with p-value=0.03 (Figure 16). The lift combination from KS continues to be the lift combination that creates the most shoulder moments out of the three lifts for both groups, and is higher for the obese group. There are interaction effects between the KS and FS lifts within the non-obese and obese groups. The average shoulder moments experienced by the non-obese group was 4 Nm for FS, 11Nm for KS, and 5Nm for FK. For the obese group, the average low back moments experienced was 5 Nm for FS, 14Nm for KS, and 5Nm for FK at the static exposure level.

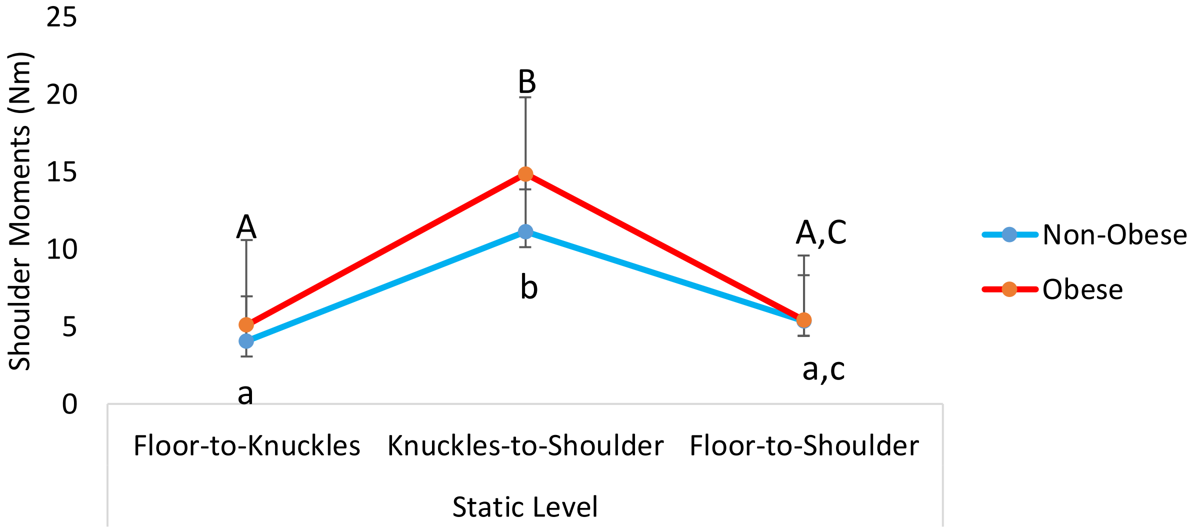

Figure 16: Shoulder Moment at static level (10th percentile) comparing between non-obese and obese group during lift and lowering task. Uppercase letters indicate significantly differences between the reach distances for the obese group. Lowercase letters indicate significantly differences between the reach distances for the non-obese group.

Significant main effect of group occurred with p-value = 0.01 (Figure 17), where there was an 18% increase in shoulder moments for the obese compared to the non-obese group.

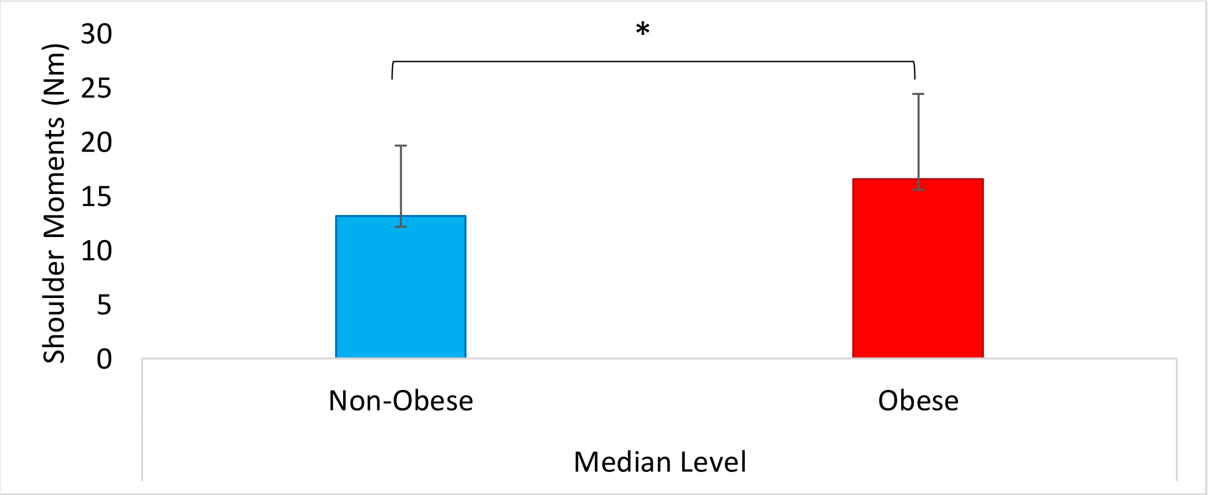

Figure 17: Shoulder Moments at median level (50th percentile) comparing between non-obese and obese group during lift and lowering task. Asterisks (*) indicate significant differences between groups.

Significant interactions occurred for height and group (p-value < 0.01; Figure 18) for the peak level where height combination of FK, KS, FS were greater by 30%, 19%, and 21% respectively for the shoulder moments of the obese group. The obese group had a steady increase in shoulder moments through the lift combinations while the non-obese group had a slightly steeper increase in shoulder moments when comparing lifts from FK to KS. The highest moments were produced during the FS lifts, which are analogous to the low back moments produced during the peak exposure as well.

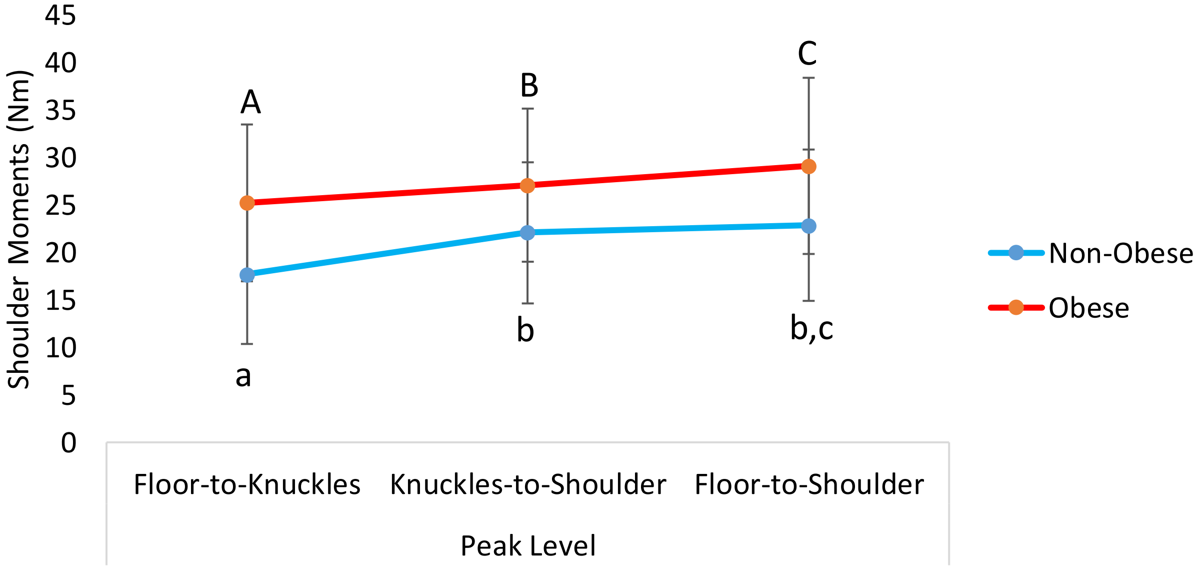

Figure 18: Shoulder Moment at peak level (90th percentile) comparing between non-obese and obese group during lift and lowering task. Uppercase letters indicate significantly differences between the reach distances for the obese group. Lowercase letters indicate significantly differences between the reach distances for the non-obese group.

Lift and Lower – Elbow

Significant main effects occurred at the elbow group at the static, median, and peak exposure levels with p-value < 0.01 for all (Figure 19). The obese group experienced higher elbow moments than the non-obese group at each exposure level during the lift and lowering tasks.

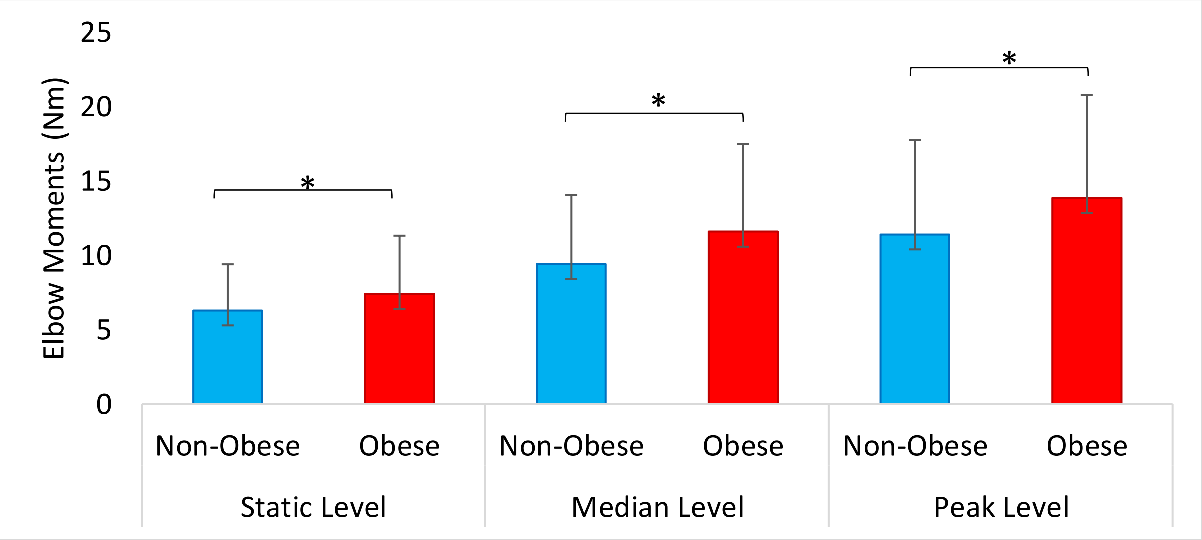

Figure 19: Elbow Moment at static, median, and peak levels (10th, 50th, and 90th percentile) comparing between non-obese and obese group during lift and lowering task. Asterisks (*) indicate significant differences between obese and non-obese groups within each exposure level.

Push - Low Back, Shoulder, Elbow, Wrist

There was no group effect for the push task for the moments at the low back, shoulder, elbow, or wrist for any of the handle height combinations and loads.

Pull - Low Back, Shoulder, Elbow, Wrist

There was no group effect for the pull task for the moments at the low back, shoulder, or elbow for any of the handle height combinations and loads.

There were interactions effects for wrist moments with handle height and group with p-value = 0.02 (Figure 20). With an increase in handle height, the obese group experienced more wrist moments, potentially due to wrist deviation in order to hold the handle and produce the required force to complete the task.

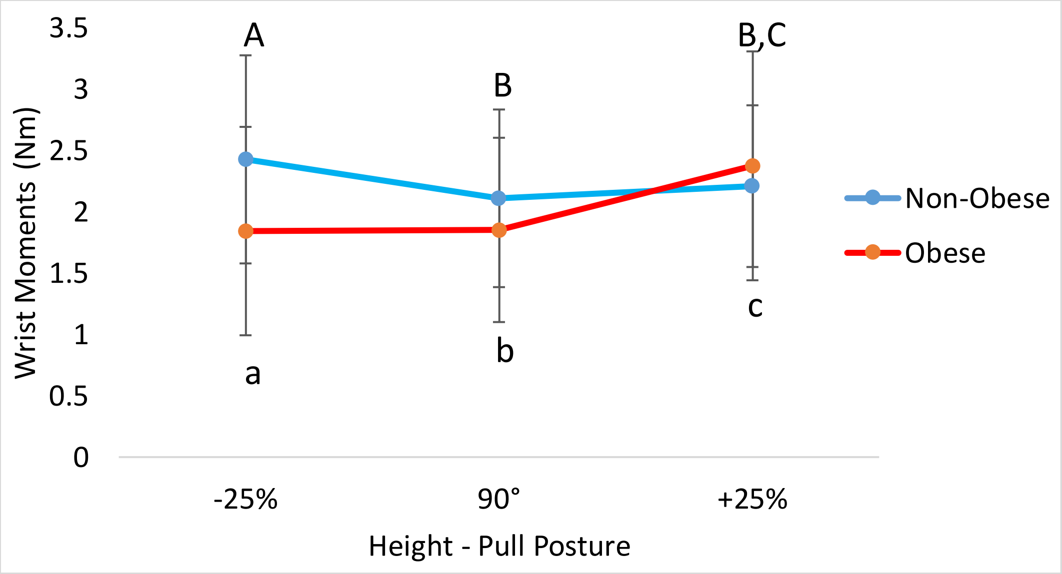

Figure 20: Wrist Moment comparing both groups and three different heights during the pull task. Uppercase letters indicate significantly different handle height for the obese group. Lowercase letters indicate significantly different handle height for the non-obese group.

4.3 Joint Angles

Load Transfer – Low Back, Shoulder, Elbow

There was no group effect for the load transfer task for low back angles. Significant main effect occurred for all exposure levels between the groups (p-value=0.00; Figure 21) where at static level the obese group had 39% more shoulder elevation with 25°, at median level there was 30% more with 33°, and at peak level there was 18% more with 44°.

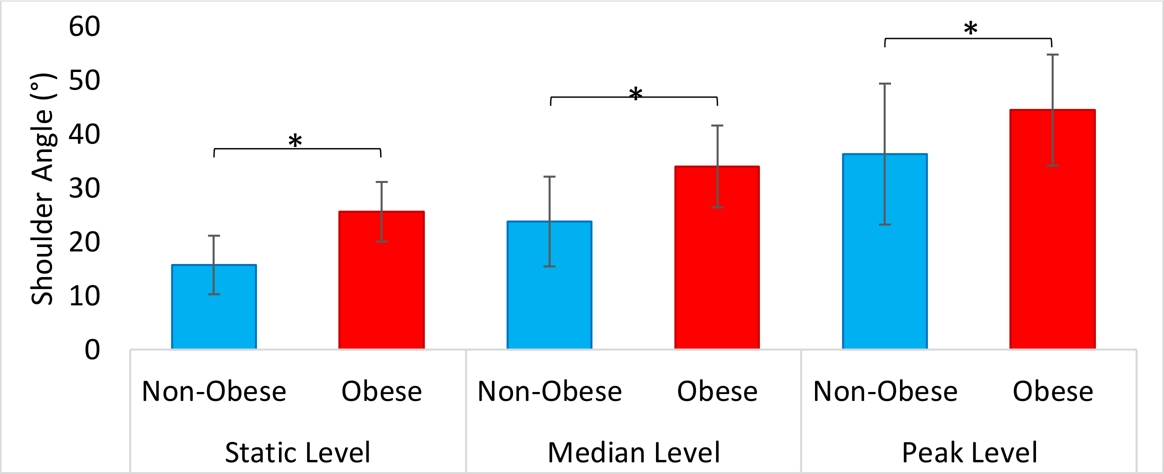

Figure 21: Shoulder angle at static, median, and peak exposure levels during load transfer between obese and non-obese groups. Positive values indicate shoulder elevation, while negative values correspond to shoulder extension. Asterisks (*) indicate significant differences between groups within each exposure level.

For the peak exposure level, significant interaction effects occurred for distance and group with p-value = 0.01 (Figure 22). Differences between the groups at distances from 30cm to 50cm was 11%, 50cm to 70cm 15%, and 30cm to 70cm was 10% higher shoulder elevation angles). The obese group had shoulder elevation angles of 34°, 44°, and 54° during the 30cm, 50cm, and 70cm reaches respectively. The non-obese group had shoulder elevation angles of 23°, 35°, and 49° during the reach distances of 30cm, 50cm, and 70cm respectively during peak exposure level. There were increases to the shoulder elevation angles with the increase in reach distances. This corresponds with the previously mentioned higher shoulder moments.

