ABSTRACT

XU, XU. The Effect of Obesity on Trunk Kinematics and Ground Reaction Forces during Lifting. (Under the direction of Dr. Gary A. Mirka and Dr. Simon M. Hsiang.)

The prevalence of obesity is increasing worldwide. In fact, in the United States, obesity has been recognized as an epidemic. Obesity has been shown to increase the risk of physical injury and illness. Among these physical disorders, low back pain (LBP) is one of the most common phenomena in both obese and non-obese individuals. However, the relationship between obesity and LBP is not fully developed and the causal link between them is insufficient. The objective of this research was to evaluate the differences between people of normal weight and obese people in measures of trunk kinematics and ground reaction force during a lifting task. The main hypothesis of this study was that obese people would have a higher mean value and a higher variability of these measures than of normal weight people.

Two subjects groups were used in this research and each group had six subjects. Group I is the normal weight subject group (BMI<25), and Group II is the obese subject group (BMI>30). In the experiment, the subjects were asked to perform a lifting task under two levels of load (10% and 25% of maximum lifting capacity) and two levels of starting asymmetric angle (0° and 45°). The Lumbar Motion Monitor was used to collect the trunk kinematics data and two force plates were used to collect the ground reaction force and moment data. To test the variability, Modified Levene’s test was employed. MANOVA and ANOVA were used to assess the effects of BMI, load, and angle on these measures. The results showed that BMI is a significant effect for mean value on several kinematics parameters. From BMI<25 to BMI>30, the rotational velocity increased by 59.2%; the rotational acceleration increased by 57.6%; the sagittal velocity increased by 30.4%; sagittal
acceleration increased by 50.5% (all statistically significant at the p<0.05 level). However, the results did not support the hypothesis that BMI would affect variability in these measures.

This study provides quantitative data describing lifting task performance for obese people, and has shown that obese people have higher sagittal velocity, sagittal acceleration, rotational velocity, and rotational acceleration during lifting task, which may lead to higher forces on spine, compared to people with normal weight. The results indicated that the regular safety evaluation of lifting job based on normal people may not be appropriate for obese people since they have different lifting pattern, which may increase the risk of injury. The data presented in this work are particularly important as the general workforce continues to get heavier and heavier.
The Effect of Obesity on Trunk Kinematics and Ground Reaction Forces during Lifting

by

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BIOGRAPHY

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1 Introduction

1.1 Ergonomics

Ergonomics is a branch of science and engineering that is concerned with the achievement of optimal relationships between workers and their work environment, with the goal of designing the job environment to fit people. Ergonomists assess the human capabilities and limitations (physical and cognitive) and then attempt to develop work environments that do not exceed these limitations. Many disciplines could contribute to the development of ergonomics including industrial engineers, industrial psychologists, occupational medicine physicians, industrial hygienists, and safety engineers.

There are three main domains within the broad discipline of ergonomics: organizational ergonomics, cognitive ergonomics, and physical ergonomics. Organizational ergonomics is the study of the optimization of the organization and process of social systems. Cognitive ergonomics is the study of human behavior and attributes such as decision-making processes and human perception. Physical ergonomics is the study of physical aspects of the workplace and human biomechanical/physiological capabilities. The current research focuses on this area of physical ergonomics.

1.2 Physical Ergonomics and Low Back Pain (LBP)

Physical ergonomics is concerned with human anatomical, anthropometric, physiological and biomechanical characteristics. Physical ergonomics principles can be applied in virtually any work environment. In the study of physical ergonomics, musculoskeletal disorders (MSDs) are a major issue due to the high cost of workers’
compensation and lost work days. In 2002, there were 1.4 million cases of occupational injuries and illnesses categorized as musculoskeletal injuries, and about 76% were related to trunk and upper extremities. Back disorders account for 27% of all nonfatal occupational injuries and illnesses in the days away from work (BLS 2002). The estimated cost of MSDs was about 13 billion in 1996, and low back pain (LBP) cost about $8000 for each case in 1989 (Bernard 1997).

Low back pain is a frequent phenomenon found in many occupational categories. Lifetime prevalence has been estimated at about 70% (Andersson 1981). It is one of the most costly problems of modern society, with an estimated cost of $8.8 billion in the U.S. in 1995 (Murphy and Volinn 1999). It is also known that back pain affects 65% of the population in Switzerland annually (Jeanneret, Frey et al. 1998). People of all ages are affected by back pain, but it generally begins between the ages of 20 – 40, and the prevalence peak between the age of 45 – 60 years, with a slight difference between male and female (Lee, Kratter et al. 2005). Most low back pain results from muscle or ligament strain which generally last from a few days to a few weeks. However, damage or injury to spinal nerves or vertebral discs also results low back pain which may persist more than 3 months and is considered chronic. Although a large number of studies and reviews have focused on the cause of low back pain, the factors leading to the complex burden of disease remain unclear (Lee, Kratter et al. 2005).

1.2.1 Anatomy of the Low Back / Spine and Low Back Disorders

The spine is a flexible column of irregular bones known as vertebrae. It is the axial support of the body and extends from the skull to its anchoring point in the pelvis, where it transmits the weight of upper body to the lower limbs. The spinal cord is protected by the vertebral column and runs through the spinal canal. The spinal cord conveys the 31 spinal
nerve pairs of the peripheral nervous system, as well as the central nervous system pathway that controls the movement and function of the body. Motor nerves of the spinal cord are responsible for controlling movement while sensory nerves entering into the spinal cord are responsible for communicating sensory information from the periphery to the brain. Intervertebral discs are located between adjacent vertebrae and are composed of an inner semifluid nucleus pulposus, which gives the disc elasticity and compressibility, and a rigid outer ring of the annulus fibrosus, which contains the nucleus pulposus and limits its expansion. The intervertebral discs absorb shock during body movement and limit the motion of the vertebra. On the surface of the spine, seven processes project from the vertebral arch. The spinous process is a posterior projection arising at the junction of the two laminae. The transverse processes are on the lateral aspects of the vertebral arch. The attachment sites for muscles and the ligaments are on both spinous process and transverse processes. The ligaments link the vertebrae to stabilize the vertebral column and the muscles move the vertebral column. The muscles, tendons, and ligaments could handle the external force put on the spine during the movement (Marieb 1989).

Two common causes of low back pain are muscle strain and lumbar sprain. Muscle strain is an injury to either muscle or tendon and can result from twisting or overstretching the back muscles or tendons. A long-time repetitive movement of the muscles may result the chronic strain (Bernard 1997). Lumbar sprain is a ligamentous injury that occurs when the ligaments are stretched beyond the normal range, or contracted suddenly. Usually, the symptoms of muscle strains and lumbar sprain are similar and can be difficult to differentiate. In addition to muscle strains and lumbar sprains, damage to spinal discs is another cause of low back pain. A herniated or slipped disc can result from severe or sudden physical trauma
to the spine and involves rupture of the annulus fibrosus and the protrusion of nucleus pulposus. When the protrusion presses on or irritate the spinal cord or the nerve root, pain and numbness can result. Another common disorder is disc degeneration, a.k.a. spine osteoarthritis. As the discs in the spine dehydrate, they lose their ability to absorb the shock. The bone and ligament contained in the spine also become less flexible and thicken. Degeneration of discs is normal, but it can be very painful when the spurs of discs or bone begin to pinch and press on the nearby nerve roots or spinal cord. In addition, internal disc disruption within the structure of the disc can result in back pain and even lower limb pain without the presence of spinal nerve root compression (Marieb 1989).

1.2.2 Physical Risk Factors

There have been many studies investigating the relationship between workplace factors and LPB. The principal factors include heavy physical work, lifting and forceful movements, bending and twisting/awkward posture, whole body vibration, and static work postures (Bernard 1997).

Heavy physical work is defined as work which has high energy demands or that requires some measure of physical strength (Bernard 1997). A number of studies have shown that LBP are associated with heavy physical work (Leigh and Sheetz 1989; Burdorf and Zondervan 1990; Heliovaara, Makela et al. 1991). However, Bernard (1997) states that exposures were assessed subjectively for the most part of the problem and that may lead to the misclassification of exposure status and an incorrect estimate of risk. Thus, Bernard believes that some of the study on heavy work load appeared to implicitly include other work-related physical factors such as awkward postures.
Some previous studies (Punnett, Fine et al. 1991; Marras, Lavender et al. 1995) have shown that low-back disorder is associated with work-related lifting and forceful movements. Punnett et al. (1991) studied the relationship between back pain and occupational exposures in auto assembly workers and found that lifting was associated with back disorder. Marras (1995) investigated the relationship between LBP and spinal loading during occupational lifting. The result demonstrated that the maximum moment was significantly different between low- and high-risk groups. Awkward trunk postures means that the torso deviates significantly from the neutral upright position. This can occur in the form of deviation in the sagittal plane (flexion), deviation in the coronal plane (lateral flexion), or deviation in the transverse plane (twisting). Awkward posture was found to be an important factor in the development of low back pain (Bernard 1997). Punnett et al. (1991) investigated the relationship between back pain and occupational exposures in auto assembly jobs and the result showed that time in non-neutral postures of mild or severe flexion and bending were strongly associated with LBP. After these researchers examined medical reports, they realized that such association was more pronounced. Holmstrom et al. (Holmstrom, Lindell et al. 1992) studied the relationship between low back pain and work task activities by a cross-sectional study of male construction worker. As a result, stooping and kneeling postures showed a dose-response relationship with LBP.

Whole body vibration is mechanical energy oscillations which are transferred to the body through a supporting system such as seat or platform. Bovenzi et al. (Bovenzi and Zadini 1992) used a cross-sectional study to investigate how vibration influenced bus drivers while maintenance employees were referred as referents. They stated that increased exposure level leads to a statistically significant increase in LBP. On the other hand, Boshuizen et al.
(Boshuizen, Bongers et al. 1992) stated that there is no association between total vibration dose and back pain. Bernard (1997) stated that whole body vibration may cause increased risk of LBP in conjunction with other work-related factors such as awkward posture.