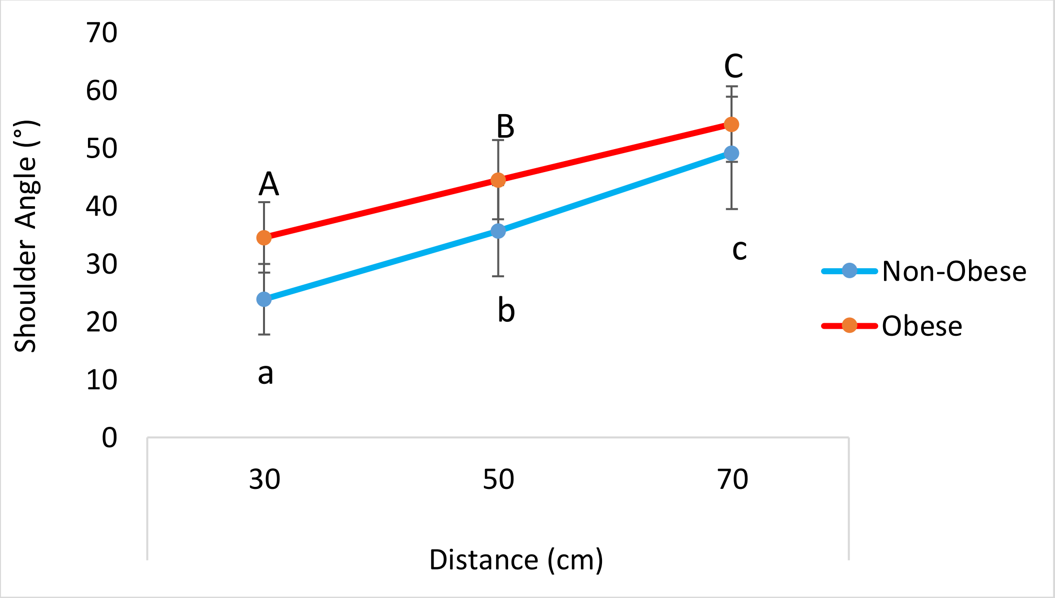

Figure 22: Shoulder angles during peak exposure levels of the load transfer task between obese and non-obese groups and three different distances. Positive values indicate shoulder elevation, while negative values correspond to shoulder extension. Uppercase letters indicate significantly differences between the reach distances for the obese group. Lowercase letters indicate significantly differences between the reach distances for the non-obese group.

Significant interactions for distance and group existed with p-value = 0.04 (Figure 23). Where the difference from the obese and non-obese group from 30cm was 9%, 50cm was 3%, and 70cm was 3% in elbow flexion angle. There was more elbow flexion for the obese group with 81° at 30cm reach, 79° at 50cm reach, and 80° at 70cm reach. The non-obese group had less elbow flexion with 72° at 30cm reach, 73° at 50cm reach, and 76° at 70cm reach. Main effects were found for higher elbow angles at the peak exposure levels for distance, load, and group with p-value < 0.01. However, load and group were not significantly different.

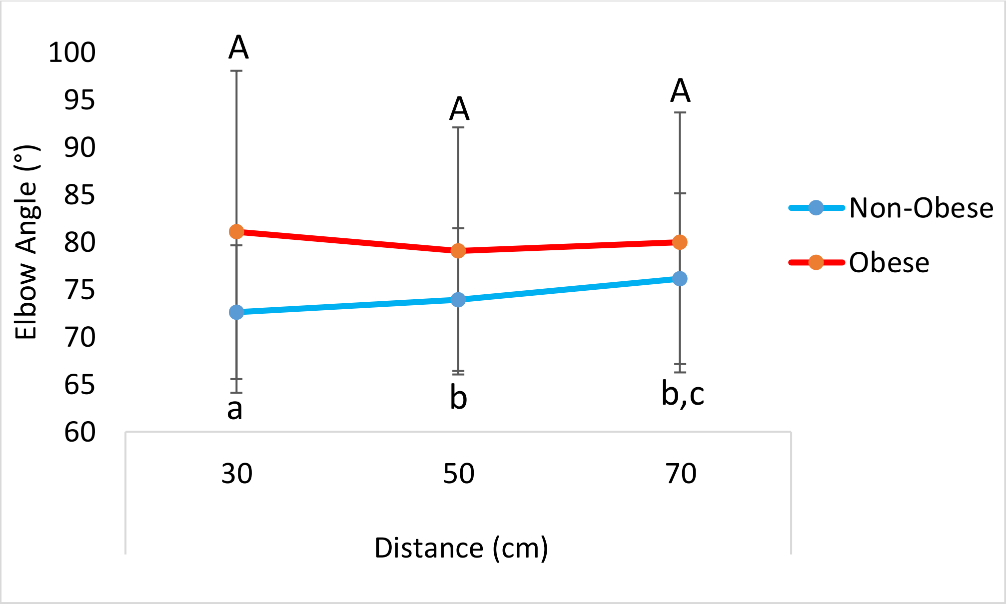

Figure 23: Elbow Angle at median exposure level (50th percentile) comparing non-obese and obese groups during load transfer. Uppercase letters indicate significantly differences between the reach distances for the obese group. Lowercase letters indicate significantly differences between the reach distances for the non-obese group.

Lift and Lower – Low Back

Significant interaction was found for lift height combinations and groups for static exposure level with p-value < 0.01 (Figure 24) with the obese group having 76% more trunk flexion. At the floor-to-knuckles (FK) lift, the mean trunk flexion required during the static exposure level was 21°, at the knuckles-to-shoulder (KS) was 3°, and the lifts from floor-to-shoulders (FS) was 5°.

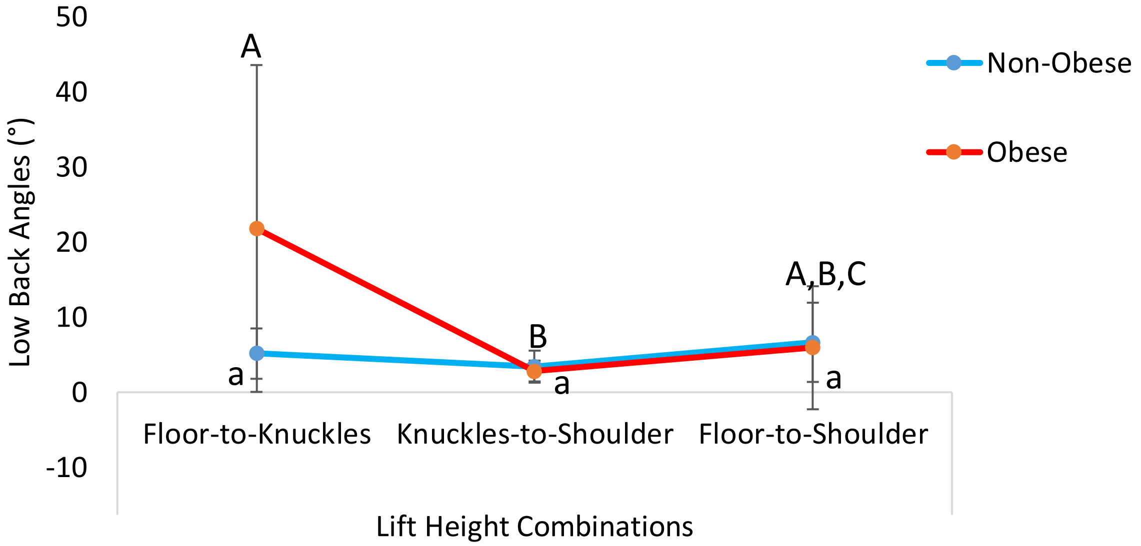

Figure 24: Low Back Angles at static level (10th percentile) comparing non-obese and obese groups during lift and lower. Positive values indicate low back flexion, while negative values correspond to low back extension. Uppercase letters indicate significantly differences between the lift combinations for the obese group. Lowercase letters indicate significantly differences between the reach distances for the non-obese group.

There was significant interaction effect for load and group for the median level with p-value=0.05 (Figure 25), where the comparison of the hand load of 2.5kg and 10kg had higher differences in trunk flexion angles. The non-obese group had trunk flexion of 13° during the 2.5kg load, 14° during the 5kg, and 18° during the 10kg load. The obese group had trunk flexion of 21° during the 2.5kg, 19° for the 5kg, and 18° for the 10kg loads.

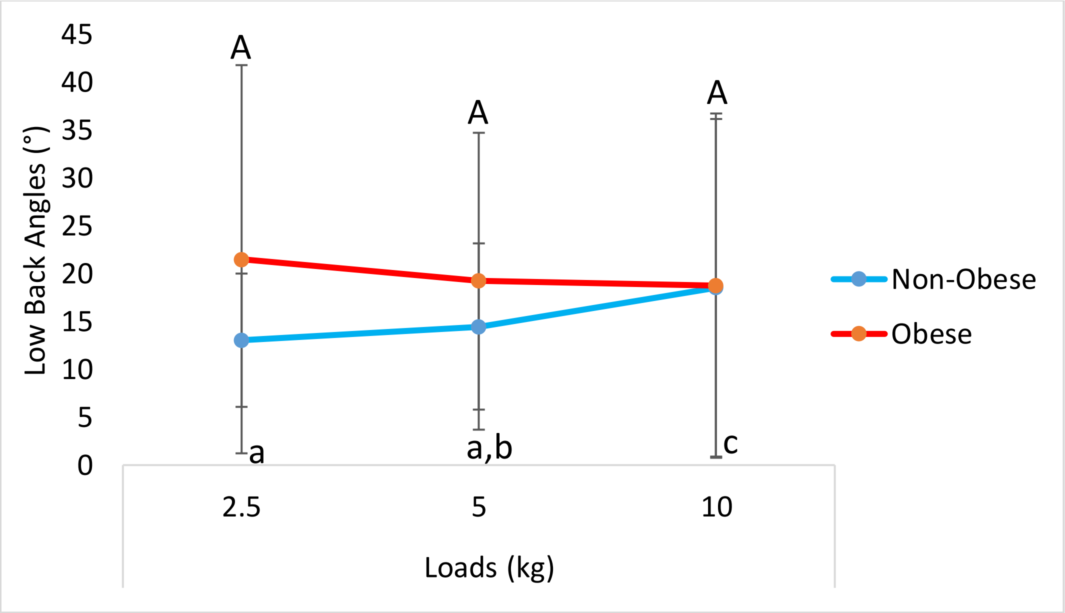

Figure 25: Low Back Angle at the median level (50th percentile) with interaction effect of load and groups during lift and lower. Positive values indicate low back flexion, while negative values correspond to low back extension. Uppercase letters indicate significantly differences between the lift combinations for the obese group. Lowercase letters indicate significantly different hand loads for the non-obese group.

There was significant interaction effect for height and group with p-value=0.01 (Figure 26) at the median exposure level. Trunk flexion for the obese group during the lifts from FK had a mean of 35°, KS a mean of 8°, and FS a mean of 17°. The non-obese group had trunk flexion of 20° for FK lifts, 10° for KS, and 15° for FS lifts.

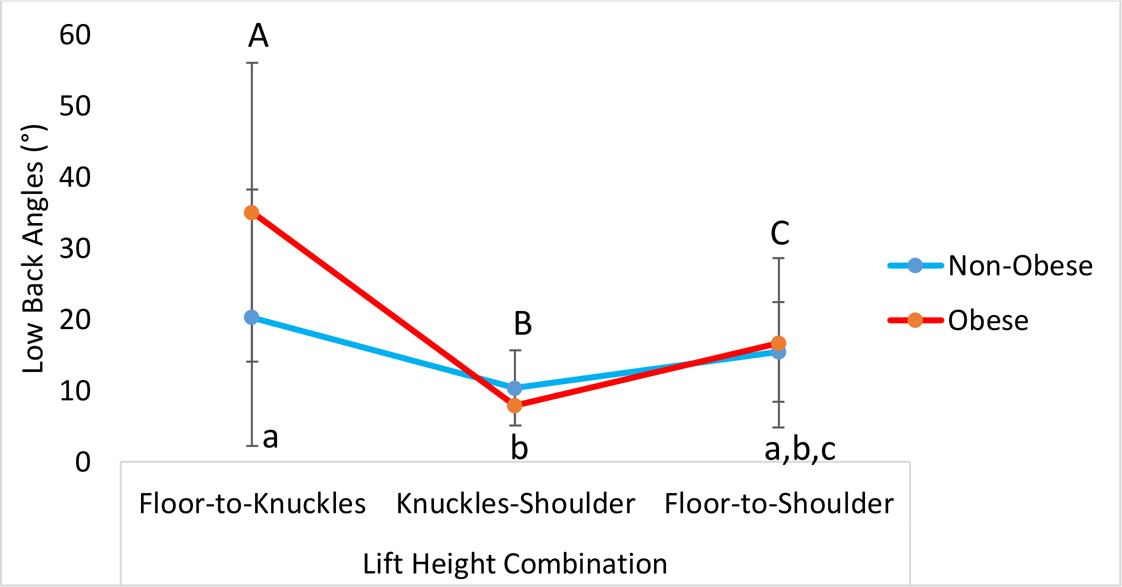

Figure 26: Low Back Angle at median level (50th percentile) with interaction effect of load and groups during lift and lower. Positive values indicate low back flexion, while negative values correspond to low back extension. Positive values indicate low back flexion, while negative values correspond to low back extension. Uppercase letters indicate significantly different lift combinations for the obese group. Lowercase letters indicate significantly different lift combinations for the non-obese group.

Lift and Lower – Shoulder

Significant main effects for the static level where there was 25% more shoulder elevation performed by the obese group (23° shoulder elevation) at the static exposure level with p-value = 0.01 (Figure 27). At the median exposure level, the obese group performed a mean of 52° shoulder elevation whereas the non-obese group had 44° of shoulder elevation with p-value = 0.04 (Figure 27).

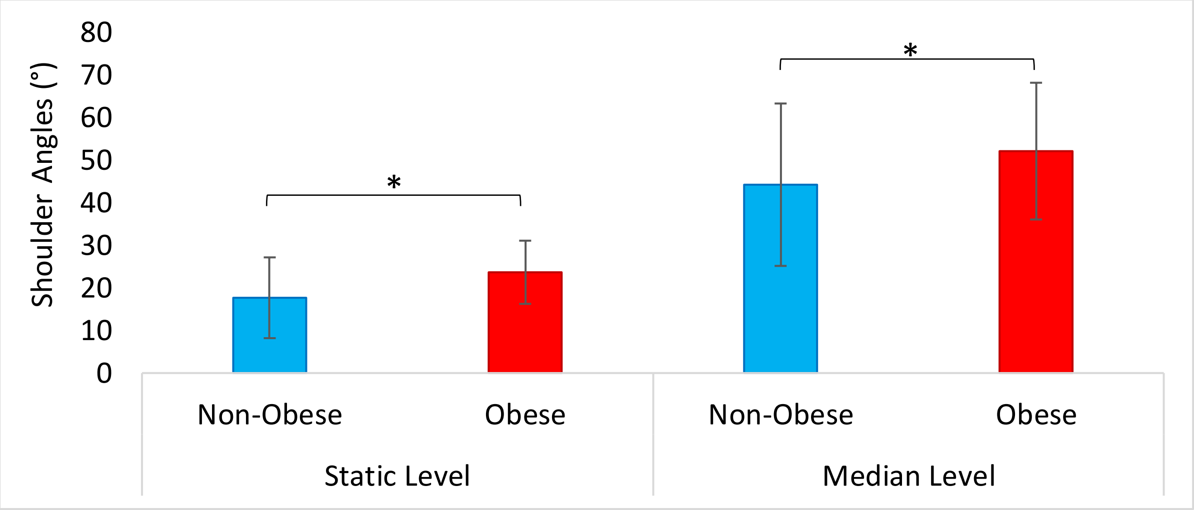

Figure 27: Shoulder Angle at static and median exposure level for height during lift and lowering tasks. Asterisks indicate significant differences between groups within each exposure level.

Interaction effects occurred for the shoulder at the peak exposure level with p-value < 0.001, with greater shoulder elevation angles (Figure 28) during lift & lowering task between groups and lift height combinations. There was interaction between FK and FS, and FK and KS for both obese and non-obese groups. Shoulder elevation angles for FK was 50°, KS was 99°, and FS 98° for the obese group while the non-obese group had 38° for FK, 98° for KS and 99° for FS.

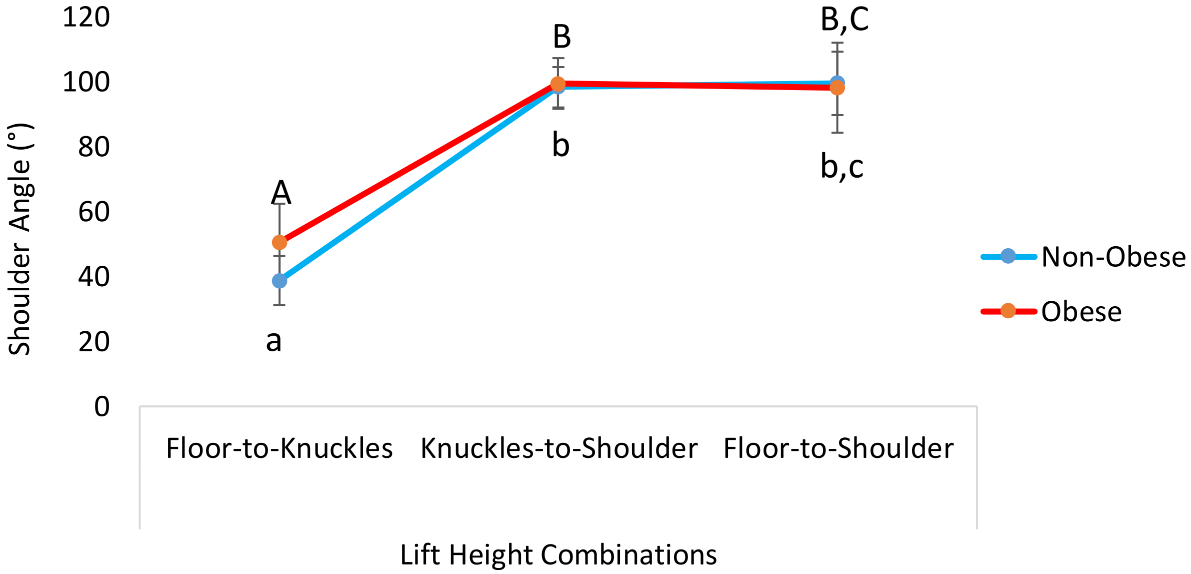

Figure 28: Shoulder Angle at peak exposure level had interaction effects for different lift height combinations and between groups. Uppercase letters indicate significantly different lift combinations for the obese group. Lowercase letters indicate significantly different lift combinations for the non-obese group.

Lift and Lower – Elbow

At the median and peak exposure level, there were main effects for groups with p-value < 0.001 (Figure 29) where at the median level there was a 2% higher elbow elevation for the non-obese group with 105°, and the obese group with 103°. At the peak level of exposure, there was a 3% higher elbow elevation angle for the non-obese group with 133°, and 130° for the obese group.

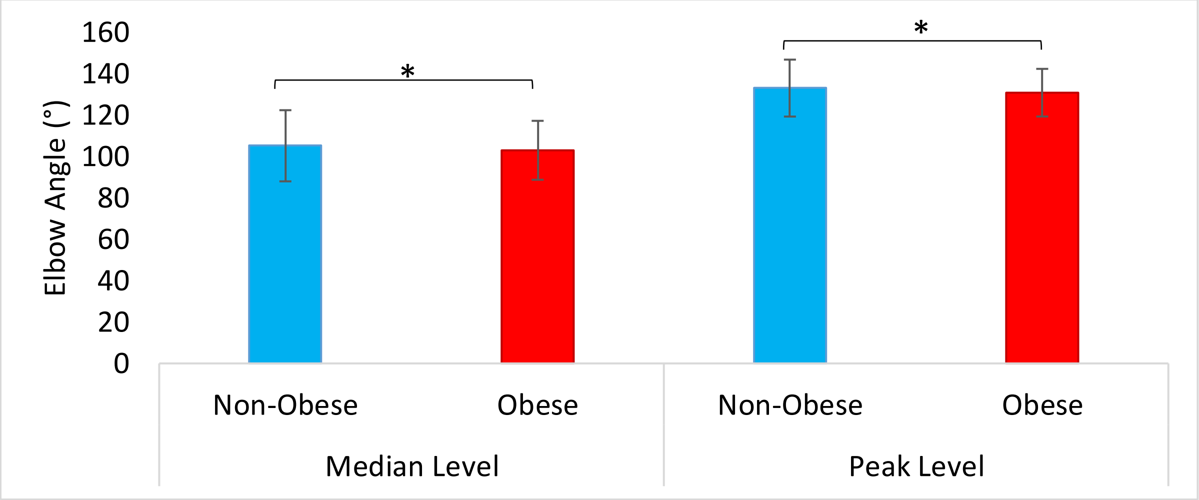

Figure 29: Elbow angles at across median and peak exposure levels with main effects between the obese and non-obese group. Asterisks indicate significant differences between groups within each exposure level.

Push – Low Back, Shoulder, Elbow

There was no main effect of group for low back and elbow angles during the push task. There was main effect for the factor group with p-value = 0.01 (Figure 30), in which it was significantly higher by 32% more shoulder elevation for the obese group with 26° shoulder elevation, and for the non-obese 20°. There was no significant main effect for load.

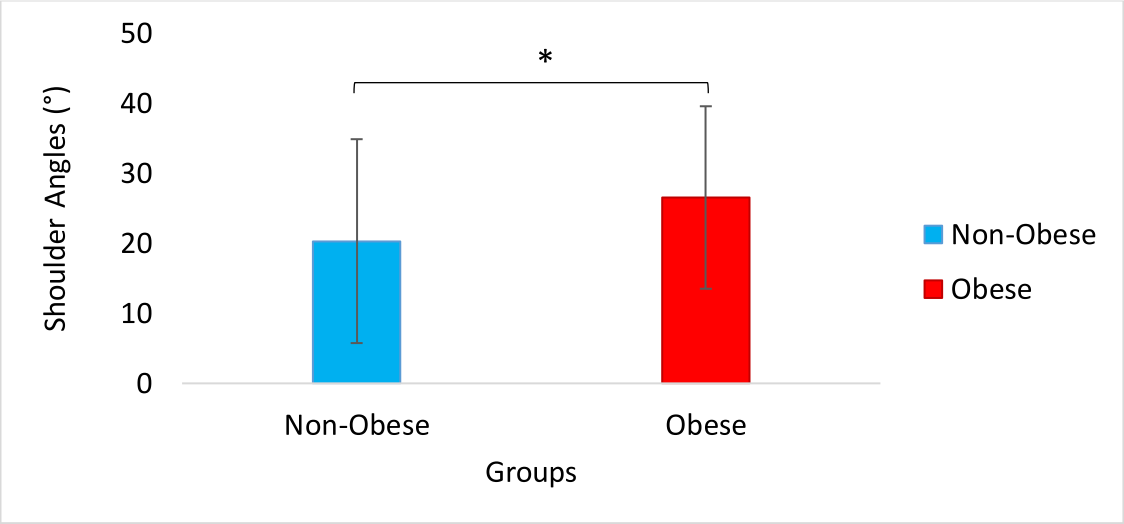

Figure 30: Shoulder angles with main effect of the factor group during the push task. Asterisks (*) indicate significant differences between groups.

Pull – Low Back, Shoulder, Elbow

Significant interaction effects at the low back were with handle height and groups with p-value = 0.02 (Figure 31) with -25% height compared to +25% handle height being significantly higher for trunk flexion of 19° and 11° respectively for the pull task. There was no significant main effect for load.

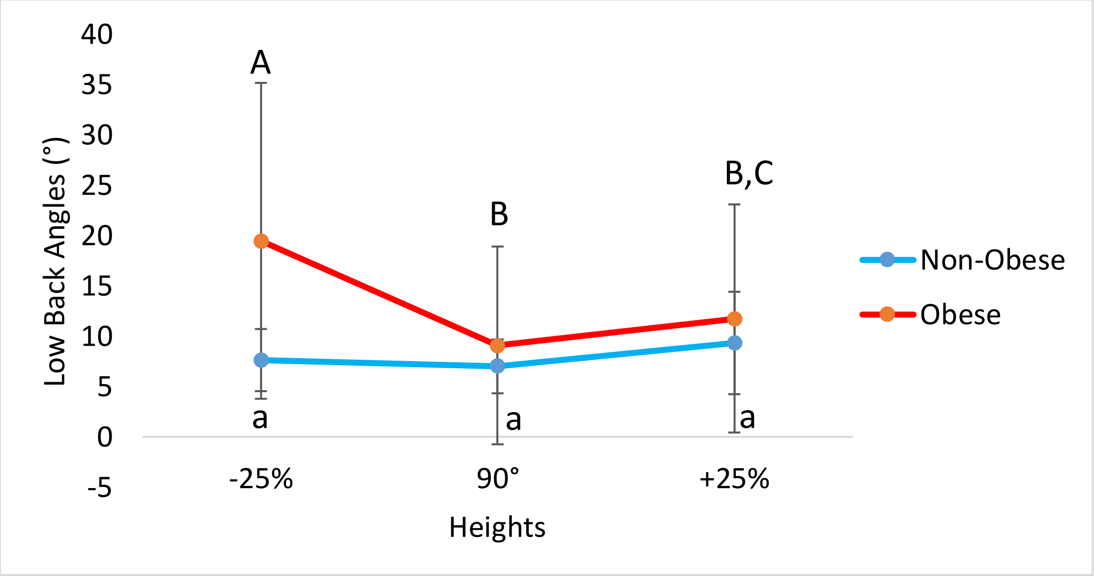

Figure 31: Low Back Angle comparing group and handle heights during Pull. Asterisks indicate significant differences. Uppercase letters indicate significantly different handle heights for the obese group. Lowercase letters indicate significantly different lift combinations for the non-obese group.

Significant main effect was found for groups with p-value = 0.02 and were significantly higher for the obese group with shoulder elevation angles of 26°, and non-obese group of 18° (Figure 32). There was no significant main effect for loads.

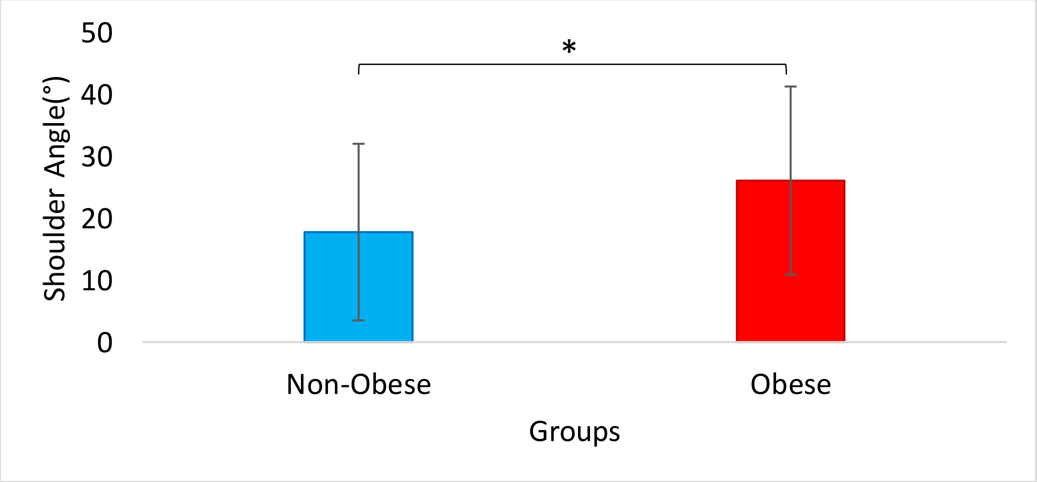

Figure 32: Shoulder angles comparing groups during the pull task. Asterisks indicate significant differences between groups.

4.4 Ratings of Perceived Effort and Discomfort

The areas of perceived discomfort which were equal to 0.9mm or more during the load transfer tasks were the right shoulder (0.11mm), right upper arm (0.14mm), right forearm (0.11mm), and right hand (0.9mm) for the non-obese group. Only the obese group experienced perceived discomfort at the right shoulder (0.10mm) and right upper arm (0.18m) during the load transfer task. During the lift and lowering task, only the obese group perceived discomfort at their right and left lower back, both with ratings of 0.09mm on the visual-analog scale. There was no perceived rating of discomfort that was above 0.9mm for the push and pull tasks for both non-obese and obese groups.

Table 14: Means, standard deviations, and p-values for local body discomfort across load transfer and lift & lower tasks and work parameters (distance, load) for 19 body sections between non-obese and obese group. Asterisk indicate significance, where p-value <0.05. Underlined values are clinically significant, values of ≥0.9mm.

	Load Transfer				**Lift & Lower**			
Body Region	**Non-Obese**	**Obese**	**SD**	**p-value**	**Non-Obese**	**Obese**	**SD**	**p-value**
Neck	0.03	0.07	0.02	0.20	0.02	0.04	0.01	0.17
L.Shoulder	0.04	0.03	0.01	0.06	0.07	0.03	0.03	**<0.01***
R.Shoulder	0.11	0.10	0.01	0.76	0.06	0.02	0.02	**0.05***
L.Mid Back	0.02	0.03	0.01	0.51	0.00	0.08	0.05	**<0.01***
R.Mid Back	0.02	0.05	0.02	0.19	0.00	0.08	0.06	**<0.01***
L.Lower Back	0.03	0.02	0.01	0.52	0.03	0.09	0.05	**<0.01***
R.Lower Back	0.03	0.04	0.01	0.58	0.03	0.09	0.05	**<0.01***
L.Buttock	0.01	0.00	0.00	0.28	0.02	0.05	0.02	**0.05***
R.Buttock	0.01	0.01	0.00	0.88	0.02	0.05	0.02	0.07
L.Thigh	0.02	0.00	0.02	**0.02***	0.03	0.02	0.01	0.28
R.Thigh	0.02	0.00	0.01	0.05	0.03	0.02	0.01	0.54
L.Shank & Foot	0.01	0.02	0.01	0.17	0.01	0.04	0.02	0.16
R.Shank & Foot	0.02	0.03	0.01	0.63	0.01	0.05	0.03	**0.01***
L.Upper Arm	0.01	0.01	0.01	0.41	0.03	0.03	0.00	0.60
L.Forearm	0.01	0.01	0.00	0.39	0.05	0.02	0.02	**<0.01***
L.Hand	0.01	0.00	0.00	0.14	0.02	0.01	0.01	**0.02***
R.Upper Arm	0.14	0.18	0.03	0.25	0.03	0.04	0.01	0.49
R.Forearm	0.11	0.05	0.04	**0.03***	0.05	0.02	0.02	**<0.01***
R.Hand	0.09	0.03	0.04	**0.01***	0.03	0.01	0.01	**0.03***

Table 15: Means, standard deviations, and p-values for local body discomfort across Push and Pull tasks and work parameters (distance, load) for 19 body sections between non-obese and obese group. Asterisk indicate significance, *, and were bolded where p-value <0.05.

	Push				**Pull**			
Body Region	**Non-Obese**	**Obese**	**SD**	**p-value**	**Non-Obese**	**Obese**	**SD**	**p-value**
Neck	0.02	0.04	0.02	0.14	0.02	0.05	0.02	0.06
L.Shoulder	0.03	0.01	0.02	**<0.01***	0.03	0.01	0.02	**<0.01 ***
R.Shoulder	0.05	0.03	0.01	0.28	0.05	0.03	0.01	0.13
L.Mid Back	0.00	0.03	0.02	0.06	0.00	0.04	0.02	**0.04 ***
R.Mid Back	0.02	0.06	0.03	**0.04 ***	0.02	0.06	0.03	**0.02 ***
L.Lower Back	0.01	0.03	0.01	0.15	0.02	0.03	0.01	0.17
R.Lower Back	0.04	0.05	0.01	0.37	0.04	0.05	0.01	0.41
L.Buttock	0.01	0.01	0.00	0.50	0.02	0.01	0.01	0.09
R.Buttock	0.01	0.03	0.01	0.16	0.02	0.03	0.01	0.83
L.Thigh	0.01	0.00	0.00	0.53	0.01	0.00	0.00	0.37
R.Thigh	0.01	0.01	0.00	0.61	0.01	0.01	0.00	0.12
L.Shank & Foot	0.01	0.04	0.02	0.10	0.01	0.04	0.02	**0.03***
R.Shank & Foot	0.00	0.05	0.04	**<0.01***	0.01	0.06	0.03	**0.02 ***
L.Upper Arm	0.01	0.01	0.00	0.52	0.01	0.01	0.00	0.53
L.Forearm	0.01	0.00	0.00	0.21	0.01	0.00	0.00	0.62
L.Hand	0.00	0.00	0.00	0.51	0.00	0.00	0.00	**0.01***
R.Upper Arm	0.06	0.05	0.00	0.80	0.06	0.06	0.00	0.83
R.Forearm	0.05	0.02	0.02	**0.01***	0.05	0.02	0.02	**0.01 ***
R.Hand	0.07	0.01	0.04	**<0.01***	0.07	0.01	0.04	**<0.01***

Table 16: Means, standard deviations, and p-values for perceived exertions across tasks between non-obese and obese group. Asterisk indicate significance, *, and were bolded where p-value <0.05.