An isometric position with very little movement and static loading on the muscles is called static work posture. Kelsey (Kelsey 1975) reported that sedentary work (sitting more than half the time at work) was associated with disc herniation for the age group 35 years and older. He also mentioned that disc herniation was associated with the truck drivers who spent much time sitting while working. Videman et al. (Videman, Nurminen et al. 1990) found that those with sedentary and heavy work had increased risk of symmetric disc degeneration and facet joint osteoarthrosis. However, the strength of association between static work postures and LBP is not easy to estimate since large proportion of estimates did not differ significantly (Bernard 1997).

1.2.3 Personal Risk Factors

In addition to workplace factors, some personal risk factors such as smoking, gender, and age have also been found to be related to LBP. In the review of smoking and back pain, Goldberg (Goldberg, Scott et al. 2000) stated that most epidemiologic articles investigating the possible link between smoking and nonspecific back pain consistently reported that smoking is strongly associated with low back pain. Several plausible biological mechanisms have been used to explain this phenomenon, such as the fact that smoking increases coughing, which increases intra-discal and intra-abdominal pressure, thus promoting herniation; smoking diminished the mineral material in the bone, resulting in osteoporosis of vertebral bodies; or smoking reduces blood flow and the metabolic balance of the discs, thus increasing the degenerative speed. However, Goldberg also mentioned that the causality
between smoking and LBP was not clear, since back pain may lead to increased levels of smoking.

Age is another factor related to the low back pain. It has been well known that aging can lead to a decrease in physical capability. As people age, their muscle strength decreases gradually, and their ability to maintain their balance declines (Wright and Mital 1999; Okada, Hirakawa et al. 2001). A decrease in muscle strength can lead to an increase in lifting injuries, as well as slips and falls, while a decline in postural control is an important factor in the fall-related injuries of the elderly. In the research conducted by Gilgil et al. (Gilgil, Kacar et al. 2005), the relationship between socio-economic-cultural factors and low back pain was investigated. The result showed that LBP sufferers were more likely to be older, in comparison with non-sufferers. Therefore, older individuals need to be very careful during locomotion.

1.3 Body Mass Index (BMI)

Another potential personal risk factor for low back pain is related to the individual’s whole body mass. BMI stands for Body Mass Index and indicates weight status in adults. It is calculated as body weight in kilograms divided by the square of stature in meters. Thus, BMI is a measure of the weight of a person scaled according to height and is used to assess how much the body weight departs from the normal level for a person of that stature. The BMI for human bodies ranks from 15 (starvation) to 40 (morbidly obese). In general, for adults aged 20 years or older, BMI falls into these categories: underweight, normal, overweight, or obese. And there are three classes in the category of obesity (Table 1).
### Table 1 Body Mass Index

<table>
<thead>
<tr>
<th>BMI</th>
<th>Weight Status</th>
<th>Obesity Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below 18.5</td>
<td>Underweight</td>
<td></td>
</tr>
<tr>
<td>18.5-24.9</td>
<td>Normal</td>
<td></td>
</tr>
<tr>
<td>25.0-29.9</td>
<td>Overweight</td>
<td></td>
</tr>
<tr>
<td>30.0-34.9</td>
<td>Obese</td>
<td>I</td>
</tr>
<tr>
<td>35.0-39.9</td>
<td>Obese</td>
<td>II</td>
</tr>
<tr>
<td>40 and Above</td>
<td>Morbid Obesity</td>
<td>III</td>
</tr>
</tbody>
</table>

#### 1.3.1 Increased Body Mass Index of People in the Workforce

Currently, the prevalence of obesity is increasing at a high rate worldwide in both developed and developing countries (Laitinen, Nayha et al. 2005). In the United States, obesity has been recognized as one kind of epidemic, and the numbers of overweight and obese adults and children are growing (Wellman and Friedberg 2002). The rapid rise of obesity rates started in the 1980’s. Between 1960 and 1980, obesity rates increased from 12 percent to 15 percent. In the past two decades, obesity rates have doubled (Finkelstein, Ruhm et al. 2005). National Center for Health Statistics stated that about 65 percent of U.S. adults were either overweight or obese in 2002 and the obesity rate increased from 15 percent in 1980 to 31 percent in 2002.

Historically, the majority of the population was more likely to suffer from being underweight than overweight and increased body weight was associated with an affluent condition. However this point of view has changed since obesity became an epidemic phenomenon in the latter part of the twentieth century. Increased body weight resulted from a surplus of consumed calories compared to calories expended (Finkelstein, Ruhm et al. 2005). Philipson (Philipson and Posner 2003) states that technological changes are responsible for obesity largely because of the effect of reducing energy expenditure in the workplace. The number of workers employed in goods-producing industries fell from 35% in 1960 to 27% in
1980. In 2000, this fraction fell to 19%. On the other hand, there was an observed trend in energy intake during this time period. The Centers for Disease Control and Prevention (CDC 2004) indicated that caloric consumption remained basically unchanged between 1971 – 1974 and 1976 – 1980, while the consumption increased 7.3% (179 calories per day) for men and 23.3% (355 calories per day) for women between 1976 – 1980 and 1999 – 2000. Putnum (Putnum and Allshouse 1999) also reports that from 1910 to 1985, energy intake remained roughly constant until it rose by about 12% between 1985 and 2000 primarily because of increased consumption of carbohydrates, such as grains, sugars and fats. The CDC (CDC 2004) reported that in 1976 – 1980 adult men and women aged 20 – 74 years consumed 1039 and 700 kcal of carbohydrates. In 1999-2000, the consumption increased to 1283 and 969 kcal. Soft drinks have also contributed to increased calories intake. In 1997, the average American consumed 53 gallons of soft drinks and 17 gallons of fruit juices per year, an increase of 51% and 40%, respectively, since 1980 (Putnum, Allshouse et al. 2003). According to Cutler (Cutler, Glaeser et al. 2003), higher snack calories are responsible for almost all of the rise in energy intake between 1977 – 1978 and 1994 – 1996.

Finkelstein believes that reductions in the price of high-energy food along with an increased prevalence of marginal cost pricing led to both an increase in food consumption at each meal and increased consumption between meals (Finkelstein, Ruhm et al. 2005). Nielsen and Popkin (Nielsen and Popkin 2003) state that growth in portion sizes for the majority of foods increased over time including French fries and sweetened beverages. Serving size began to increase in 1970s and continued to increase in the 1980s and 1990s while obesity rates rose. In the United States, serving sizes are larger than those in Europe. A rise in wages might be another reason for increased obesity rate, because it allows for an
increase in the consumption of foods at restaurants where food usually contains more calories than home-cooked meals. From the investigation (Lakdawalla, Philipson et al. 2005), there is no significant effect of wages on men’s weight. However higher wages are associated with lower weight in women. Finkelstein (Finkelstein, Ruhm et al. 2005) also reports that television contributes to the obesity epidemic because there is a link between viewing television and an increase in serving size and the percentage calories from fat consumed while watching television. Children are exposed to about 10 food commercials per hour, most for fast food, soft drinks and sugar-sweetened cereals which may increase body weight by a significant amount.

In the U.S. workforce, Hertz et al. (Hertz, Unger et al. 2004) state that the prevalence of normal weight has significantly decreased between 1988 – 1994 and 1999 – 2000. The obesity rate for men increased from 19.0% to 26.1%, and the obesity rate for women increased from 22.2% to 33.3%. The obesity rate also increased as age increased: 26.9% of workers aged 20 – 39; 31.9% of workers aged 40 – 59; and 34% of worker aged older than 60 had a BMI greater than 30 kg/m². From 1988 to 2000, the rate of obesity increased more than 50% among both younger and older workers and about 25% among middle-aged workers. At present overweight or obese worker account for 59.2%, 67.5% and 77.0% of younger, middle-aged and older workers, respectively. Obese workers are significantly more likely than normal-weight workers to report they are limited in some types of work because of physical, mental, or emotional problems. Among both men and women, work limitations of those who were classified as obese people were significantly higher than those who are overweight. These authors also state that the workforce limitations rate of younger obese workers is similar to the rate of middle-aged normal-weight workers (4.1% vs. 3.6%), and the
work limitation rate of middle-aged obese workers is similar to the rate of older normal-weight workers (8.0% vs. 8.4%). Hertz et al. also concludes that obesity is on the rise among members of the workforce. The increase in obesity rate of workforce was 9.0% from 1988 to 2000, which is slightly more than the 7.6% change for the total adult population.

1.3.2 The Relationship between Body Mass Index (BMI) and LBP

The spine is used to support the body weight and external load; when excess weight is carried, the spine may undergo structural damage due to high force and high moment on the vertebra and vertebral disc. As a result obesity may make the spine more vulnerable to low back pain since obese people have high body weight. In addition, the lack of exercise among obese people could lead to poor flexibility and weak back muscles, which may induce back injury by the decreased postural control. Therefore, obesity is a potential factor of low back pain. However, the current research only showed a weak relationship between them.

Leboeuf-Yde (Leboeuf-Yde 2000) did a systematic literature review of 56 journal articles to investigate the relationship between body weight and low back pain. From his review, in 21 (32%) of the 65 articles there was statistically significant positive association between weight or relative weight and LBP. A total of 111 LBP variables had been used in these 65 studies and 25 variables of these were positively associated with weight or relative weight. The author concluded that there is not enough evidence to determine whether there was a causal relationship between body weight and LBP.

Kostova et al. (Kostova and Koleva 2001) conducted a cross-sectional study investigating the effect of some risks factors on back disorders, including impact of obesity. This study examined 898 workers and employees who were divided into different groups according to their occupation and their basic personal characteristics. After calculating the
BMI in different groups, researchers found a statistically significant link between obesity and LBP. Obesity and back disorders in men and women over 40 exhibited a similar trend. Their results also showed believed the risk for developing LBP and back problems due to obesity may be even more significant in elderly men who tend to gain weight as aged. The authors also mentioned that although a positive relationship between excess body weight and risk for back disorders was shown in many studies, the causality between them was still not clear.

Marcus (Marcus 2004) conducted a study that investigated the link between obesity and the impact of chronic pain. In their investigation, patients were asked to provide and average pain severity score from 0 (no pain) to 10 (excruciating). And subjects were divided into 3 weight categories: normal, overweight, and obese. From the patient demographics, back pain accounted for 20.4% of primary pain in the normal category, 24.8% in the overweight category, and 25.4% in the obese category. This data showed there was an increasing trend of back pain as the primary pain while the body weight increased.

Bayramoglu et al. (Bayramoglu, Akman et al. 2001) reports that obesity is directly and indirectly associated with LBP. In their research, the study group included patients who had been experiencing low back pain for at least 3 month. The control group included age-matched subjects not having any known history of low back pain in the past 2 year. The results indicate that the LBP patients had significantly higher BMI than the control group. Therefore they conclude that obesity is one etiologic factor in LBP. However they also admit that inactivity caused by LBP may result in secondary obesity.

On the other hand, some investigations showed that BMI did not have a significant effect on LBP. Chung-Yol Lee et al. (Lee, Kratter et al. 2005) conducted a cross-sectional study investigating the factors associated with back pain. In their study, body mass index was
known for 10,306 participants, of whom 6514 participants (63%) had a normal weight (BMI between 19kg/m² and 25kg/m²), 513 participants (5%) were obese (BMI>30 kg/m²), 2710 participants (26%) were overweight (BMI between 25kg/m² and 30kg/m²), and 569 participants (6%) were underweight (BMI<19 kg/m²). Participants were asked to report whether they suffered from back pain explicitly, not at all, a little, or severely, in the previous 4 weeks. This research found that obese people had worse flexibility, upper body strength, and abdominal musculature. However, the authors did not found the association between BMI and back pain.

Sward et al. (Sward, Eriksson et al. 1990) investigated the relationship between anthropometric characteristics and back pain in athletes. The subjects in their study were between 16 and 25 years old and consisted of wrestlers, gymnasts, soccer players and tennis players. To guarantee the homogeneity of the groups, all chosen athletes had trained during childhood and adolescence. All subjects had been involved in the respective sports since the age of 10 years or earlier. In the experiment, all the subjects completed a questionnaire relating to previous or present back pain. Back pain was graded according to the severity: moderate or severe. If the athlete could continue to train or compete with the pain, it was regarded as moderate. If the athlete was not able to train because of the pain, it was regarded as severe. The incidence of back pain among the 116 athletes was: 35.3% reported no previous or present back pain, whose BMI is 23.0 ± 4.0; 32.8% reported moderate back pain previously or at present, whose BMI is 22.5 ± 1.6; 31.9% reported severe back pain previously or at present, whose BMI is 23.0 ± 1.7. After statistical analysis, the researchers found no significant relationship between BMI and back pain. However, since the athletes have stronger physical constitution due to the long-term effect of the training, the subject
groups can not represent normal people. Therefore the results of this study may change after expanding the subject groups to a wider range that has a better representation of the actual workforce.

From a quick review of the researches above, we can see that the current literature does not reach an agreement on the relationship between obesity and LBP. Some researchers consider obesity a possible factor of LBP, while others do not. Since there is not a consistency of opinion regarding the link between obesity and LBP, it’s meaningful to clarify whether obesity is a factor that influences the lifting pattern, which in turn affects the spinal load and is a potential factor of LBP.

1.4 Biomechanical Variability

Variability is a natural component of human performance and many statistical assessment techniques attempt to distinguish the variability associated with the factor (Marras, Granta et al. 1999). There are two types of variability: inter-individual variability defined as the variability between individuals, and intra-individual variability defined as the variability within an individual. It’s clear that with many ways of performing lifting tasks, technique variability both between and within individuals exists. Since the biomechanical effects of obesity influence people to varying degrees, it could lead to much variability in lifting technique. In terms of biomechanical performance and spinal load during lifting task, such variability may increase the risk of low back disorder (Granata, Marras et al. 1999).

Granata et al (1999) investigated the variability in lifting motions, trunk moments, and spinal loads associated with repeated lifting. He stated that one task could have an average compressive load with a narrow distribution of loads resulting in a low probability of exertion exceeding spinal tolerance levels. On the other hand, another lifting task may have
an identical mean spinal load but with a wider distribution, which could result in a high
probability of exertion exceeding spinal tolerance levels. However, since the mean values of
these two tasks are same, the task with the wide distribution might still assessed as a safe one
by traditional interpretation.

1.4.1 Inter-individual variability

Inter-individual variability is quite common in manual material handling jobs which
includes lots of lifting actions. For the same lifting job, different people may use different
lifting techniques. In the research of different lifting techniques, Burgess-Limerick (Burgess-
Limerick 2003) stated that lifting technique can be defined in terms of the posture adopted
just before the load is lifted. Different lifting techniques including stooped posture, semi-
squat posture, and a full squat posture place different parts of the body at risk for
musculoskeletal injuries because of the differences in muscles force requirements and
loading at the joints of the body. For example, the author believed that a stooped lift is more
likely to induce a higher risk for low back injury than a semi-squat lift because of the
posture-specific loads that were developed.

In the research of Granata et al. (1999), the authors tried to quantify the variability in
lifting motions, trunk moments, and spinal loads associated with repeated lifting tasks. The
subjects in this study consisted of experienced manual material handlers and inexperienced
college students. Both groups were asked to perform sagittally symmetric lifts or asymmetric
lifts 60° to the right with 13.6kg or 27.3kg box load from knee height to the upright posture.
The subjects were told to use a preferred lifting velocity or a faster-than-preferred lifting
velocity to lift the box. The experimenter collected EMG data from the erector spinae, rectus
abdominis, latissimus dorsi, external abdominal obliques, and abdominal obliques. Trunk
motion data were recorded by electrogoniometers which measured sagittal, lateral and twisting motions of the lumbar region. The dynamic external loads were collected from a force plate on which the subjects stood during the experiment. The results showed that subject-to-subject differences typically accounted for the largest source of variability in trunk motion, lifting moments, and spinal load. The weight of the load accounted for significant amount of the variability associated with dynamic sagittal trunk moment and spinal compression.

Since overweight and obese people may lack in exercise, their flexibility, ability of balance control and muscle capacity could decrease to some extent (Malina, Beunen et al. 1995; Corbeil, Simoneau et al. 2001). Such deceases in physical/physiological abilities that obese people undergo can be at different rates, which can lead to greater inter-subject variability in lifting technique of obese people. We already know that the population with higher inter-individual variance may be at greater risk for injury because the work tasks affect individuals differently. In addition, greater inter-individual variance may make it more difficult to predict injury. Therefore, it is reasonable to investigate the variability of lifting techniques in obese people and normal weight people.

1.4.2 Intra-individual variability

Since the subject may not use an identical lifting technique for repetitions of a certain task, intra-variability needs to be considered. Mirka et al. (Mirka and Baker 1996) stated that since the lifter has the ability to change the lifting technique, variability in this technique or strategy could lead to variability in the biomechanical stresses experienced by the spine and the risk of low-back injury. They proposed that the number of most stressful lifting tasks was underestimated. Granata et al. (1999) reported that based on the evidence of motor control
analysis and musculoskeletal measurements, there was potential for significant variability during the repeated performance of some certain tasks. Therefore, the variability of the lifting biomechanics should be considered as important as the mean value when assessing the risk of the lifting tasks.

In the investigation of Granata et al. (1999), the trial-to-trial variations account for 12-24% of the trunk moment variability. And such variations in spinal load ranged from 14% in compression to about 32% in lateral shear load and accounted for 20-67% of the task acceleration variability. These results showed that identical lifting tasks did not always produce the same kinetics or kinematics. It is also important to know how workplace factors influence the variability. Mirka et al. (Mirka and Baker 1996) found that the higher derivatives of motion were associated with greater variability. After importing the trunk motion data into the dynamic biomechanical model, they found that the range of peak torques across the experiment revealed that a torque at two standard deviations above the average is between 5% and 11% higher than the average of the peak sagittal torques, which indicated that an average peak torque applied on an average lifting exertion may not fully represent the type of loading which may occur under the same condition due to changes in the lifting dynamics chosen by the subject.

During lifting task, obese people need to generate more muscle force to compensate for their greater trunk weight. With this increase of magnitude of muscle force, the variability of the muscle contraction may increase (Mirka and Marras 1993). From the simulation, Corbeil (2001) showed that obese people need greater torque on the ankle joint to counteract the perturbation. This suggests that when sustaining the postural stress and perturbation, obese people have poor stability and need more muscle force to keep the body stable. This
higher magnitude of muscle force can lead more variability from trial to trial during lifting performance. Since the same lifting tasks may not yield the same spinal loads on one certain subject and an increased variability is harmful because of the greater chance of exceeding tissue tolerance, it is meaningful to investigate the intra-variability of obese people and see whether such variability similar to the variability seen in people of normal weight.