	Mean			
Tasks	**Non-Obese**	**Obese**	**SD**	**p-value**
Load Transfer	2.50	2.32	0.12	0.41
Lift & Lower	3.19	3.43	1.12	0.25
Push	2.58	1.95	0.68	**<0.01***
Pull	2.78	1.83	0.74	**<0.01***

V. Discussion

The purpose of this research was to assess differences in physical exposures between obese and non-obese individuals while performing manual materials handling tasks. Better understanding of the effects of obesity could identify potential injurious work parameters from manual materials handling tasks. The results indicate relationships between the non-obese and obese groups for three associated joints through moments (low back, shoulder, and elbow) and four associated joints through angles (low back, shoulder, elbow, and wrist). There were increased exposure outcomes in the obese group, compared to the non-obese group, suggesting obese individuals have a higher risk of injury when performing tasks.

To revisit the four hypotheses:

1) **Obesity will influence kinematic outcome variables in all MMH tasks; there will be increases in arm elevation and decreases in trunk flexion for the obese group.**

Partially accepted. The obese group had greater trunk flexion and arm elevation than the non-obese group throughout all three-exposure levels for the load transfer task. The average trunk flexion angles were relatively similar between the two groups during the three exposure levels, but the obese group had greater standard deviations at each of the reach distances. There was more trunk flexion with further reaches at 70cm during the load transfer task for both groups. The obese group on average had more arm elevation during all three-exposure levels during the load transfer task. The obese group had greater deviations with arm elevation angles when completing the load transfer task. This suggests that, in order to limit loads on the low back, compensatory arm elevation occurred in the obese group. Even though low back and shoulder moment were higher for the obese group at all exposure levels during the load transfer tasks.

The lift combinations from floor-to-knuckle height always involved more trunk flexion and arm elevation from the obese group. During lift and lower, obese groups had higher low back flexion angles during the floor–to-knuckles lift combination at all three exposure levels, and arm elevation similar to the non-obese group. There was overall higher arm elevation for the obese group at the static and median levels of exposure for lift and lowering task compared to the non-obese group. During peak exposure level, shoulder elevation was the lowest for the non-obese and obese group during the floor-to-knuckles lift combination; whereas knuckle-to-shoulder and floor-to-shoulder had higher arm elevation, mainly due to the shelf positioned at shoulder height. During the push and pull task, the obese group had more trunk flexion and arm elevation than the non-obese group at the three different handle heights.

2) **Absolute joint moments of the wrist, elbow, shoulder, and low back will increase for the obese group (higher BMI classifications) during MMH.**

Accepted, except for the wrist. Moments at the low back, shoulder, and elbow were all higher than the non-obese group for all exposure levels during the load transfer, lift & lower, and push task. Only the pull task had lower moments at the wrist for the obese group compared to the non-obese group. Low back moments were greater for the obese group during the 70cm reach of the load transfer task for the median exposure level. Both groups had increased low back moments during the peak exposure level of load transfer task with increase in distance, but the obese group had a more steady increase in low back moments. Shoulder moments were also greater for the obese group during all three-exposure levels when performing the load transfer task. The obese group had higher moments at the elbow for all three-exposure levels and at the static level for the wrist during the load transfer task.

During the lift & lower tasks, the obese group experienced greater low back moments than the non-obese group during all three-lift combinations at the static and peak exposure levels. During the bilateral lift and lowering tasks, the lift combination of knuckles-to-shoulders height had the highest low back moments produced by both obese and non-obese. Floor-to-shoulder height lifts were the task that caused higher low back moments during peak exposure levels than the knuckles-to-shoulder height lifts for the obese group.

For the pull and push handle heights, the configuration that was 25% lower than the 90° neutral position had the higher low back and shoulder moments with an increase in loads. It can be expected that BMI would have the least effect on the wrist since the weight of the hand would be minimal compared to the arm and trunk. There was also limited postural flexibility for the wrist due to the handle constraints imposed, which may have prevented adaptive strategies.

3) **The obese groups will have greater upper arm, upper leg, waist, and hip circumferences than the non-obese group.**

Accepted. All mean circumference measurements were greater for the obese group compared to the non-obese group with p-value < 0.00 and effect sizes of over 1%.

4) **Isometric muscular strength will be greater and functional strength will be lower in the obese group.**

Partially accepted. Absolute isometric joint strength was greater for the obese group, but once normalized to body mass the strength values were lower when compared to the non-obese groups. Absolute maximal functional strength was higher for obese groups, but when normalized by body mass, these values were lower for obese individuals.

5.1 How Did Obesity Influence Strength?

Obesity status influenced strength; specifically, absolute strength values were higher in the obese group for isometric and functional joint strength, but were lower when normalized to body mass. For hypothesis 3, it was thought that obese individuals would be weaker during maximal functional strength testing, due to lack of flexibility to optimize strategies to produce force, or other possible reasons such as sarcopenic obesity (Capodaglio, 2010), reduction in range of motion (Park et. al, 2009), or reduced motor unit activation during exercise (La Fortuna, 2005). With the aging workforce, it is important to investigate individuals who are obese as they are susceptible to sarcopenia (Rosenberg, 1997; Marcell, 2003; Doherty, Vandervoort, Brown, 1993). Sarcopenia is age-related loss of muscle mass and it is believed that age-associated decline of muscle strength is largely due to a parallel decline of muscle mass (Doherty et al., 1993; Campbell, McComas, Petito, 1973). For obese elderly workers who perform manual materials handling tasks, it necessary to examine if this population is at higher risk of work-related musculoskeletal injuries. However, with maximal functional strength tests, only the push, downward, and bilateral lifting exertions had positive correlations for the obese group with increasing BMI. Previous literature suggests that obese individuals producing higher absolute MVC torque and power may be due to positive training on skeletal muscle from extra fat mass at the limbs (Thoren et al., 1973; Bosco et al., 1986). However, work-related muscloskeletal disorders (WMSD) arise from a complex interaction of events that may accumulate over time (Melin & Lundber, 1997), such as postural stresses which are associated with increased risk of WMSD (Armstrong 1986; Armstrong et al., 1993). Increase in mass due to obesity has an effect of amplifying changes in the moment arm which are the consequences for postural changes (Park et al., 2009). With prolonged and sustained work with greater masses of each segment, it is expected to increase risk of WMSD. The weight of an elevated upper limb alone can cause increases in shoulder moment (Anthony and Keir, 2010). Absolute pull and up exertions had negative correlations, suggesting exertions that align with gravitational pull were higher, as weights of the segment could have also contributed to higher strength values. It is possible that obese individuals leveraged their covert weight to produce greater strength values for these three specific tests. When comparing normalized strength, there were negative correlations between increase in strength and BMI, similar to findings by Katmarzyk (2003). All isometric and maximal functional strength tests had negative correlations with increasing BMI. Individuals with higher BMI had lower strength values once normalized; this could be due to difficulty optimizing muscular activation to produce higher forces. Previous literature corroborates these results, as obese persons previously generated higher absolute values (Hulens et al., 2001; Maffiuletti et al., 2007), but once normalized to their body mass these values may reflect their ability as an individual to generate strength optimally, similar to La Fortuna et al. (2005). Obese individuals had lower strength values once normalized with body mass; this could predispose them to risk of injuries in the workplace. Strength measurements are simple evaluations or screening tools for industry jobs to assess if a future employee will be capable of doing their job for a given role. Further investigation of these obese groups could update current guidelines for evaluating risk factors during manual materials handling tasks or help employers determine whether an individual is capable of doing the work for the job.

5.2 How Did Obesity Affect Joint Moments and Angles During Manual Materials Handling?

Obesity status affected joint moments and angles at each associated joint across all four manual materials handling tasks. During manual materials handling, obesity increased joint moments for both load transfer and lifting & lowering tasks while the push and pull tasks were further influenced by other factors, such as handle height. Joint angle moments are discussed in the order of tasks: load transfer, lift & lower, push, and pull based on interaction effects then main effects. With greater covert weight, the extra mass of each segment creates greater reaction moments and the further away the mass is from the joint centre of rotation, a larger gravitational moment is required to overcome the mass to maintain the same position. Due to limited data on obese populations, it was assumed that the mass was distributed across the limbs based on published parameters derived from non-obese populations. The calculated moments at the joints could be an underestimation of what the obese individuals truly experienced due to the previous assumption of mass distribution across the limbs. Specifically, additional body mass alters shoulder, lumbar, and knee joint ranges of motion and increases postural stress (Park et al., 2009). Total body and upper and lower limb fat mass, measured by body composition analysis, also positively correlate with reports of lower back pain (Urquh et al., 1976). Following this logic, hypothesis 2 should be true for individuals with higher BMIs when coupled with waist circumferences greater than 102cm for males, and 88cm for females (Canadian Diabetes Association, 2017). With the classification of participants into non-obese and obese groups, a significant difference was identified between the groups at all levels of normalized moment exposure (static, median, and peak) for the low back, shoulder, and elbow for the load transfer task. A similar trend occurred for the lift and lower task at all three levels of exposure for the low back, shoulder, and elbow between the obese and non-obese groups. A larger body composition with excess weight imposes altered mechanics, which could partly explain the higher incidence of occupational musculoskeletal injuries for the obese population (Kouvonen et al., 2013). The push and pull tasks were not significantly different as both tasks were constrained and required less time to complete; due to the task parameters, participants' free range of movement was also limited.

Load Transfer

Obesity combined with task parameters showed interactions depending on the exposure level experienced during the load transfer tasks. The obese group experienced higher joint moments at each joint and greater arm elevation and trunk flexion during the load transfer task at peak exposure levels compared to the static exposure levels, for the load transfer task. At the peak exposure level there was more trunk flexion at the 70cm reach which increased low back moments for both groups. Arm elevation was significantly different during the static and peak exposure levels for 30cm, 50cm, and 70cm reaches between obese and non-obese groups. Arm elevation was always higher for the obese group than for the non-obese group. Shoulder muscle activity are doubled when shoulder flexion went from 30° to 90° of shoulder flexion (Anthony & Keir, 2010); similar to the shoulder flexion angles produced by both non-obese and obese groups during the load transfer task specifically during the median and peak exposure levels. Greater arm elevation angles for the obese group suggests that it is possible for this group to have raised their arm higher to complete the task despite already flexing more at the low back. During the median exposure level, the obese group had gone beyond the 30° shoulder flexion, while the non-obese group was less than 30°. Thus, at the median and peak exposure level, muscle activity should be reaching towards a value that is doubled for the obese group.

Low back moments are affected by the postural stance the obese group tends to adopt when reaching toward targets beyond 30cm. Low back moments were higher during the 30cm reach for obese group even though both groups experienced similar trunk flexion angles when completing the load transfer. Both non-obese and obese groups were more upright during the static exposure level, contributing to less low back moments during the load transfer task. There was more variability in low back flexion and extension from the obese group during the median and peak exposure level when compared to the non-obese group. Obese individuals had a wider range of strategies used when completing the load transfer task at all three-exposure levels as indicated by the large standard deviations in low back angles. These interactions suggest that the obese individuals used more diverse methods to complete the task; however, these strategies required higher moments at the low back. Previous literature found that, obesity negatively affects control of goal-directed upper limb movements, such as pointing to a target, due to effects on control of balance while standing (Berrigan, Simoneau, Tremblay, Hue, & Teasdale, 2006). The non-obese group had a more upright posture and lower arm elevation when completing the load transfer task when compared to the obese group. Elbow moments were different across all three-exposure levels between the groups. The obese group had more arm elevation during the load transfer task, which could have prevented high low back moments. The load transfer task was one of the more difficult MMH tasks performed with reaches set farther away from midline of the body which are considered as infrequent or occasional reaches. This task was incorporated as one of the MMH tasks because there is little information on the obese population completing these infrequent or occasional reaches. The Canadian Standards Association (2011) recommends limiting these awkward postures by performing them less frequently or having the work surface or dimensions adjusted to reduce risk of shoulder and back injuries. These guidelines continue to apply for the obese group as their low back moments and shoulder moments nearly doubled at 70cm reaches during peak exposures. Previous studies confirm that reaches that are farther away from neutral standing position are generally more difficult with obesity due to increased trunk weight (Corbeil et al., 2013). The load transfer task required participants to use just their dominant arm throughout the task, and required the most time to complete. The task was of varied difficulty as targets were placed at various distances from subjects and bottle weight was modified. During peak exposure levels, both low back and shoulder moments were significantly higher for the obese group. A strategy to decrease the moments produced at the shoulder and the following distal joints may be to reevaluate reaches limits for obese workers. The farther the target was for the participant, the more they had to move in order to complete the task. An increase in abdominal region adipose tissue or fat yields a greater horizontal distance of the worker's spine and shoulders from a workstation and modifies functional reaching distances and available joint ranges of motion (Capodaglio, 2010). The obese group had more arm elevation to potentially compensate for limited low back movement; therefore, there were increased shoulder moments. This strategy may potentially help avoid overloading at associated joints when completing tasks by alternating between different joints to attempt to reduce loading by sharing with several different joints.

Lift and Lower

Lifting and lowering resulted in greater moments for the obese group at certain joints and exposure levels. Interactions occurred at the low back and shoulder angles at certain APDF levels involving the load and groups, as well as the heights of the lifts and groups. Post hoc analysis revealed that low back angles involving lifts from floor-to-knuckles required more flexion from obese groups than the non-obese group and the two other lift combinations at the static exposure level. Obese groups had more trunk flexion during the lift and lower combination from floor-to-knuckles during the static and median exposure level, but had less arm elevation during the static and peak exposure levels. This suggests that with lifts from floor-to-knuckles, obese individuals had a tendency to increase trunk flexion and decrease arm elevation compared to the non-obese group to complete the tasks. Shoulder moments were significantly higher for the obese group during the floor-to-shoulder lift at static level, and during the median exposure level. Higher body mass increases the moments about the joints primarily in the back (Gilleard &

Smith, 2007; Hue et al., 2007). Shoulder moments were also higher for all three different lift combinations during peak exposure levels for the obese group. The increased torso flexion combined with increased shoulder flexion moves the load farther from the body (Lang, 2015), which increases the load on both the shoulder and the low back (Waters, Putz-Anderson, Garg & Fine, 1993). This lifting technique could be worse for the obese group as with heavier lifts; there are increases in loads to the shoulders and low back that would be greater than the non-obese group. The interactions between load and group occurred for the non-obese group lifting 10kg, where the amount of low back flexion required for 10kg was more than the 2.5kg and 5kg at the median exposure level. Interactions between the groups and lift heights existed for the low back and shoulder at the peak exposure level. The non-obese group performed the three lift combinations with less trunk flexion and had less arm elevation than the obese group during all three-exposure levels. Although trunk flexion angles were relatively similar for floor-to-shoulder and knuckles-to-shoulder between the two groups, the obese group had significantly higher shoulder elevation angles during the static and median exposure levels to complete the same task. The obese group had increased elbow moments at all three exposure levels during the lift and lowering tasks, but had less elbow flexion when completing the task. Obese individuals had more trunk flexion, arm elevation and less elbow flexion to complete these lifts while the non-obese group had less trunk flexion and arm elevation but more elbow flexion. This supports previous biomechanical models of the musculoskeletal system indicating that obese individuals experience higher joint loading during lifting tasks (scaled to 10% and 25% of their capacity) (Xu et al. 2008). Obese subject may have required more trunk flexion to obtain the crate, as they would have excess adipose tissue around their torso. The gross abdominal morphology of the obese handler also limits the possibility of bringing the load closer, which reduces his margin of maneuver (Corbeil, Plamondon, Teasdale, Handrigan, Ten Have, Manserolle, 2014). These biomechanical factors expose the obese group to greater risk of musculoskeletal injuries during industrial tasks requiring lifting and lowering movements. The obese groups are experiencing greater moments at each associated joints because the greater mass to be lifted (gravity acting on a greater body mass).

Push & Pull

There were no interactions between the handle height with the groups or with the different hand loads and groups for moments at the low back, shoulder, or elbow. Shoulder moments were greater for the obese group compared to the non-obese group during the push task even though these were set handle heights. Instead of adopting a flexed trunk posture for the lower height, the obese group adopted to use more elbow extension and a more upright posture during the pushes.

The obese group had more arm elevation during the push task for all three different handle height combinations. With higher handle heights, there was more shoulder elevation and more elbow elevation. Whereas with the lower handle height, there was less shoulder and elbow elevation. These angles and moments were somewhat constrained by the task parameters as participants’ feet were staggered. Staggered foot positions may increase forward and backward turning moments (Chaffin and Andres, 1983). A rearward foot position in pushing enables participants to lean forward more, rotating about their rearward foot while using the forward foot as additional weight to increase the forward turning moment of the body around the centre of pressure (Chow, 2010). This could explain why the moments at the low back and shoulders were higher during the push task than the pull task. The trend of having a lower handle height produces more low back and shoulder moments with an increase, in hand loads occurred for both push and pull tasks. Obese individuals adopted a more flexed posture at the trunk and more shoulder flexion in order to complete the push and pull tasks with the handle heights at 25% lower. Similarly to Chow (2010), with respect to pulling, increased trunk flexion, which occurs more often with lower handle heights due to physical constraints, may allow the participant to take advantage of the high inertial properties of the upper-body to generate momentum in the extension direction to pull against the handle (MacKinnon & Vaughan, 2005).

The importance of investigating these MMH tasks is to gain more context on the obese population as there is limited data on the influence of their body composition. There is a real need to better understand the impact of obesity on the functionality of the human being (Wearing et al., 2006; Xu et al., 2007). These four tasks chosen are transferable to work found in the industry, although it only focuses on a small window in a realistic work day. Workers may be required to complete only push tasks or a combination of multiple MMH tasks. Therefore, it is crucial to examine these work task parameters with obese individuals for longer durations to better represent the related issues for this population.

5.3 Rating Perceived Discomfort and Exertions during Manual Materials Handling

The rating of perceived discomfort for the load transfer task was reflective of previous studies where increased discomfort was experienced during these tasks were likely due to the repetitive movements found in these tasks (Cudlip, 2014). Refering back to the minimum clinically significant difference in VAS pain scores of 9mm (Kelly, 1998), only the load transfer task at the right shoulder had discomfort ratings above this score for both groups. Although there was more discomfort experienced by the non-obese group during the load transfer task, only certain regions of the body were considered clinically significant. The lift & lower, push, and pull tasks were tasks where both groups reported discomfort in the various regions of the body; however, these scores were under the threshold of clincally significant. The rating of discomfort for the non-obese group during load transfer was at the right shoulder, right upper arm, right forearm, and right hand, while the obese group felt discomfort only at the right shoulder and right upper arm. The ratings of discomfort for the upper, mid, and lower back were all under the threshold for clinicially significant for both groups. The load transfer task required the use of the participant's dominant arm throughout all trials which could explain why only the right side of the upper limbs felt discomfort. While the hands were required to perform repetitive movements and to maintain a constant grasp of the weighted bottle, it resulted in increased discomfort simliarly to Kronberg et al., (1990).

For the lifting & lowering task, trunk flexion increase for the obese group, for all three exposure levels and lift height combinations, may have been due to their physical attributes associated withgreater ratings of perceived discomfort. The obese group felt discomfort at the left and right lower back regions during the lift and lowering tasks, while the non-obese group did not experience discomfort that would be clincally significant. Unconventional lifting and lowering strategies may be adopted for various weights and different shelf heights creating more discomfort between lifts. Previously, greater fat, but not lean tissue mass, was associated with high levels of low back pain intensity and disability (Urquhart, 2011). Generally a strategy to minimize the moment arm or distance between the load and trunk is by bringing the load closer to oneself to attempt to reduce loading at the L5/S1 (McGill, 2002; Marras, 2006; 2008; Plamondon et al., 2010). But with obese handlers, this option may not always be practical given their trunk dimensions (Corbeil et al., 2014). The distance between the box and L5/S1 was slightly greater for obese handlers, but only the healthy-weight handlers were able to bring the load closer to minimize the moment arm effect on lumbar loading(Corbeil et al., 2014). Having greater RPD values for the obese group could be associated with increased low back moments due to greater demands were required for the task as shown with the TOI. The obese group did exemplify greater strength values which could have compensated for the excess adipose tissue that needs to be carried with each lift and lower. This could be linked to RPE values that were not signficantly different between the groups when completing this task. While the non-obese group used a more shoulder dominant strategy that could have association with the TOI as well.

During the push and pull task, there were no body regions rated as experiencing discomfort that were clinically significant for both obese and non-obese groups. The effects of handle height and angle of pull from the horizontal plane on one-handed dynamic pulling strength found that the shoulders were perceived as most stressed, based on ratings of perceived exertion for the elbow, shoulder and back (Garg & Beller, 1990). With the staggered stance, the obese group may have used their rearfoot to push forwards causing perceived discomfort when performing the pushes. Also, they may have used their foot placed infront of them to leverage their pull backwards during the pull task causing perceived discomfort in their left shank and foot. Rating of perceived exertions were significantly lower for the obese group during the push and pull tasks, which could be associated with leveraging their body mass to help push forward and pull backwards to maintain the hand forces required to complete the tasks (Table 18). Again, the obese group had higher absolute values when it came to the maximal functional strength tests for push and pull. These two MMH tasks could have been easier for the obese group because they would overall have exerted a smaller percentage of their absolute strength to recreate the 40N, 60N, and 80N.

5.4 Limitations:

There were some limitations to this study. With a smaller sample size, it reduced the power of the statistical test to identify sex effects. Sex effects would have been an important factor since elderly females with BMI higher than 30kg/m^2 were twice as likely to display functional limitations compared to normal-weight females (Zoico et al., 2004). However, there is an inability to comment on sex effects due to lack of statistical power. Evaluating obese workers with age and height-matched healthy-weight counterparts could disclose specific work capacities and vulnerabilities, as these MMH tasks were adjusted to the participant's anthropometrics. Separating the BMI groups into only two categories of non-obese and obese groups was a necessary simplification due to sample size; however, this introduces the inability to comment on kinematic, kinetic or strength differences between Obese I, Obese II, and Obese III, if any exist. Previous research investigated BMI >40, finding substantially increased risk of functional limitation (Friedmann, Elasy, & Jensen, 2001); however, we do not know if there are differences between BMI of 30kg/m^2 -34.9kg/m^2, 35kg/m^2 -39.9kg/m^2, and >40 kg/m^2. The division of BMI to create the non-obese and obese groups may have affected the results to be more conservative or not display further significance. If the division of non-obese groups included only individuals classified as normal weight, and the obese group included overweight and Obese I, II, and III from BMI cut-offs, there could be greater differences in the outcome variables. Participants were not age-matched which meant that we are unable to see potential strength differences due to age (Keller & Engelhardt, 2013, Amaral, Alvim, & Castro, 2014), especially since the average age of the non-obese group was 27.00±5.74 years, while the obese group was 30.94±14.59. The wide spread of the obese group could affect the results of the force production; therefore, future studies should include age-matched participants when comparing to the obese group to eliminate age as a factor to have influenced force production. Skin artifact would have caused errors in joint kinematic and kinetic calculations due to accuracy of palpation of landmarks and skin movement, with respect to underlying bones. Soft tissue artifact arose from movement of the subcutaneous tissues associated with muscular contractions (Cappozzo, 1996, Cappozo 1986). Movement artifacts depend on physical characteristics of the individual (Holden et al., 1997) and the nature of the movement task being performed (Fuller et al., 1997). Normally bony landmarks serve as good indicators of movement as there is little skin artifact. Previous studies have found that markers over the anatomical landmarks of the thigh exhibit significant soft tissue artifact (>10mm) (Peters et al., 2010); these may be similar for the upper extremity as well when excess adipose tissue is present. Presence of subcutaneous adipose tissue at anatomical landmarks of marker placement would affect the location of joint centers for calculating joint kinematics and kinetics, especially for the pelvis and torso.

A more comprehensive picture of the participants' history of their health status could have been documented, such as the participants' occupation or physical activity level. When obese individuals undertake or begin an exercise program, caution should be taken as there is the possibility that even light physical activity such as walking may be too exhausting and cumbersome (Mattsson, Larson, Rossner, 1997). More information on the physical activity levels of the obese individuals could have provided more information to their RPD and RPE scores for these MMH tasks. Other information on how long the participant was overweight or obese could have also changed the performance of work or kinematics. Structural and functional limitations imposed by overweight and obesity from increased body weight may interfere with normal musculoskeletal function through a variety of kinetic and kinematic impairments (Del Porto, Pechak, Smith, Reed-jones, 2012). Physical adaptations lead to impaired balance and increased incidence of muscle weakness(Guelich, 1999; Zecevic, Salmoni, Speechley, Vandervoort., 2006). If an individual had sudden weight gain/loss, they may not be familiar with their body and would not be representative of the individuals’ movement patterns, which would reflect their body composition.

Only one trial was examined for each task to minimize potential fatigue across all confounding factors. A minimum two-minute rest was also given after each strength test to avoid muscular fatigue suggested by Chaffin (1975) and Mathiassen et al. (1995). Obese individuals may be more susceptible to fatigue compared to non-obese individuals, as there is a reduction in supply of blood flow to capillaries that limits the amount of oxygen and energy sources. Alternatively, decreases the size and amount of mitochondria necessary to produce energy (Cavuoto & Nussbaum, 2014). Under these circumstances, recovery performance is less efficient and may lead to more rapid fatigue. Only four MMH tasks were examined to mimic industrial work. However, these four tasks are commonly found in industry as push and pulls make up 50-75% of all MMH tasks (Baril-Gingras & Lortie, 1990). Longer duration or more repetition of each task should be further investigated to obtain a better understanding of the influences of obesity on MMH in a realistic environment.

Normalizing the strength values from the strength tests created a ratio from scaling these strength values to body mass to allow for each strength test to be assessed between two different groups. By normalizing to body mass, we are effectively removing body-composition dependence and allowing for comparisons of persons (Bazett-jones et al., 2011, Davies & Dalsky, 1997). Normalizing isometric-joint strength and maximal functional strength test with muscle mass would provide accurate comparisons of strength capabilities between obese and non-obese individuals. By normalizing strength values with muscle mass instead of body mass we can investigate more clearly if obese individuals are stronger due to the production of force from muscles or if they are leveraging their segmental mass to produce higher strength values. This could provide more context as to why the absolute values were greater for both isometric-joint and maximal functional strength test, but lower when we normalized to body mass.

Joint angles were calculated using the dot product method that accounts for gravity and provides a robust value to complement the value of joint moments as it is relevant from a loading perspective (Winter, 2009). For future analysis, Euler angles can be used to supplement the magnitude of moments by identifying the posture during each task. With Euler angles, it could provide further detail and description of posture to further support kinetics (Zatsiorsky, 2002). The kinematics for the push and pull tasks are influenced by the participant’s anthropometrics; in order to overcome this in the future, considerations for height-matched participants may be useful in eliminating height factors. The lack of some obvious anthropometric differences should be highlighted as a potential mitigator of observing other differences through mechanical outcomes. The assumption of body mass being evenly distributed across the segment was also made, future implementation of DXA scans, which will provide mass distribution at each limb more accurately will allow for more accurate kinetic results. A top-down quasi static method was used to calculate kinetics instead of using a dynamic model because the assumption of inertial properties would have had to been made for the obese group. Increased mass at each segment could have increased error with further assumption of mass distributions (Winter, 2009). Amplitude probability distribution functions (APDF) were used to evaluate exposures at the 10th, 50th, and 90th, percentiles for the load transfer and lift & lower tasks. The levels of 10th, 50th, and 90th percentile were used as 'work load' predictors by Robertson (2010). APDF were developed by Hagberg & Jonsson (1975) for ergonomics research to examine electromyography signal analysis. This method of examining kinematics with APDF have been used previously by La Delfa, Grondin, Cox, Potvin, and Howarth (2016) to examine biomechanical demands at the shoulder and neck. With the load transfer and lift & lower tasks being dynamic tasks involving a longer period of time to complete than the push and pull, the use of APDF was able to represent the whole task and the exposures at each joint at various exposure levels.

VI. Conclusions

This work served to advance insight on the effects of body composition on the performance of several common tasks and their associated joint and whole-body level exposures. The primary conclusions stemming from this work follow:

1) Obese tended to have increased arm elevation compared to non-obese when completing dynamic MMH tasks, such as load transfers. Increased arm elevation postures coincided with increased shoulder moments. This could pose an increased risk of musculoskeletal injuries if workers are required to sustain constant arm elevation throughout their work shift. Decreased trunk flexion angles where participants maintained an upright posture could have been the root cause for increased arm elevation, which could be a technique used by the obese group to decrease low back loading.
2) Depending on the task, the obese group have greater low back demands, such as the load transfer task. While the shoulders had greater moments during the lift & lowering tasks, this could be due to difficulty in bringing the load closer to the body in an attempt to reduce low back loading.
3) The obese group exemplified higher absolute isometric joint strength and maximal functional joint strength. When strength values were normalized to body mass, these values were lower when compared to the non-obese group. The non-obese group had higher normalized strength values for both isometric joint and maximal functional joint strength.
4) Perceived rating of discomfort was prominent during the lift & lowering task for the left and right lower back, which is reflective of the higher low back moments, even

> though trunk flexion was relatively similar between the groups except for the floor-to-knuckles lift & lowers. The dominant arm also experienced clinically significant discomfort for the right upper limb for non-obese groups, while the obese group experienced it in the right shoulder and upper arm only.

Further investigation is required to determine whether obese individuals experience greater demands on associated joints when completing MMH tasks compared to non-obese individuals. With further investigation on this population and their experience with MMH tasks, which can be directly applied to improving work for persons with high BMI. Considerations of using DXA scans to employ better anthropometric data for obese population databases as it is generally regarded as a gold standard method in evaluating human body composition. This will provide more accurate and representative data of the current population to more accurately calculate kinetic outcomes. Future analysis should elucidate the kinematic and kinetic strategies employed by the different BMI groups to better understand differences in physical demands between body composition groups. This study demonstrated that the obese group did experience higher loading at the low back, shoulder, and elbow joints, as well as experiencing more trunk flexion and arm elevation. Though, epidemiological data will be required to establish a direct relation with obesity as a risk factor for WMSD.

It would be incorrect to assume that obese workers are less capable than their non-obese counterparts, although the findings suggest the obese group does experience greater moments at certain joints and performs more mechanical work when doing the same tasks. A major purpose of this research was to provide more information on obese groups when working within current ergonomic guidelines and to investigate if body composition is a motivating factor for becoming prone to higher exposures and consequently additional risk of musculoskeletal injuries. Additional clarity is needed to determine if individuals within each BMI classification of Obese I, Obese II, or Obese III move differently during MMH tasks. An increase in sample size will provide a better overall presentation from each BMI group instead of only three males and females in each BMI category. The implementation of more trials for each task could provide a better reflection of an average workday for an individual who performs industrial tasks. A greater number of trials could also reveal if obese individuals fatigue faster or require a longer recovery time before returning to MMH tasks.