1.5 Coordination between Trunk Bend and External Moment

A novel way of evaluating the dynamics of a lifting motion is to assess the degree of coordination between trunk posture and lifting moment. During a lifting task, if the ground reaction force does not point to the center of gravity (CoG) of body, an external moment is generated. In a dynamic biomechanical model, this external moment is equal to the change rate of the angular momentum of the entire body. Since the calculation of the angular momentum of the trunk in the sagittal plane involves in the kinematics parameters, it would be interesting to see how such kinematics variables coordinate to the external moment. Considering that the lifting technique used by obese people may be different from the technique used by people with normal weight, as a result, the pattern of the coordination between trunk bend and external moment for obese people and people with normal weight may be not same.

To describe the process of performing this analysis an example is presented here. Sagittal bend angle vs. time and external moment in the sagittal plane vs. time plots for an example lift are shown in Figure 1. As can be seen in this figure, sagittal bend angle and external moment in the sagittal plane had same pattern on the trend of increase and decrease, which indicated the coordination between these two measurements. To observe this coordination, the conventional way is to plot one variable as a function of the other (Fig. 2)
(Burgess-Limerick, Abernethy et al. 1993). A normalization procedure was used to plot this graph. All values were subtracted by the mean value of the trial and then divided by the standard deviation of the trial. In fact, after being normalized the original data were transformed to their z-score. In this graph, the positive gradient indicates that the coordination is in-phase. If the coordination was perfectly synchronous, the locus in this plot would be a straight line. However, Burgess-Limerick mentioned that when the deviation from the perfect synchronization is significant, quantification of the coordination from this graph is difficult since the lag between the two movements could not be observed from it.

Figure 1 Sagittal trunk bend angle and external moment in the sagittal plane during a single lifting trial as a function of time
Figure 2 Normalized external moment in the sagittal plane plotted as a function of normalized sagittal trunk bend angle

As suggested by Burgess-Limerick et al., such in-phase coordination could be quantified by the relative phase angle between trunk bend and external moment. In the phase plane analysis, the variables vs. their derivative were plotted as coordinates of the points, and the argument of each point was calculated and called the phase angle. For the lifting task in this research, the trial started from negative X-axis on the phase planes for both trunk bend and external moment in the sagittal plane, where the angular position and the external moment were small and the angular velocity and the derivative of external moment were about zero (Fig. 3 and 4). Given any point in time during each lift, we could obtain two phase angles from two phase planes ($\alpha$ and $\beta$, in Fig 3 and 4), which represented the instantaneous phases. Between two phase plots, there were phase lags which can be represented by the relative phase angle, i.e. subtracting the phase angle from the other, or $\beta-\alpha$. The positive/negative relative phase showed the leading relation between two variables (Fig. 5). When the relative phase angle is equal to zero, it means that the two phase planes have the same phase angle at that instant in time.
For each lift there is one maximum relative phase and one minimum relative phase. In the research conducted by Burgess-Limerick et al. (Burgess-Limerick, Abernethy et al. 1993), they used the minimum relative phase between a pair of joints to quantify the lifting patterns and reported that increasing load mass during lifting increased the deviation from perfectly-in-phase coordination and delayed the time of the minimum relative phase during extension. In the investigation conducted by Lindbeck et al. (Lindbeck and Kjellberg 2001), they used both the maximum relative phase and minimum relative phase as the dependent variables to describe interjoint coordination and the lifting pattern. However, the authors stated that there should not be any value judgment of relative phase angle in terms of good/bad lifting techniques since the relative phase only represented the phase lag. In addition, Chaffin (Chaffin 1999) stated that the lifting pattern had a strong effect on the external moments. People using various lifting techniques may have different effects on compensating the moment generated by trunk bend. By the kinematics model, load moments at each joint would be transferred to the ground, and the different lifting techniques would be represented to some extent by the external moment given by the ground. Therefore, it is reasonable to consider the relative phase angle of sagittal trunk bend and external moment as an index to represent the pattern of lifting. Like the dependent variables chosen in the research conducted by Lindbeck et al, we used maximum relative phase and minimum relative phase as the dependent variables in the current study.
Figure 3 Sagittal trunk bend during one lifting trial plotted on angular position vs. angular velocity phase plane

Figure 4 Phase plane of external moment in the sagittal plane vs. derivative of external moment in the sagittal plane
Figure 5 The Relative phase angle between sagittal trunk bend and external moment in the sagittal plane

1.6 **Objective and Hypotheses**

The objective of this study was to explore the differences in lifting patterns between normal weight people (BMI<25) and obese people (BMI>30). The lifting patterns are evaluated by exploring the mean value, inter- and intra-subject variability of ground reaction force and trunk kinematics. The coordination between sagittal trunk bend and external moment was also investigated to evaluate the lifting pattern. It is hypothesized that:

1. The mean values of trunk kinematics and ground reaction forces between normal people and obese people are not the same during the lifting task.
2. The intra- and inter-subject variability of trunk kinematics and ground reaction forces between normal people and obese people are not the same during the lifting task.

3. The maximum/minimum values of the relative phase angles of sagittal trunk bend and external moment are not the same in the lifting task as performed by normal people and obese people.
2 Method

2.1 Subjects

There were two subject groups in this experiment. One was the normal weight subject group which was subjects whose BMI is lower than 25. The other one was the obese subject group which was subjects whose BMI is greater than 30. Twelve volunteers from North Carolina State University student body and surrounding community participated in this experiment with six subjects in each group. Each subject was male, had no current or chronic low back problem, and fit into one of the two groups. Anthropometric data are listed below in Table 2. The particular BMI values of each group were listed in Table 3, and the quantile summary was represented by the box plot (Fig. 6).

<table>
<thead>
<tr>
<th>Table 2 Anthropometric Data of the Subjects</th>
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<tbody>
<tr>
<td>Normal Weight</td>
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<tr>
<td>Stature (m)                   Max</td>
</tr>
<tr>
<td>Weight (kg)                  83.462</td>
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<tr>
<td>Shoulder to L5/S1 (m)       0.457</td>
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<tr>
<td>Obese</td>
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<tr>
<td>Stature (m)                   1.900</td>
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<tr>
<td>Weight (kg)                  116.122</td>
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<tr>
<td>Shoulder to L5/S1 (m)       0.480</td>
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</tbody>
</table>

<table>
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<tr>
<th>Table 3 BMI values of normal weight group and obese group</th>
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<tbody>
<tr>
<td>Normal Group</td>
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<td>--------------</td>
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<tr>
<td>Obese Group</td>
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</table>
2.2 Apparatus

2.2.1 Lumbar Motion Monitor

The lumbar motion monitor (LMM) is an exoskeleton of spine with electrogoniometers which can measure the instantaneous angular position, velocity and acceleration of the trunk in the sagittal, coronal, and transverse planes. The LMM (Chattanooga Group Inc., TN) was used to capture the kinematics of trunk motion during lifting task and positioned in line with the spine and attached by a harness at the thorax and pelvis (Fig.7). When the subjects lift or do other manual material handling tasks, the potentiometers in LMM measured the voltage changes at a rate of 60 Hz and mapped the
voltages to specific angles. Angular velocity and acceleration are then obtained by differentiating the angular position as a function of time.

**Figure 7 Lumbar Motion Monitor**

### 2.2.2 Force Plate

The ground reaction forces and moments were collected by two force plates (Bertec Corporation, Model 4060A) which were set apart by 4cm (Fig. 8). Each force plate has piezoelectric transducer for measuring 3-dimension forces and moments. The output voltages yielded by the force plate are proportional to the acting forces and moments. The signal from the force plate were sampled at 120 Hz. (Fig. 8)
2.2.3 Asymmetric Reference Frame

An apparatus called the asymmetric reference frame (ARF) (Mirka and Marras 1993) was used to measure the participants’ maximum voluntary contractions (MVC) while stooped in a 45° sagittal bend posture (Fig. 9). This value was used to calculate the load to be lifted during the experiment.
2.2.4 Box

In this experiment, the weight for lifting was placed in the wooden box length by width by height of 36cm by 36 cm by 30 cm. The handles of the box were 19 cm from the bottom side of the box. There was a vertical bar in the middle of the bottom to secure the cast iron weight in a central location.

2.2.5 Platform

The starting position of the wooden box with load was either directly in front of the subjects (symmetric position) or 45° off to the right side (asymmetric position). To keep the moment arm constant across different starting positions, a wooden platform was designed and built. With this platform, the moment arm from the subject to the box was always 51 cm. And the platform also insured that the box was lifted from the same position in each trial. (Fig. 10)

![Figure 10 Set-up of Platform](image)
2.3 Experimental Design

2.3.1 Independent Variables

The independent variables in this study were BMI (between-subjects variable), weight of load (within-subjects variable), and starting position of the load (within-subjects variable). There were two levels of Body Mass Index – BMI>30 and BMI<25, two levels of weight – 10% and 25% of lifting capacity, two levels of starting position of load - 0° and 45°, where 0° represented a sagittally symmetric lifting and 45° represented the starting position were to the right side of the subject.

2.3.2 Dependent Variables

The dependent variables in this study were of three types. The first set were related to the peak values of the trunk kinematics of the lifting process collected by LMM and the peak ground reaction forces collected by force plates during each concentric lift. The trunk kinematics variables included the peak rotational velocity, peak rotational acceleration, peak sagittal velocity and peak sagittal acceleration. The ground reaction force variables were the peak values of lateral shear, anterior shear, and vertical ground reaction forces on the right foot, which contained the most pertinent information since the asymmetric lifts were performed to the right side.

The second set of dependent variables evaluated the variability of the above variables. The intra-subject variability was obtained by calculating the variance within each subject.

Hence, the intra-subject variability of peak rotational velocity, the intra-subject variability of rotational acceleration, the intra-subject variability of sagittal velocity, and the intra-subject variability of sagittal acceleration; the intra-subject variability of peak lateral shear, the intra-
subject variability of peak anterior shear, the intra-subject variability of downward force of the right foot were dependent variables also.