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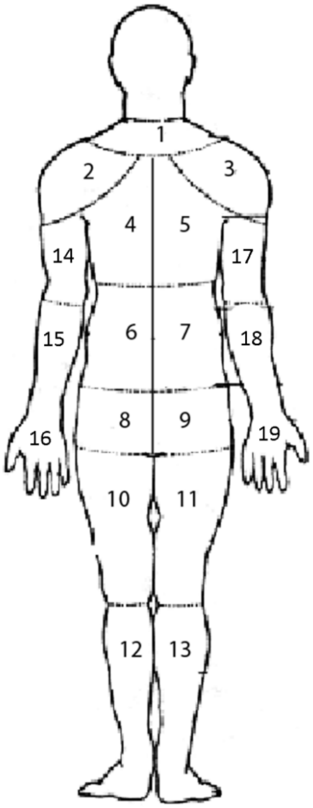
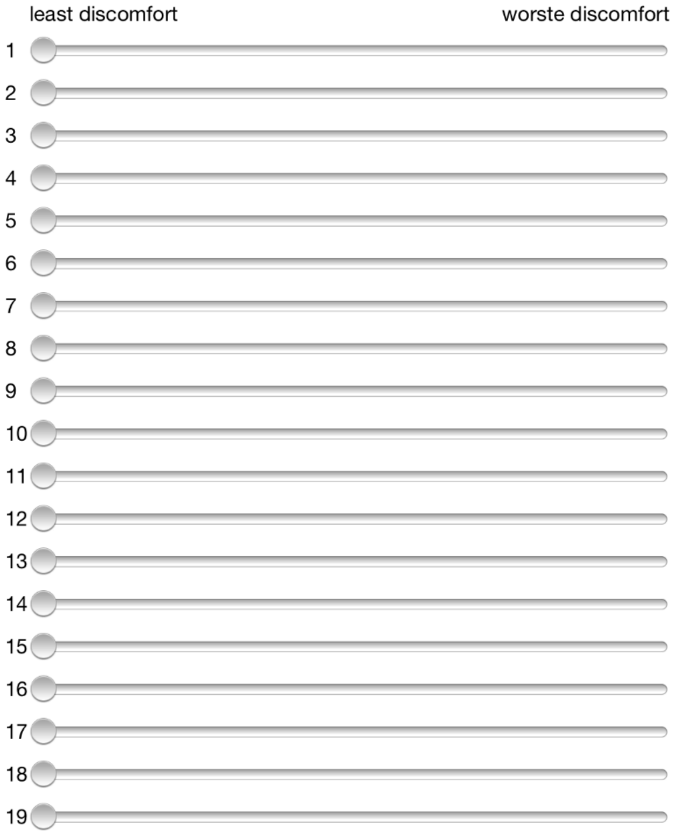
Appendix A. 1: Visual Analogue Scale for Rating of Perceived Discomfort





Appendix A. 2: Modified Borg Ratings of Perceived Exertion Scale (CR-10)

0 Nothing at all

0.5 Very, very weak (just noticeable)

1 Very weak

2 Weak (light)

3 Moderate

4 Somewhat strong

5 Strong (heavy)

6

7 Very strong

8

9

10 Very, very strong (almost maximal)

* Maximal

Appendix B. 1: The following figures display correlations between non-obese and obese groups for each isometric joint and maximal functional strength test for absolute and normalized values. Each figure displays the peak of each strength test and the line of best fit.

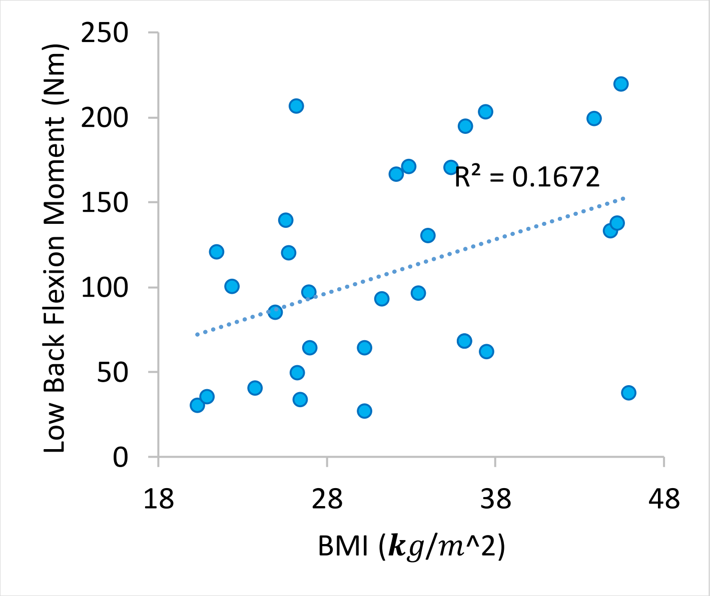


Figure B. 1: Isometric Joint Strength – LB flexion moment and BMI (kg/m^2) Correlations

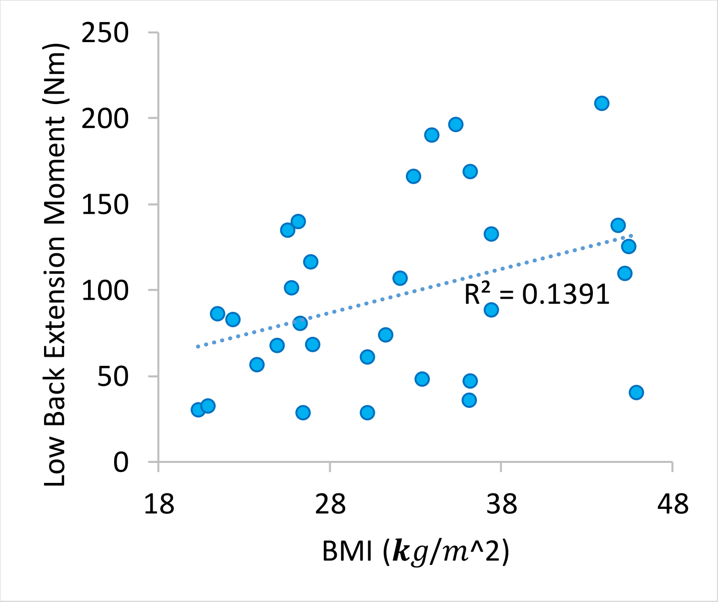


Figure B. 2: Isometric Joint Strength – LB extension moment and BMI (kg/m^2) Correlations

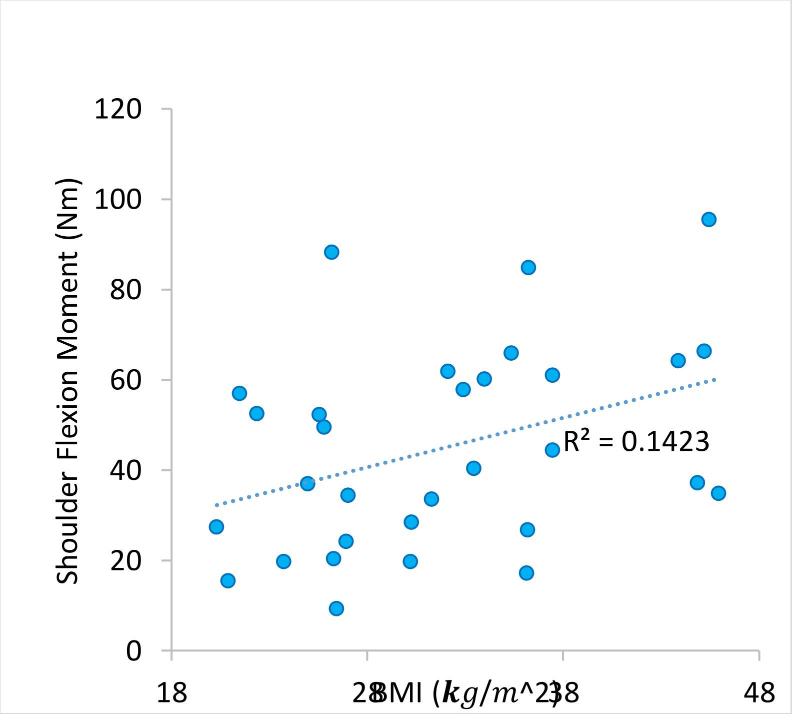


Figure B. 3: Isometric Joint Strength – Shoulder Flexion moment and BMI ($\boldsymbol{k}g/m$^2) Correlations

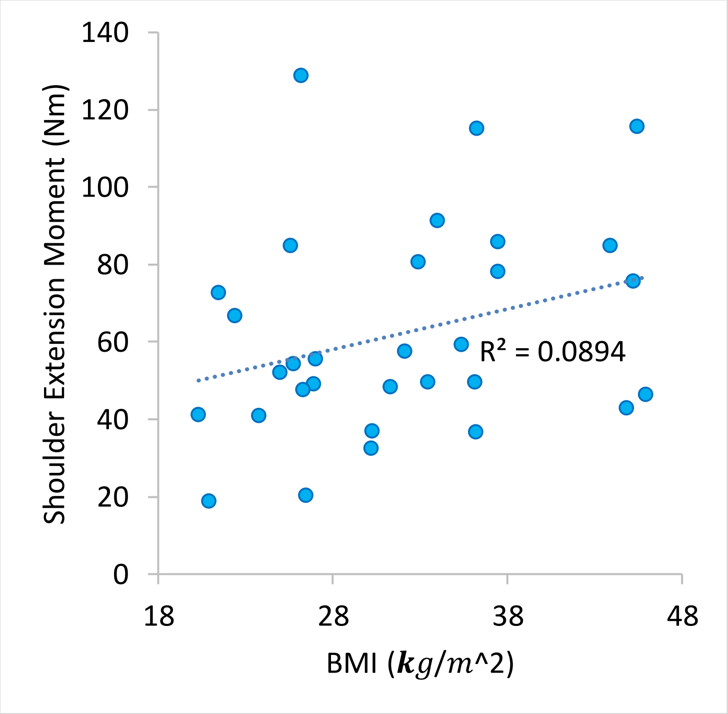


Figure B. 4: Isometric Joint Strength – Shoulder Extension moment and BMI ($\boldsymbol{k}g/m$^2) Correlations

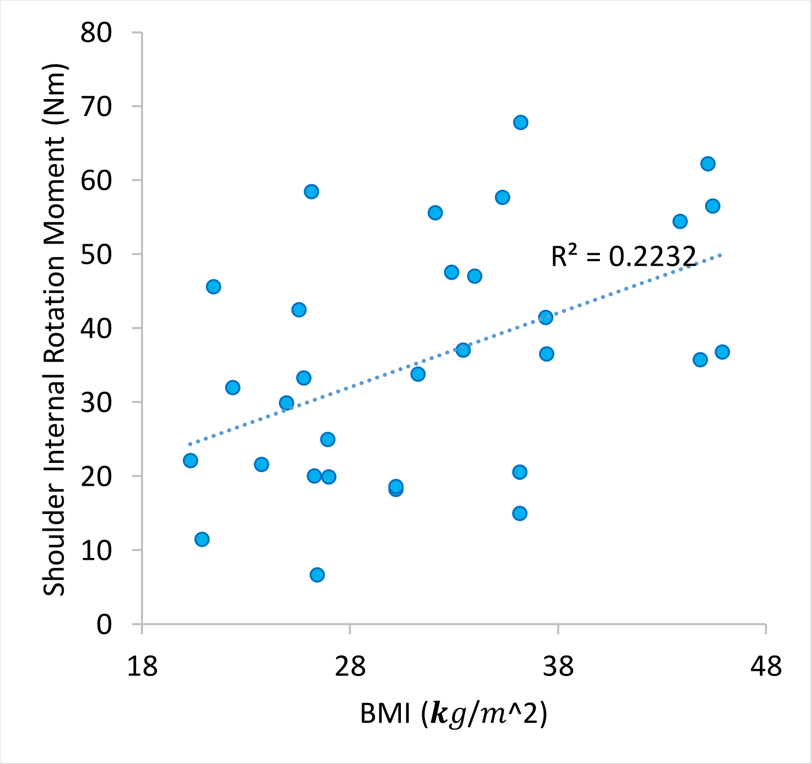


Figure B. 5: Isometric Joint Strength – Shoulder Internal Rotation moment and BMI ($\boldsymbol{k}g/m$^2) Correlations

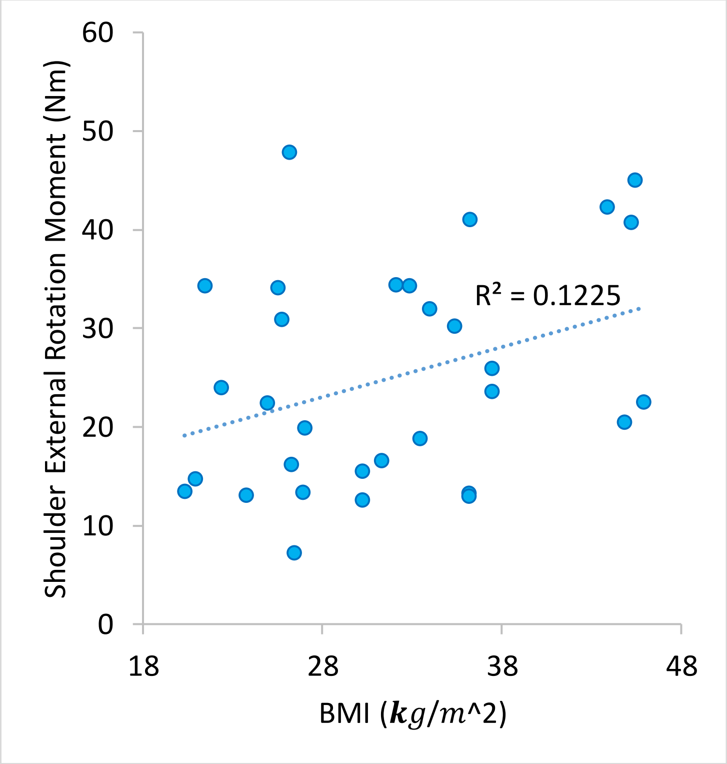


Figure B. 6: Isometric Joint Strength – Shoulder External Rotation moment and BMI ($\boldsymbol{k}g/m$^2) Correlations

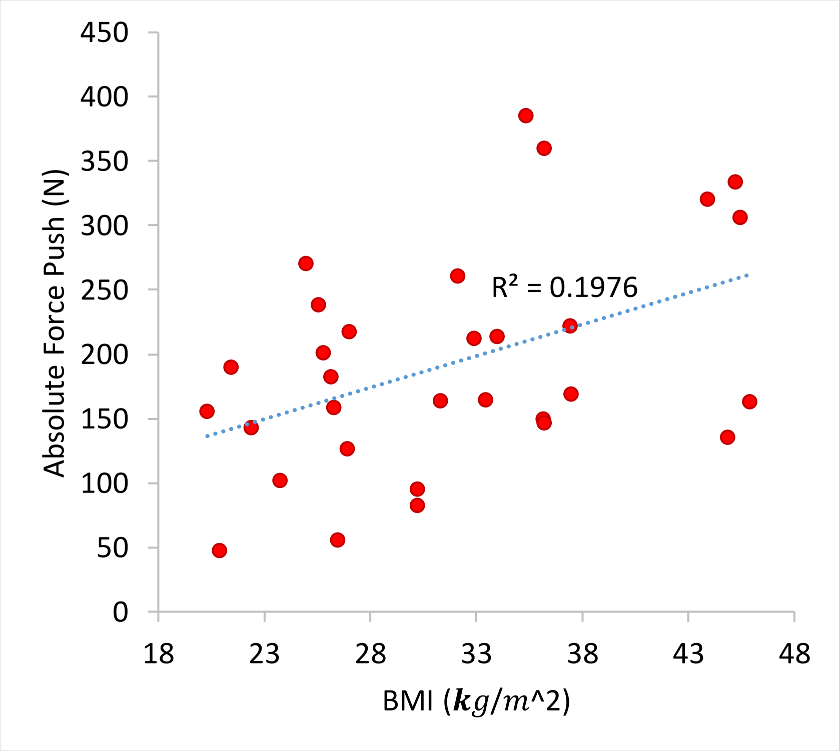


Figure B. 7: Absolute Maximal Functional Strength Tests – Push and BMI ($\boldsymbol{k}g/m$^2) Correlations