The inter-subject variability was obtained by calculating the variance between subjects in each group. So the inter-subject variability of peak rotational velocity, the inter-subject variability of rotational acceleration, the inter-subject variability of sagittal velocity, and the inter-subject variability of sagittal acceleration; the inter-subject variability of peak lateral shear, the inter-subject variability of anterior shear, the inter-subject variability of and downward force of the right foot were dependent variables.

In addition, to assess the coordination between external moment in the sagittal plane and sagittal trunk bend, the maximum relative phase and the minimum relative phase angles were calculated as dependent variables.

2.4 Procedure

During initial conversations with potential subjects, eligibility requirements (height, weight and lack of current or chronic back and upper extremity musculoskeletal problems), experimental procedures and the informed consent process was described to the subjects. If the person was willing to participate, an appointment was made.

Upon arrival, the researcher explained and demonstrated the lifting task thoroughly. The subject was asked to sign the Informed Consent Form approved by North Carolina State University Institutional Review Board. This form included detailed description of this experiment. Several basic anthropometric measurements were taken including subject height, weight, and shoulder to L5/S1 length. The subjects were given a five-minute warm-up and stretching period which focused on the low back to prepare the subject for the task. To measure the maximum voluntary contractions (MVC) of back extensors, subjects were asked
to stand in the asymmetric reference frame and push against a padded roller in a 45° forward bend trunk angle (Fig. 9) as hard as they could for three seconds. The MVC value (as measured by the load cell transducers of the ARF) was used to calculate the lifting load in this experiment. The lumbar motion monitor (LMM) was then placed on the subject's back. While performing lifting task, the subject stood on the force plates. A five-minute break was given before the experimental trials commence.

The experimenter demonstrated the box lifting tasks to be performed by the participant. Before each experiment trial started, the subject was asked to tentatively lift the box to realize the weight of load. The subject was also told to stand with the midpoint between the ankles at a specified location to ensure that the load moment arm was 51 cm and then position of the subject’s feet were marked. Between each trial the subject was allowed to get off the force plates to take a rest, and was asked to put his feet on the marked position before the next trail starting. During the experiment, the subject was given a box load that corresponding to 10% or 25% of their personal capacity (as established during the maximum contractions in the ARF) to lift starting from a position at floor level (either directly in front of the subject or off to the right at 45 degrees) to mid-chest height. The end position was directly in front of the subject (Fig. 11~13). The subject performed a free-style lift using two hands but their feet were not allowed to move during the lift. There were 4 conditions (2 starting positions X 2 weights) and each of the 4 conditions was performed three times (4x3=12 trials for total). Six consecutive lifts were performed in each trial and finished in 1 minute (one lift per 10 sec.) and the last 4 lifts of the 6 were monitored by LMM and force plates. Therefore, there were 4 recorded lifts in each trial. A 1-minute break (standing without load) was given between each trial. Trial order was fully randomized and thus the
experiment was a randomized complete block design. The trunk kinematics parameters were gathered by LMM and the ground reaction forces were gathered by using the force plate.

Figure 11 Sagittally symmetric lift starting position

Figure 12 45° lift starting position
2.5 Data Processing

The data obtained by LMM and force plates needed to be processed to create the appropriate dependent variables. This process involved the identification of the peak values, the conversion to force values (force plate only), the calculation of the measures of intra- and inter-subject variability, and the calculation of the relative phase angle.

2.5.1 Lumbar Motion Monitor

To process the data obtained from LMM, a Matlab program was written to extract the time-dependent kinematic parameters from the dataset. The program identified each lifting cycle and identified the peak values for each of the four dependent variables in the data collected during concentric portion of each lift. Since the subject tended to move back and forth when standing straight, it was difficult to define when the subject stood upright. 30 degrees of sagittal bend angle was then set as the end angle of the concentric portion of the lift in this research. Therefore the concentric portion of the lift was defined as the trunk movement from the maximum sagittal position (the point where the subjects grabbed the box and started lifting) to 30 degrees of sagittal bend angle. Such definition of concentric portion preserved the peak value of all kinematics variables which were the dependent variables of the current research.

2.5.2 Force Plate

A Matlab program was developed that used the calibration equations to transform the data from the voltage values from the force plate transducers to measures of force and
moment and then extract the peak values of the these measures collected during the
concentric portion of each lift.

Because the magnitude of the lateral, anterior, and vertical ground reaction forces are
highly correlated to the subject’s bodyweight, the ground reaction force data was normalized
to subject’s weight. To normalize the force, all lateral, anterior, and vertical ground reaction
forces were divided by subject’s body weight.

### 2.5.3 Intra-Subject Variability

To calculate the intra-subject variability of LMM and force plate variables, the
calculations for the modified Levene test was used (Equation 1). Within each subject, the
median was calculated from the 12 lifts for each condition (4 monitored lifts in each trial X 3
repetitions per trial). Since there were 4 conditions, we have 4 median values per dependent
variable for each subject. The individual peak values of rotational velocity, rotational
acceleration, sagittal velocity, and sagittal acceleration; lateral, anterior and vertical ground
reaction force were then subtracted from the median of respective condition, and the absolute
values of the difference were taken as the intra-subject variability. Since there were 12 values
for each dependent variable for each condition and all these values was subtracted by their
common median, the intra-subject dataset also had 12 values for each dependent variable for
each condition for each subject.

\[
d_{ijklm} = \left| y_{ijklm} - \bar{y}_{ijkl} \right|
\]  

(1)

where

\( i \) corresponds to angle (i = 1-2)
\( j \) corresponds to weight (\( j = 1-2 \))

\( k \) corresponds to BMI (\( k = 1-2 \))

\( l \) corresponds to subject nested within BMI (\( l = 1-6 \))

\( m \) corresponds to the repetition (\( m=1-12 \))

\( y_{ijklm} \) corresponds to the observation of the \( m \) th repetition in a certain condition

\( \bar{y}_{ijkl} \) corresponds to the median of the certain condition

\( d_{ijklm} \) is the absolute deviation for the \( m \) th repetition from the median.

## 2.5.4 Inter-Subject Variability

Within each subject, the mean of 12 values (4 monitored lifts X 3 repetitions per condition) for each condition for each dependent variable was calculated. For each subject, there were 4 means for each dependent variable, corresponding to 4 conditions. These means were separated into two groups – one for means of the normal weight (BMI<25) subjects and one for averages of the obese subjects (BMI>30). In this research, each group had six subject’s data. Within each group, the median of the averages of the same condition was calculated. Thus the median was calculated from six values because there were six values for each condition for each dependent variable in each group, and there were two kinds of median, one for the normal weight group, the other one for the obese group. Then the averages value for each subject in each group was subtracted by the median of corresponding group. The inter-subject variability was calculated by taking the absolute value from the subtraction (Equation 2)

\[
d_{ijkl} = \left| \bar{y}_{ijkl} - \bar{y}_{jk} \right|
\]  

(2)

where
\(i\) corresponds to angle (\(i = 1-2\))

\(j\) corresponds to weight (\(j = 1-2\))

\(k\) corresponds to BMI (\(k = 1-2\))

\(l\) corresponds to subject nested within BMI (\(l = 1-6\))

\(\bar{y}_{ijkl}\) corresponds to the mean of 12 repetitions of a certain condition

\(\hat{y}_{ijk}\) corresponds to the median of the \(\bar{y}_{ijkl}\)

\(d_{ijkl}\) is the absolute deviation for the \(l\)th subject from the median of his group.

2.5.5 Maximum and Minimum Relative Phase Angle of Sagittal Trunk Bend and External Moment in the Sagittal Plane

For each lifting motion, time dependent sagittal angular velocity and time dependent derivative of the external moment in the sagittal plane were calculated from the time dependent trunk bend angular position and the time dependent external moment in the sagittal plane respectively by differential equation. These four variables were then normalized to their z-score. Two phase plane plots were plotted for trunk bend angular vs. trunk bend velocity and external moment in the sagittal plane vs. derivative of external moment in the sagittal plane, by the normalized values. The relative phase angle was calculated by subtracting the instantaneous external moment phase angle from the instantaneous trunk bend phase angle, and was used as an index of the coordination between the sagittal angle and the external moment in the sagittal plane. In this research, the positive relative angle indicated that the phase of sagittal angle led the phase of sagittal plane moment, and the negative relative angle indicated that the phase of sagittal plane moment led the
phase of sagittal angle. For each lift, the maximum and minimum relative phase angles were calculated.

2.6 Statistical Analysis

To analyze the effect of BMI, angle, weight, and their interaction on the mean values and the variability of trunk kinematics, ground reaction force, and maximum/minimum relative phase, Multivariate Analysis of Variance (MANOVA) and subsequent univariate Analysis of Variance (ANOVA) were used.

2.6.1 Checking Assumptions of the Analysis of Variance

To use analysis of variance to test the hypothesis of no difference in treatment means, the assumption that the residuals are normally and independently distributed with mean zero and the constant variance of error must be valid. These assumptions were evaluated using the graphical technique advocated by Montgomery (Montgomery 2001). Appendix A displays the example of figures illustrating the evaluation of these assumptions.

The normality assumption was evaluated by normal probability plot of the residuals for each dependent variable. As the error distribution accords normal distribution, all points would centralize around a straight line. To test the independence of error assumption, plotting the residuals in time order of collection was performed. The residual should equally distribute above and below time axis randomly without any tendency. A tendency of continuous positive or negative residuals implies the independence assumption may be violated. The homogeneity of variance assumption is tested by plotting the residuals versus the predicted values. If the residuals are unrelated to the predicted values, the plot should be
structureless and the residuals are randomly distributed with constant variance. (Montgomery 2001)

2.6.2 Statistical Model

In the statistical model, BMI, weight, and angle were nominal numeric variables, and all the dependent variables were continuous numeric variables. Subject was nested in BMI. Weight and angle were the factorial factors. For mean value, intra-subject variability, and coordination, the model included all three main effects (BMI, weight, and angle) and all two-way interactions. The error terms of this nested model were defined as follows: subject(BMI) is the error term for the BMI effect; weight*subject(BMI) is the error term for the weight and BMI*weight effects; angle*subject(BMI) is the error term for the angle and BMI*angle effects; weight*angle*subject(BMI) is the error term for the weight*angle effect.

The linear model is:

\[ y_{ijklm} = \mu + \tau_i + \lambda_j + \beta_k + \gamma_{i(k)} + \tau\lambda_{ij} + \lambda\beta_{jk} + \tau\beta_{ik} + \lambda\gamma_{ijk} + \tau\gamma_{ijkl} + \lambda\tau\gamma_{ijkl} + \epsilon_{ijklm} \]

where

\( \tau_i \) corresponds to angle (i = 1-2)
\( \lambda_j \) corresponds to weight (j = 1-2)
\( \beta_k \) corresponds to BMI (k = 1-2)
\( \gamma_{i(k)} \) corresponds to subject nested within BMI (l = 1-6)
\( \tau\lambda_{ij} \) corresponds to the interaction of angle and weight
\( \lambda\beta_{jk} \) corresponds to the interaction of weight and BMI
\( \tau\beta_{ik} \) corresponds to the interaction of angle and BMI
\lambda \gamma_{j(k)} \) corresponds to the interaction of weight and subject nested within BMI

\tau_{i(l(k))} \) corresponds to the interaction of angle and subject nested within BMI

\lambda \tau \gamma_{j(l(k))} \) corresponds to the interaction of weight and angle and subject nested within BMI

\varepsilon_{ijklm} \) corresponds to the error in the model

For the inter-subject variability, the subjects were treated as blocks and thus the interaction between subjects and other main effects were eliminated. Then the linear model is:

\[ y_{ijklm} = \mu + \tau_i + \lambda_j + \beta_k + \gamma_{l(k)} + \tau \lambda_{j} + \lambda \beta_{j} + \tau \beta_{j} + \varepsilon_{ijklm} \]

where

\( \tau_i \) corresponds to angle \((i = 1-2)\)

\( \lambda_j \) corresponds to weight \((j = 1-2)\)

\( \beta_k \) corresponds to BMI \((k = 1-2)\)

\( \gamma_{l(k)} \) corresponds to subject nested within BMI \((l = 1-6)\)

\( \tau \lambda_{j} \) corresponds to the interaction of angle and weight

\( \lambda \beta_{j} \) corresponds to the interaction of weight and BMI

\( \tau \beta_{j} \) corresponds to the interaction of angle and BMI

\( \varepsilon_{ijklm} \) corresponds to the error in the model
2.6.3 Analysis Process

Mean values of kinematics parameters including sagittal velocity, sagittal acceleration, rotational velocity, and rotational acceleration were grouped to the first dependent variables set. Intra-subject variability of sagittal velocity, sagittal acceleration, rotational velocity, and rotational acceleration of kinematics parameters were grouped to the second dependent variables set. Inter-subject variability of sagittal velocity, sagittal acceleration, rotational velocity, and rotational acceleration of kinematics parameters were grouped to the third dependent variables set. Mean value of the three ground reaction forces were grouped to the fourth dependent variables set. Intra-subject variability of three ground reaction forces were grouped to the fifth dependent variables set. Inter-subject variability of three ground reaction forces were grouped to the sixth dependent variables set. The maximum and minimum relative phase angle between sagittal trunk bend and external moment in the sagittal plane were grouped to the seventh dependent variable set. Multivariate Analysis of Variance (MANOVA) was performed on all these seven dependent variable sets. If the MANOVA revealed significant effects, univariate Analysis of Variance (ANOVA) was performed to see which of the dependent variables were affected and yielded the difference.

3 Results

After checking the assumptions of the ANOVA, all dependent variables in the mean value and relative phase angle dataset accorded these three assumptions. In both intra- and inter-subject variability dataset, dependent variables violated the assumption of constant variance of residuals. The variance of the observations increased as the predicted value increased. To deal with this non-constant variance, a logarithmic transformation was used on
intra- and inter-subject variability dataset. Then, MANOVA and ANOVA were performed on these logarithmic transformed data. There are four sections in this section: Mean values, intra-subject variability, inter-subject variability, and relative phase angle. The first three sections are split into “Trunk Kinematics” and “Ground Reaction Forces”.

3.1 Mean Values

This section shows the results of the evaluation of the mean values of parameters from the LMM and the force plate. The MANOVA was performed on the mean values of kinematics parameters of LMM and ground reaction forces separately. The results indicated that BMI, angle, and weight were significant on LMM dependent variables and angle and weight were significant on force plate dependent variables. ANOVA was then performed to identify which dependent variables took responsibility for the significant effect.

3.1.1 Trunk Kinematics

The following table (Table.4) presents the ANOVA of BMI, angle, and weight for the mean values of rotational velocity, rotational acceleration, sagittal velocity, and sagittal acceleration.

Table 4 MANOVA and ANOVA results relative to the mean values of peak kinematics parameters

<table>
<thead>
<tr>
<th>MANOVA</th>
<th>Rotational Velocity</th>
<th>Rotational Acceleration</th>
<th>Sagittal Velocity</th>
<th>Sagittal Acceleration</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMI</td>
<td>F value</td>
<td>p value</td>
<td>F value</td>
<td>p value</td>
</tr>
<tr>
<td>4.14</td>
<td>0.0494*</td>
<td>9.1</td>
<td>0.013*</td>
<td>10.57</td>
</tr>
<tr>
<td>weight</td>
<td>24.97</td>
<td>0.0003*</td>
<td>7.29</td>
<td>0.0223*</td>
</tr>
<tr>
<td>angle</td>
<td>5.66</td>
<td>0.0236*</td>
<td>12.97</td>
<td>0.0048*</td>
</tr>
<tr>
<td>BMI*weight</td>
<td>0.85</td>
<td>0.5345</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>BMI*angle</td>
<td>1.21</td>
<td>0.3848</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>weight*angle</td>
<td>1.38</td>
<td>0.3228</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

An * indicates a significant effects
According to the above table, the BMI and weight had a significant effect on the rotational velocity, rotational acceleration, sagittal velocity, and sagittal acceleration. Angle had a significant effect on the rotational velocity, rotational acceleration, and sagittal velocity. Figure 14 displays the effects of BMI, load weight, and asymmetric angle on the rotational velocity (The error bars in this and subsequent figures of this chapter indicate the standard error). The rotational velocity increases 59.2% from BMI<25 to BMI>30, decreases 11.3% from 10% of MVC to 25% of MVC, and increases 72.7% from 0 degree to 45 degrees.

![Rotational Velocity Chart](chart.png)

**Figure 14** Effects of BMI, weight, and angle on the mean value of the peak rotational velocity

Figure 15 illustrates the effects of BMI, load weight, and the asymmetric angle on the rotational acceleration. The rotational acceleration increased 57.6% from BMI<25 to
BMI > 30, decreases 13.0% from 10% of MVC to 25% of MVC, and increases 66.4% from 0 degrees to 45 degrees.

Figure 15 Effects of BMI, weight, and angle on the mean value of the peak rotational acceleration

Figure 16 shows that the effects of BMI, load weight, and asymmetric angle on the sagittal velocity. The sagittal velocity increases 30.4% from BMI < 25 to BMI > 30, decreases 7.4% from 10% of MVC to 25% of MVC, and increases 4.6% from 0 degree to 45 degrees.
Figure 16 Effects of BMI, weight, and angle on the mean value of the peak sagittal velocity

Figure 17 illustrates the effects of BMI and load weight on the sagittal acceleration. The sagittal acceleration increases 50.5% from BMI<25 to BMI>30, and decreases 14.0% from 10% of MVC to 25% of MVC.
3.1.2 Ground Reaction Force

The following table (Table 5) presents the ANOVA data. Interestingly, BMI did not have a significant effect on the ground reaction forces.

Table 5 MANOVA and ANOVA results relative to the mean values of peak ground reaction forces

<table>
<thead>
<tr>
<th></th>
<th>MANOVA</th>
<th>Lateral Force</th>
<th>Anterior Force</th>
<th>Vertical Force</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F value</td>
<td>p value</td>
<td>F value</td>
<td>p value</td>
</tr>
<tr>
<td>BMI</td>
<td>0.29</td>
<td>0.8347</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>weight</td>
<td>30.81</td>
<td>&lt;0.0001*</td>
<td>14.51</td>
<td>0.0034*</td>
</tr>
<tr>
<td>angle</td>
<td>110.58</td>
<td>&lt;0.0001*</td>
<td>7.2</td>
<td>0.0229*</td>
</tr>
<tr>
<td>BMI*weight</td>
<td>2.14</td>
<td>0.1735</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>BMI*angle</td>
<td>3.31</td>
<td>0.0782</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>weight*angle</td>
<td>2.66</td>
<td>0.1116</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

An * indicates a significant effects

According to this table, weight had a significant effect on the lateral force, anterior force, and vertical force. Angle had a significant effect on the lateral force, anterior force,
and vertical force. Figure 18 demonstrates the effects of load weight and asymmetric angle on the lateral force. The lateral force increases 11.9% from 10% of MVC to 25% of MVC, and increases 15.8% from 0 degree to 45 degrees.