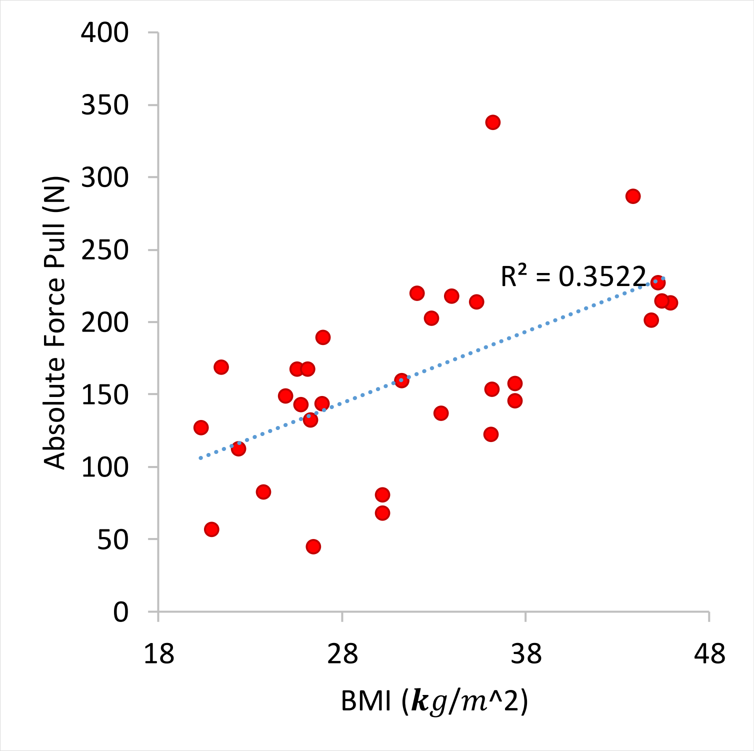


Figure B. 8: Absolute Maximal Functional Strength Tests – Pull and BMI ($\boldsymbol{k}g/m$^2) Correlations

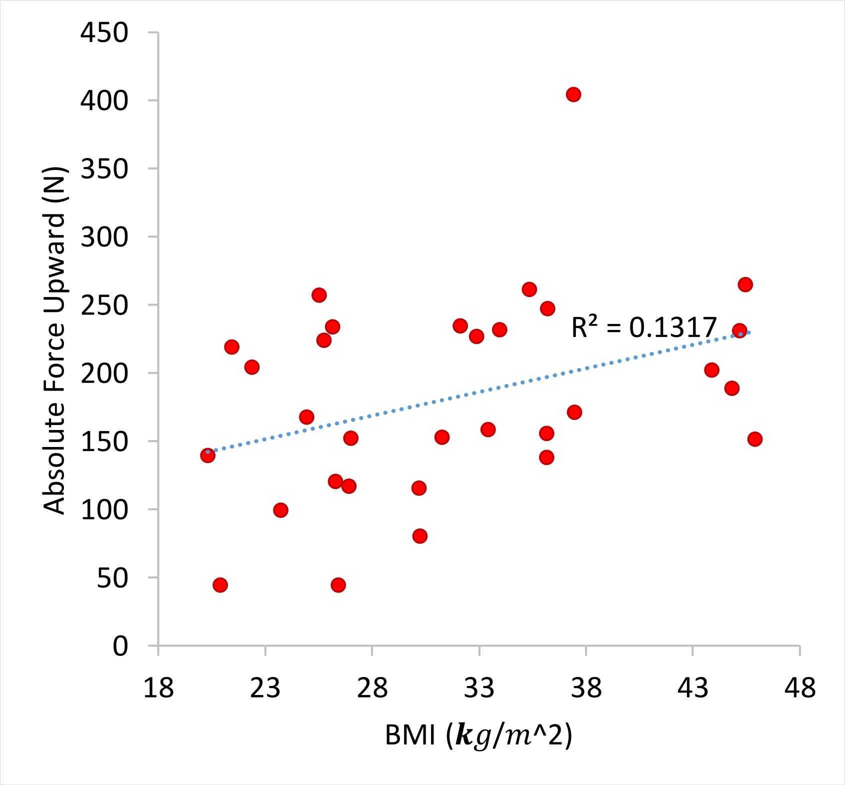


Figure B. 9: Absolute Maximal Functional Strength Tests – Upward and BMI ($\boldsymbol{k}g/m$^2) Correlation

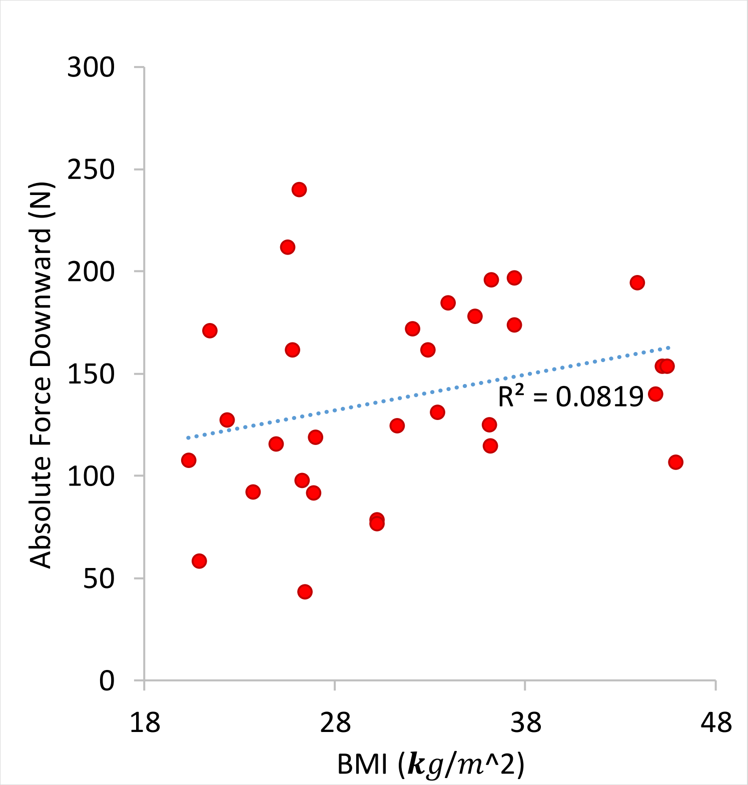


Figure B. 10: Absolute Maximal Functional Strength Tests – Downward and BMI ($\boldsymbol{k}g/m$^2) Correlations

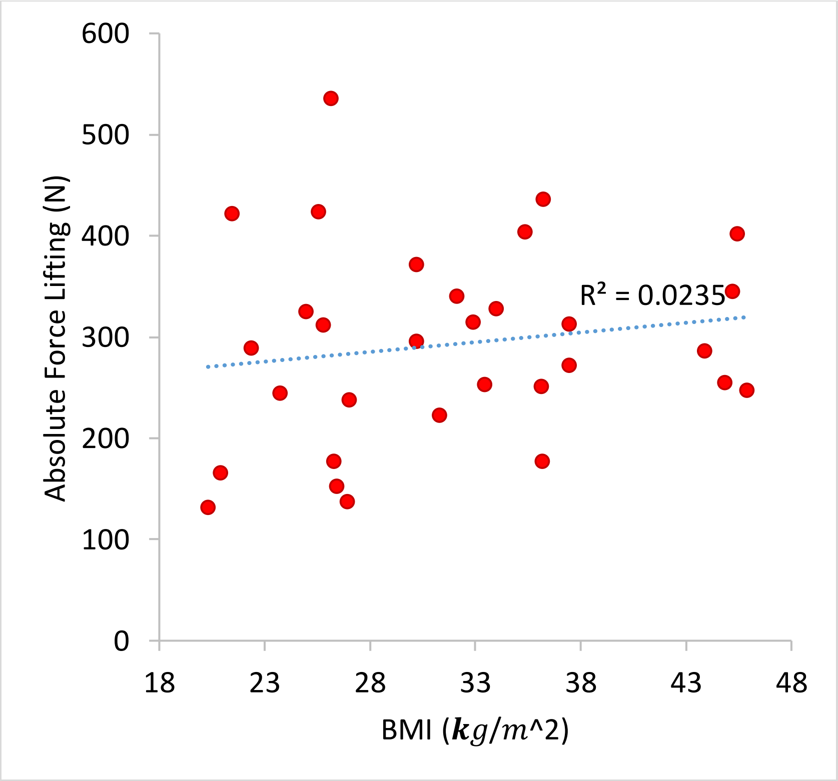


Figure B. 11: Absolute Maximal Functional Strength Tests – Lifting and BMI ($\boldsymbol{k}g/m$^2) Correlations

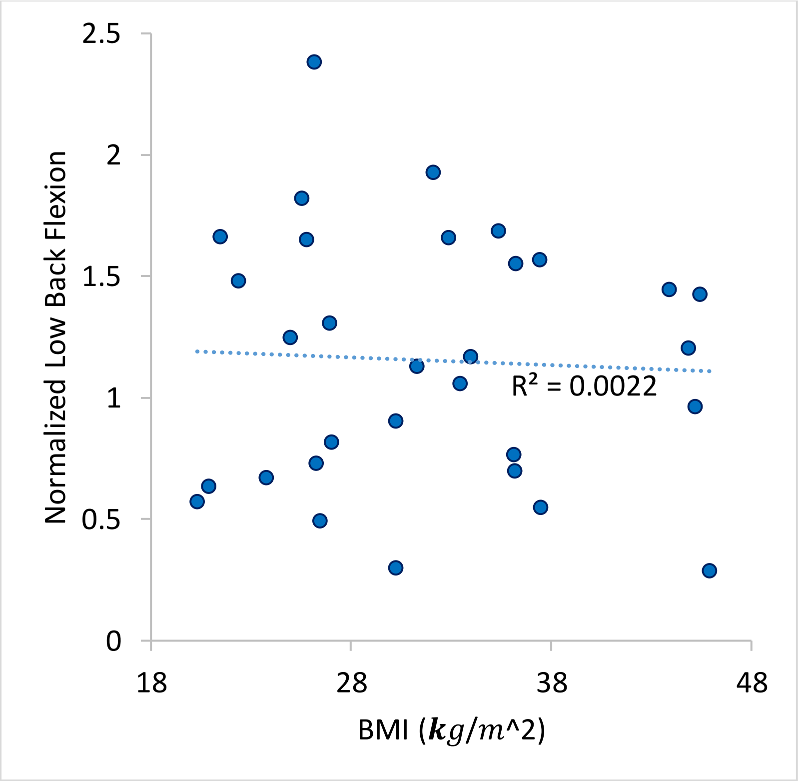


Figure B. 12: Normalized Isometric Joint Strength Tests – Low back flexion and BMI ($\boldsymbol{k}g/m$^2) Correlations

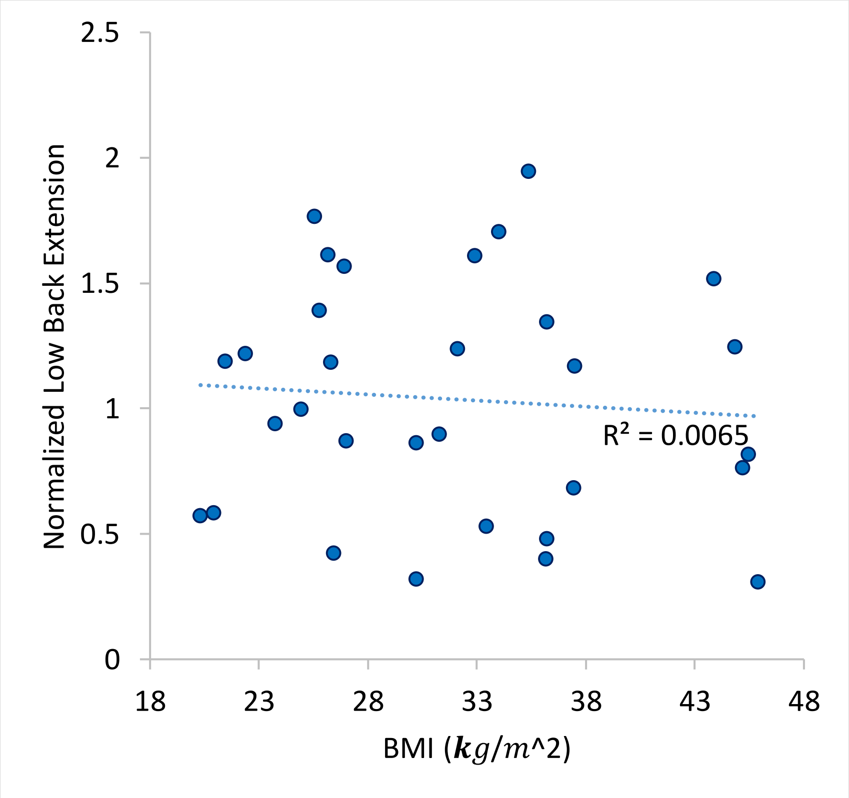


Figure B. 13: Normalized Isometric Joint Strength Tests – Low back Extension and BMI ($\boldsymbol{k}g/m$^2) Correlations

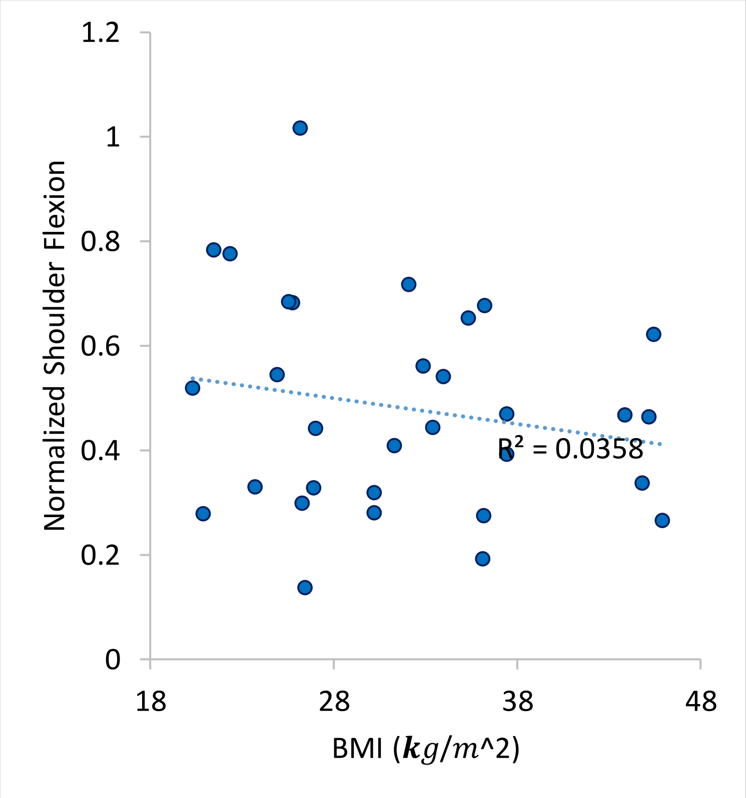
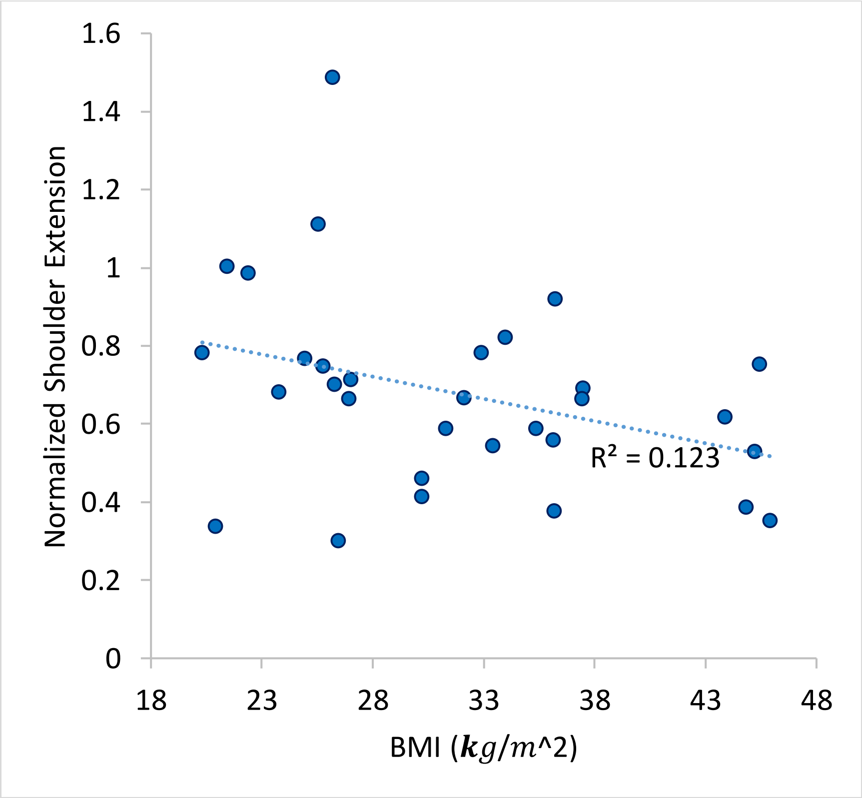