Figure 18 Effects of weight and angle on the mean value of the peak lateral force

Figure 19 displays the effects of load weight and asymmetric angle on the anterior force. The anterior force increases 43.1% from 10% of MVC to 25% of MVC, and decreases 63.2% from 0 degree to 45 degrees.
Figure 19 Effects of weight and angle on the mean value of the peak anterior force

Figure 20 illustrates the effects of load weight and asymmetric angle on the anterior force. The anterior force increases 7.1% from 10% of MVC to 25% of MVC, and decreases 51.8% from 0 degree to 45 degrees.
3.2 Intra-Subject Variability

This section presents the result from the intra-subject variability dependent variable of the LMM and the force plate. The MANOVA was performed on the intra-subject variability dependent variables of LMM and force plate separately. The result indicated that weight and weight*angle were significant on LMM dependent variables and angle was significant on force plate dependent variables. Univariate ANOVAs were performed to identify which dependent variables took responsibility for the significant effect.
3.2.1 Trunk Kinematics

The table (Table.6) below displays the ANOVA of weight and weight*angle for the intra-subject variability of rotational velocity, rotational acceleration, sagittal velocity, and sagittal acceleration.

Table 6 MANOVA and ANOVA results relative to the intra-subject variability of the peak kinematics parameters

<table>
<thead>
<tr>
<th></th>
<th>MANOVA</th>
<th>Rotational Velocity</th>
<th>Rotational Acceleration</th>
<th>Sagittal Velocity</th>
<th>Sagittal Acceleration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F value</td>
<td>p value</td>
<td>F value</td>
<td>p value</td>
<td>F value</td>
</tr>
<tr>
<td>BMI</td>
<td>1.94</td>
<td>0.2082</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>weight</td>
<td>3.18</td>
<td>0.0870</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>angle</td>
<td>0.53</td>
<td>0.7211</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>BMI*weight</td>
<td>0.14</td>
<td>0.9632</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>BMI*angle</td>
<td>1.28</td>
<td>0.3632</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>weight*angle</td>
<td>5.37</td>
<td>0.0212*</td>
<td>8.87</td>
<td>0.0128*</td>
<td>1.07</td>
</tr>
</tbody>
</table>

An * indicates a significant effects

According to this table, the weight*angle is a significant effect on the rotational velocity. Figure 21 displays that the weight*angle interaction is a significant effect on the intra-subject variability of peak rotational velocity. At 0 degree, the intra-subject variability between 10% of MVC and 25% of MVC is not significantly different. At 45 degrees, the intra-subject variability is significantly different (F=12.22, p=0.0058), and decrease 41.4% as weight increases from 10% of MVC to 25% of MVC. At 10% of MVC, the intra-subject variability is significantly different (F=9.72, p=0.0109), and decrease 176.3% as angle increases from 0 degree to 45 degrees. At 25% of MVC, the intra-subject variability between 0 degree and 45 degrees is not significantly different.
The Intra-Subject Variability of the Rotational Velocity (degree/s)

Figure 21 Effect of interaction of weight*angle on the intra-subject variability of the rotational velocity

3.2.2 Ground Reaction Force

Table 7 displays the ANOVA of angle for the intra-subject variability of lateral, anterior, and vertical ground reaction force.

Table 7 MANOVA and ANOVA results relative to the intra-subject variability of the ground reaction forces

<table>
<thead>
<tr>
<th></th>
<th>MANOVA</th>
<th>Lateral Force</th>
<th>Anterior Force</th>
<th>Vertical Force</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F value</td>
<td>p value</td>
<td>F value</td>
<td>p value</td>
</tr>
<tr>
<td>BMI</td>
<td>0.92</td>
<td>0.4732</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>weight</td>
<td>1.47</td>
<td>0.2943</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>angle</td>
<td>8.03</td>
<td>0.0085*</td>
<td>26.16</td>
<td>0.0005*</td>
</tr>
<tr>
<td>BMI*weight</td>
<td>0.39</td>
<td>0.7682</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>BMI*angle</td>
<td>1.31</td>
<td>0.3373</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>weight*angle</td>
<td>2.66</td>
<td>0.1119</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

An * indicates a significant effects
According to this table, angle is a significant effect on the lateral force and vertical force. Figure 22 displays the effect of asymmetric angle on the intra-subject variability of lateral force. The lateral force increases 61.6% from 0 degree to 45 degrees.

Figure 22 Effect of angle on the intra-subject variability of the lateral force

Figure 23 shows the effect of asymmetric angle on the intra-subject variability of vertical force. The vertical force increases 25.0% from 0 degree to 45 degrees.
3.3 Inter-Subject Variability

This section describes the result of inter-subject variability dependent variables of the LMM and the force plate. MANOVA was performed on the inter-subject variability dependent variables. According to the result, for the inter-subject variability dependent variables of LMM, no effect was significant. P-values of all effects are greater than 0.05. For the inter-subject variability dependent variables of the force plate, angle is the only significant effect. Univariate ANOVAs were then performed to identify the dependent variables that were significantly influenced by the angle effect.

Figure 23 Effect of angle on the intra-subject variability of the vertical force
3.3.1 Trunk Kinematics

Since the MANOVA showed that no effect was significant on the inter-variability dependent variable of LMM, it was not necessary to perform the subsequent ANOVA analysis.

3.3.2 Ground Reaction Force

Table 8 displays the ANOVA of angle for the intra-subject variability of lateral, anterior, and vertical ground reaction force.

<table>
<thead>
<tr>
<th>MANOVA</th>
<th>Lateral Force</th>
<th>Anterior Force</th>
<th>Vertical Force</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMI</td>
<td>F value 2.81</td>
<td>p value 0.1077</td>
<td></td>
</tr>
<tr>
<td>weight</td>
<td></td>
<td>F value -</td>
<td>p value -</td>
</tr>
<tr>
<td>angle</td>
<td>F value 7.09</td>
<td>p value 0.0010*</td>
<td>8.68</td>
</tr>
<tr>
<td>BMI*weight</td>
<td>F value 1.04</td>
<td>p value 0.3913</td>
<td></td>
</tr>
<tr>
<td>BMI*angle</td>
<td>F value 1.14</td>
<td>p value 0.3512</td>
<td></td>
</tr>
<tr>
<td>weight*angle</td>
<td>F value 0.98</td>
<td>p value 0.4170</td>
<td></td>
</tr>
</tbody>
</table>

An * indicates a significant effects

According to this table, angle is a significant effect on the lateral force, the anterior force, and the vertical force. Figure 24 displays the effect of asymmetric angle on the inter-subject variability of the lateral force. The lateral force increases 59.6% from 0 degree to 45 degrees.
Figure 24 Effect of angle on the inter-subject variability of the lateral force

Figure 25 illustrates the effect of asymmetric angle on the inter-subject variability of the anterior force. The anterior force increases 45.1% from 0 degree to 45 degrees.
Figure 25 Effect of angle on the inter-subject variability of the anterior force

Figure 26 shows the effect of asymmetric angle on the inter-subject variability of the vertical force. The vertical force increases 45.1% from 0 degree to 45 degrees.
3.4 Coordination between Sagittal Trunk Bend and External Moment in the Sagittal Plane

This section presents the result of maximum and minimum relative phase angle between sagittal trunk bend and external moment in the sagittal plane. The MANOVA was performed on the maximum and minimum relative phase angle. The result indicated that BMI, angle, and weight were significant. Univariate ANOVAs were then performed to identify which dependent variables lead to the significant effect. According to the table below (Table 9), BMI and weight were significant on the maximum relative phase angle, and angle was significant on the minimum relative phase angle. The result also showed that the largest deviation from the perfectly synchronized coordination was represented by the maximum relative phase that occurred in the eccentric portion of the lifting.
Table 9 MANOVA and ANOVA results on the relative phase plot angle

<table>
<thead>
<tr>
<th></th>
<th>MANOVA</th>
<th>maximum relative phase</th>
<th>minimum relative phase</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F value</td>
<td>p value</td>
<td>F value</td>
</tr>
<tr>
<td>BMI</td>
<td>5.87</td>
<td>0.0233*</td>
<td>11.41</td>
</tr>
<tr>
<td>weight</td>
<td>11.36</td>
<td>0.0034*</td>
<td>10.06</td>
</tr>
<tr>
<td>angle</td>
<td>4.89</td>
<td>0.0365*</td>
<td>2.32</td>
</tr>
<tr>
<td>BMI*weight</td>
<td>0.22</td>
<td>0.8041</td>
<td>-</td>
</tr>
<tr>
<td>BMI*angle</td>
<td>0.19</td>
<td>0.8831</td>
<td>-</td>
</tr>
<tr>
<td>weight*angle</td>
<td>1.05</td>
<td>0.3864</td>
<td>-</td>
</tr>
</tbody>
</table>

An * indicates a significant effect.

Figure 27 illustrates the effect of BMI on the maximum relative phase angle between sagittal bend and external moment in the sagittal plane. The maximum relative phase increases 25.1% from BMI<25 to BMI>30.

![Figure 27 Effect of BMI on the maximum relative phase angle](image)

Figure 28 shows the effect of load weight on the maximum relative phase angle between sagittal bend and external moment in the sagittal plane. The maximum relative phase increases 10.6% from 10% of MVC to 25% of MVC.
Figure 28 Effect of weight on the maximum relative phase angle

Figure 29 demonstrates the effect of asymmetric angle on the minimum relative phase angle between sagittal bend and external moment in the sagittal plane. The minimum relative phase increases 175.2% from 0 degree to 45 degrees.
Figure 29 Effect of angle on the minimum relative phase angle
4 Discussion

The main goal of this research was to investigate the differences in the lifting patterns of normal weight people and obese people. The main hypothesis was that the mean value, the variability, and the coordination of trunk kinematics and external moment are not the same between the group of BMI<25 and the group of BMI>30. Therefore, the relationship between the results and the hypothesis are discussed in four sections: 1) the mean values of trunk kinematics and ground reaction forces; and 2a) the intra-subject variability of the trunk kinematics and ground reaction forces; and 2b) the inter-subject variability of the trunk kinematics and ground reaction forces; and 3) The maximum/minimum values of the relative phase angles of sagittal bend and external moment in the sagittal plane.