Figure B. 14: Normalized Isometric Joint Strength Tests – Shoulder flexion and BMI ($\boldsymbol{k}g/m$^2) Correlations



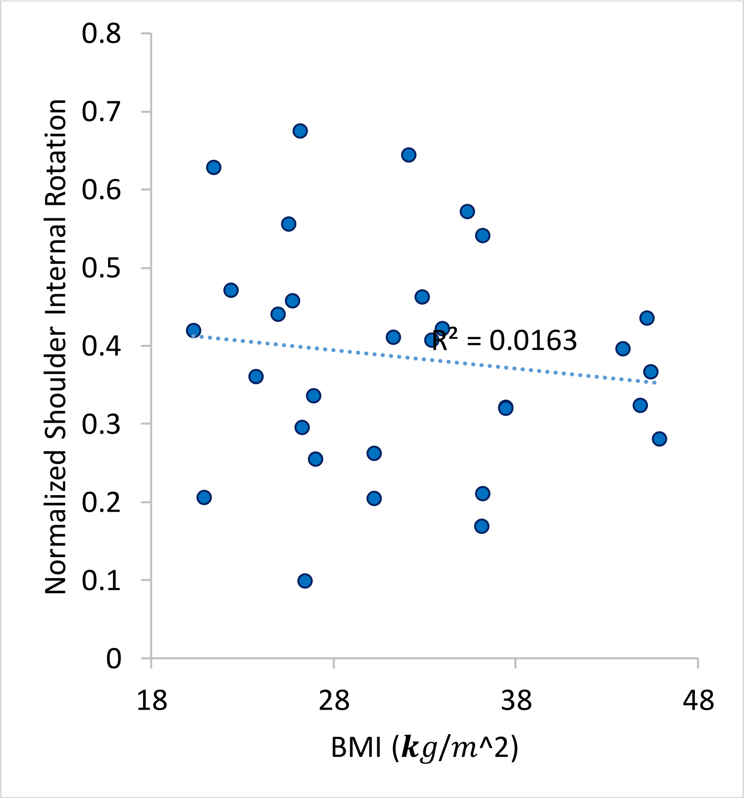


Figure B. 15: Normalized Isometric Joint Strength Tests – Shoulder extension and BMI ($\boldsymbol{k}g/m$^2) Correlations

Figure B. 16: Normalized Isometric Joint Strength Tests – Shoulder internal rotation and BMI ($\boldsymbol{k}g/m$^2) Correlations

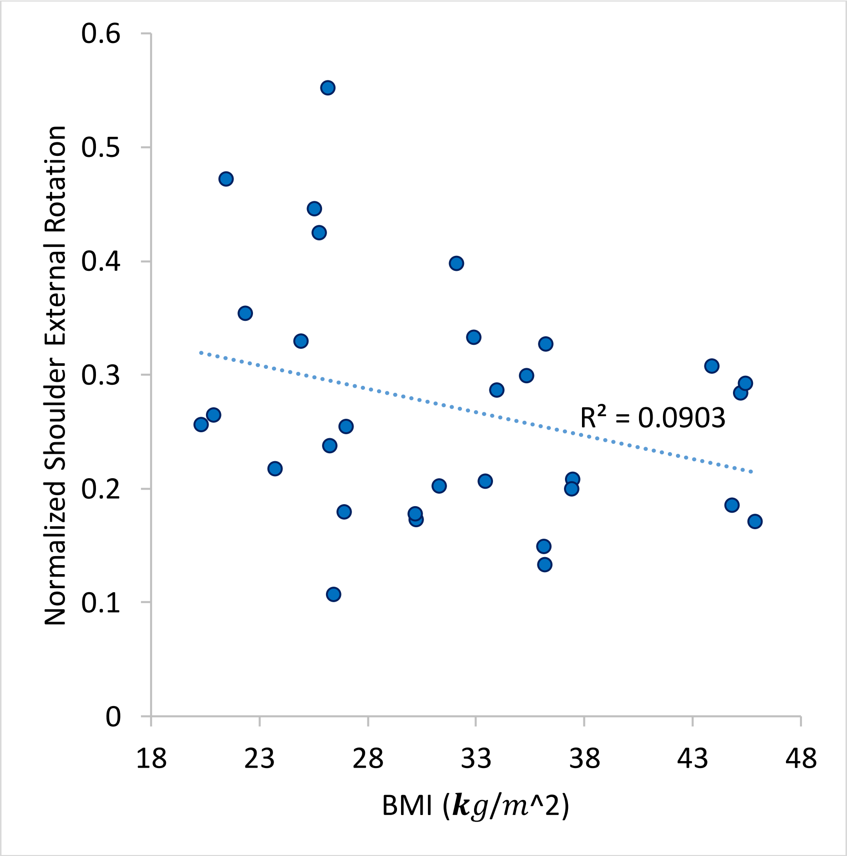


Figure B. 17: Normalized Isometric Joint Strength Tests – Shoulder External rotation and BMI ($\boldsymbol{kg}/m$^2) Correlations

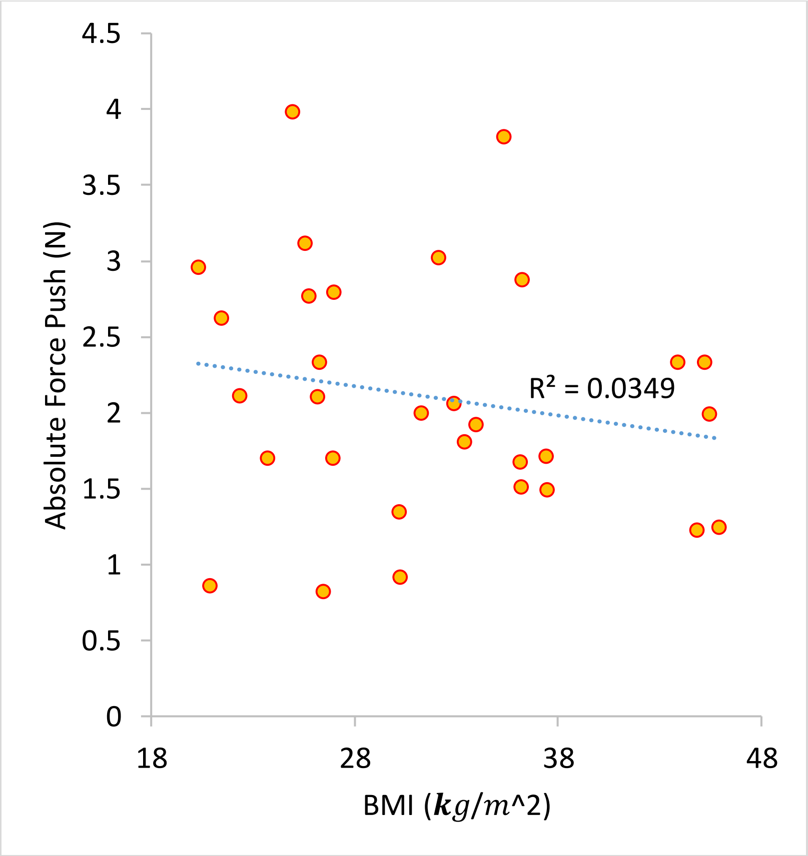


Figure B. 18: Normalized Maximal Functional Strength Tests – Push and BMI ($\boldsymbol{kg}/m$^2) Correlations

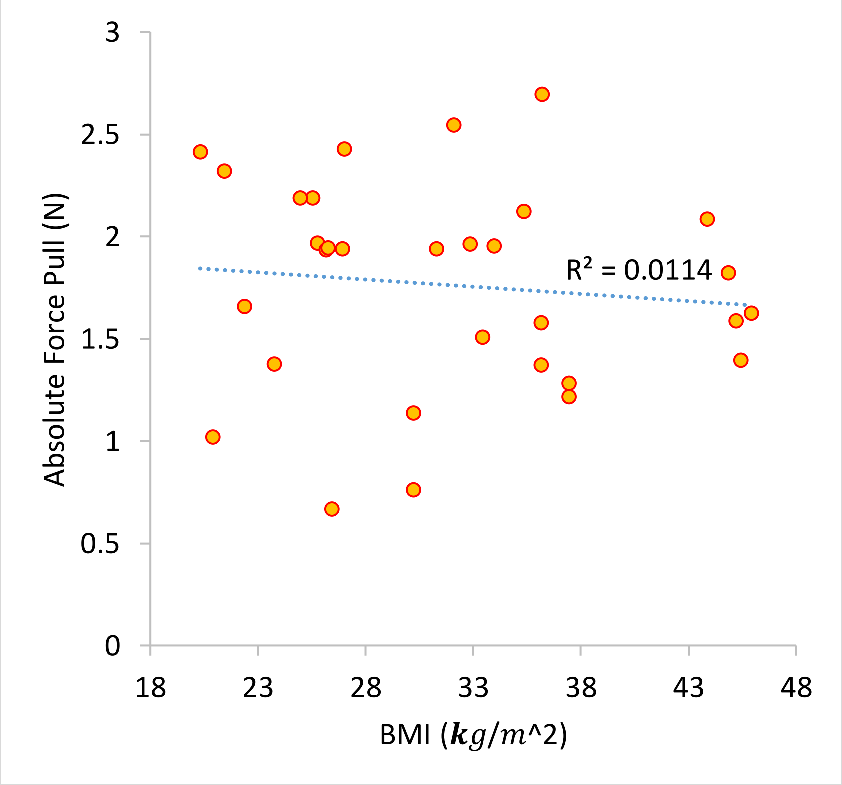


Figure B. 19: Normalized Maximal Functional Strength Tests – Pull and BMI ($\boldsymbol{k}g/m$^2) Correlations

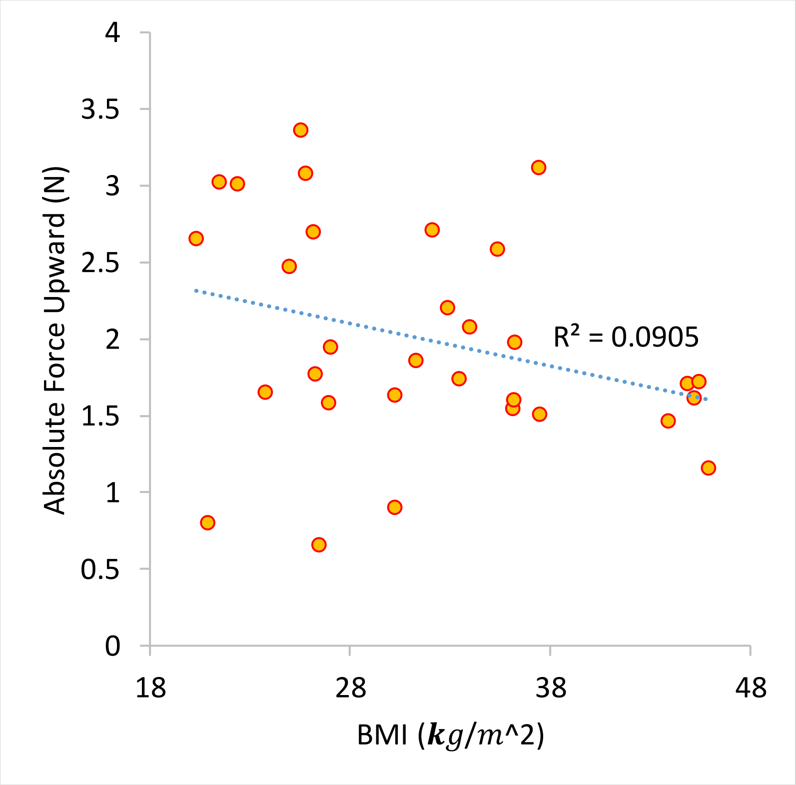


Figure B. 20: Normalized Maximal Functional Strength Tests – Upward and BMI ($\boldsymbol{k}g/m$^2) Correlations

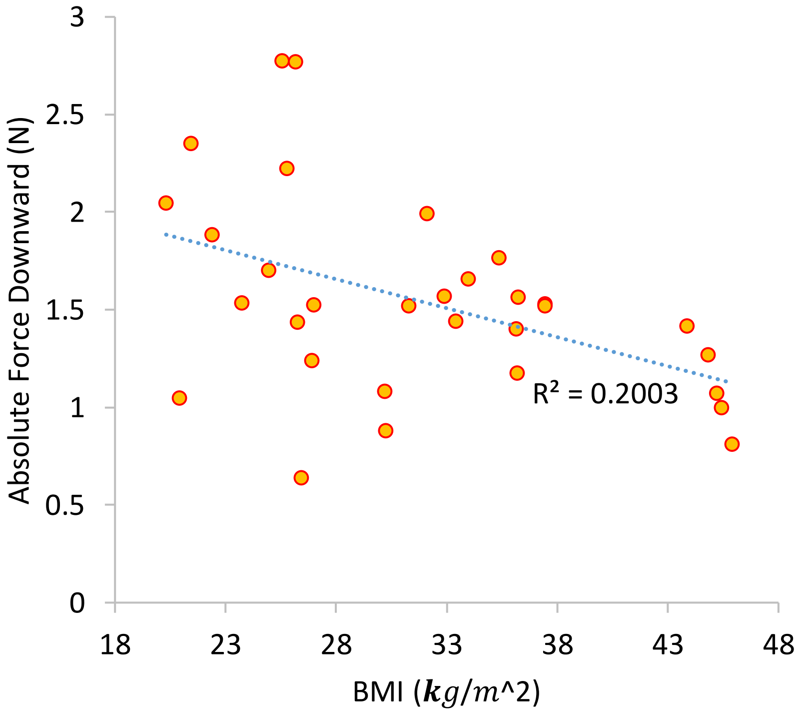


Figure B. 21: Normalized Maximal Functional Strength Tests – Downward and BMI (kg/m^2) Correlations

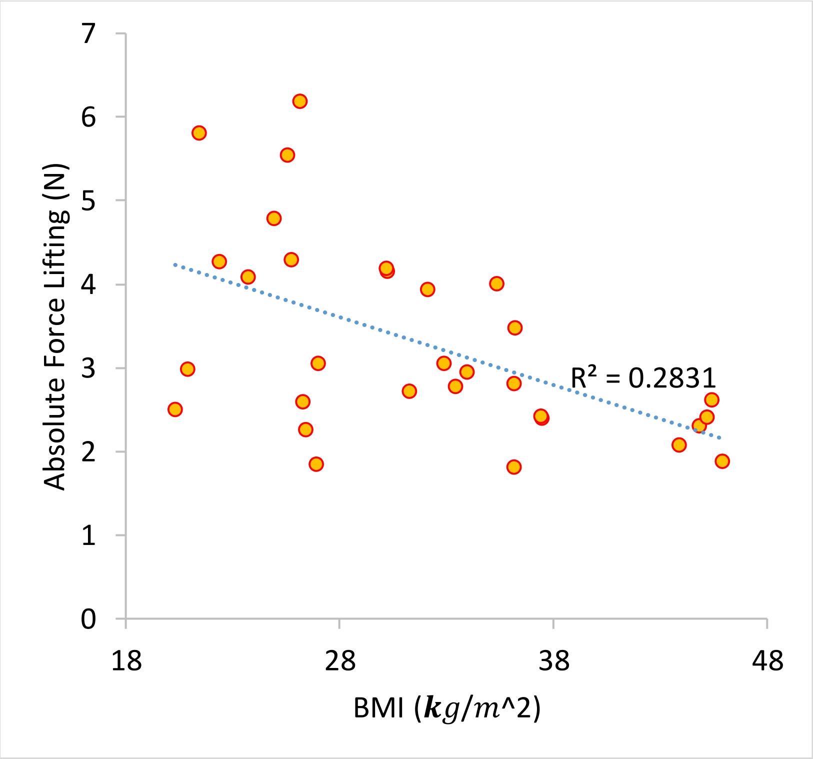


Figure B. 22: Normalized Maximal Functional Strength Tests – Lifting and BMI (kg/m^2) Correlation