Besides BMI, load weight and lifting rotation angle were also investigated since they might interact with BMI. The results showed that these independent variables did indeed have effects on the lifting pattern. However, since the effect of BMI was the main effect to be considered, the discussion will not cover the effects of them.

**Hypothesis 1: The mean values of trunk kinematics and ground reaction forces between normal people and obese people are not same during lifting tasks.**

The results of this experiment showed that the BMI had an effect on the mean values of all kinematics dependent variables captured from the LMM: rotational velocity, rotational acceleration, sagittal velocity, and sagittal acceleration. All four kinematics parameters in the group of BMI>30 were found to be greater than those in the group of BMI<25. Therefore, the Hypothesis 1 was supported.
From the psychophysical aspect, one possible explanation for the increasing trend on kinematics parameters with respect to the effect of increasing BMI is that the obese subject may have a higher threshold for detecting and responding to external forces (compared to normal people) which is not generated by his body mass. By Weber’s law, the change in stimulus intensity that can be distinguished is a constant fraction of the starting intensity of the stimulus (Gescheider 1997). Therefore, the same percent of MVC may have greater influence on the normal weight people, e.g. reducing velocity and acceleration in sagittal and rotational plane. In addition, although BMI is a reasonable method for assessment of the relationship between whole body mass and stature, its use in assessing fitness/human performance is limited. The correlation between the BMI and body composition (i.e. percent body fat) varies by sex, age, race and training experience etc. As a result, a high BMI value may be found in both a person with a high percent body fat (very unfit) or a very muscular person (very fit) (Gallagher, Visser et al. 1996). In the current research, the subjects whose BMI were higher than 30 may be more muscular than the subjects in the normal weight group. Thus the subjects in the high BMI group tended to lift with greater velocity and acceleration.

This result may also explain the conclusion of Xiang et al. (Xiang, Smith et al. 2005) that a higher BMI was associated with an increased risk of nonfatal unintentional injuries. In their research, a population-based survey was conducted to investigate the relationship between obesity and nonfatal injuries. A significant association between extreme obesity and increased risk of injuries was revealed. The authors state that physical limitations are one of the major factors for the increased risk among obese people, since obese people are more likely to suffer activity limitation. Such association probably can be explained from the
aspect of biomechanics. In the dynamic biomechanical model (Chaffin 1999), the moment on L5/S1 is positively related to the angular acceleration, and the compression force on L5/S1 is also positively related to angular acceleration. Therefore, for obese people not only the great static moment due to the greater trunk mass, but also the great angular velocity and acceleration lead to a great moment and compression forces on L5/S1, which could be a potential risk for low back injury.

**Hypothesis 2a: Obese people may have greater intra-subject variability in trunk kinematics and ground reaction forces than normal people while lifting.**

Obesity is a potential factor to influence the stability of postural control. Corbeil (Corbeil, Simoneau et al. 2001) used simulation to prove that obese people needed nonlinear increase of torque for stabilization. To generate greater torque, the magnitude of the muscle contraction needs to increase. While the magnitude of muscle force increases, the variability of the muscle may increase as well (Mirka and Marras 1993). Individuals with more muscle strength variance will perform lifting more variably than those who have less muscle strength variance. Therefore, it was reasonable to expect greater intra-subject variability of kinematics parameters and ground reaction force for obese people.

This hypothesis was not supported by the results of this experiment. BMI was neither a significant main effect nor a factor in significant interaction for any kinematics parameters or ground reaction force. One possible explanation is that obese people have less flexibility than normal people. Some research showed that BMI was negatively related to flexibility (Malina, Beunen et al. 1995; Sibella, Galli et al. 2003; Ozdirenc, Ozcan et al. 2005). The whole-body movement during lifting may be constrained by the lower flexibility of obese
people. Such constraint may compensate for the potential large intra-subject variability generated by high BMI and increase the consistency of lifting task.

**Hypothesis 2b: Obese people may have greater inter-subject variability in trunk kinematics and ground reaction forces than normal people while lifting.**

By the modeling and simulating, obese people tend to have reduced postural control and reduced balance (Corbeil, Simoneau et al. 2001), and in reality such balance reduction may have different effects between obese individuals. Therefore, it is reasonable to hypothesize that obese people have greater inter-subject variability. However, this hypothesis was not supported by the result of this experiment since BMI was neither a significant main effect nor a factor in significant interaction for any kinematics parameters or ground reaction force. One possible explanation is that BMI is not able to indicate exactly the extent of obesity. BMI is a function of both body weight and height, which may influence the kinematics parameters and ground reaction forces separately in the dynamic biomechanical model. Since tall people have a larger moment of inertia of body trunk during lifting tasks, muscles need to generate a larger magnitude of force in order to provide the required moment. Therefore, the body height can potentially affect the inter-subject variability. In case the inter-subject variability generated by the height is much larger than the variability generated by the obesity, we may not be able to observe the variability introduced by the obesity. In addition, the BMI does not reflect the percent of body fat. Those who have a large muscle mass and low percent body fat may have the same BMI as people having more body fat, since the calculation of BMI does not distinguish the weight of fat and the weight of muscle.
If this is the case, the subject having more muscle in the obese group could decrease the inter-subject variability and compensate the effect induced by the obese subject.

**Hypothesis 3: The maximum/minimum values of the relative phase angles of sagittal trunk bend and external moment in the sagittal plane are not the same in lifting tasks between normal people and obese people**

While lifting, the external moment is generated to counterbalance the moment of the whole body, which is the derivative of the total angular momentum. The angular momentum of the trunk accounts for the majority of the total angular momentum. Since obese people may have poorer flexibility, weak back muscle endurance (Ozdirenc, Ozcan et al. 2005), and great trunk mass, their lifting pattern may be different from the lifting pattern of normal weight people. Such differences can be indicated by the difference on the coordination between sagittal trunk bend and external moment in the sagittal plane in some extent. As mentioned by Lindbeck et al (2001), the maximum and the minimum relative phase angle could be used to represent the deviations from synchronized coordination. Therefore, it was hypothesized that the maximum/minimum values of the relative phase angles of sagittal trunk bend and external moment in the sagittal plane are not the same in lifting tasks between normal people and obese people. The results supported this hypothesis and showed that BMI had a significant effect on the maximum relative phase, but did not support the idea that the BMI might also have a significant effect on the minimum relative phase. Because the largest deviation from the perfectly synchronized coordination was represented by the maximum relative phase that occurred in the eccentric portion of the lifting rather than the minimum relative phase, the result indicated that the coordination between the sagittal trunk bend and
the external moment in the sagittal plane was better for the normal weight people compared with the obese people.

From the physical model, the external moment is the summation of the derivative of angular momentum of each body segment (Toussaint, Commissaris et al. 1995),

\[ M_{ext} = \sum_{i=1}^{n} \dot{h}_i \]

where \( n \) is the number of the body segment, and \( \dot{h}_i \) is the rate of change of the angular momentum of the \( i \)th segment. Since the sagittal trunk bend only contributed to the change of the angular momentum of trunk segment, the difference of deviation from synchronization could be induced by the derivative of angular momentum of the other segment of the body, except the trunk. Therefore, one possible reason may be that, during lifting tasks, obese people tend to move body segments other than the trunk in a different way compared to normal weight people. The pattern adopted by obese people led a large deviation from the synchronizing coordination. However, as mentioned above, the difference in maximum relative phase angle that observed for obese people and normal people are only an index of lifting pattern, rather than a value judgment of lifting technique (Lindbeck and Kjellberg 2001).

**Implications**

There are many industries and jobs that require employees to perform lifting tasks throughout their workdays, e.g. UPS deliverers, grocery stockers, and construction workers. Since the results of this study have shown that people with a high BMI have different lifting patterns compared with normal people, a regular safety evaluation based only on normal weight people may not adequately reflect the true risk of injury for higher BMI individuals.
Therefore, while assessing the safety of a lifting task, one may need to consider the characteristics of the lifters (body weight, height, obesity level, age, etc.). Since overweight and obese workers continue to grow in number in the workforce, it may be important to consider these differences in evaluating lifting tasks.

**Limitations**

This research was conducted in a laboratory environment in which the lifting is controlled more strictly than in a work environment. For instance, the subject was asked to lift the load and stop when his forearm was parallel to the ground. However in a work environment, the movement of the upper extremity may have a different pattern, and generate extra forces and moments to influence the whole body. Also, in the experiment, the subject was asked to not move his feet during the lift. But in a work environment, workers might move their feet to change the center of gravity, the ground reaction force, and the external moment. Consequently, a laboratory environment may constrain the subject and influence the results of the experiment. In addition, a worker who needs to perform lifting tasks for a long time could become fatigued, and the fatigue may have interactions with BMI and other independent variables. However, in this research, such potential interactions were not considered. This issue has particular relevance to those individuals who are less physically fit. Since BMI is not a direct measure of fitness (i.e. body composition), other methods such as skinfold thickness measurements could be used to more precisely quantify body fitness.

Finally all test subjects were recruited from the university environment and the experience in manual material handling varied. In a real work setting, experienced manual material handlers may have adaptations to their level of fitness/BMI.

**Future Research**
In the future research, the limitation in the current research should be considered. Recruiting subjects from a wider field would give a better representation of the actual workforce. Lengthening the time of the lifting task would test the effect of the fatigue and the interactions between fatigue and other independent variables on the variables of trunk kinematics and ground reaction force discussed in the research. To quantify the lifting pattern in detail, relative phase angles between ankle, knee and hip joint should be collected to represent the interjoint coordination. Measuring the flexibility would be helpful to explain the result of the current research.
5 Conclusions

The objective of this study was to investigate the differences in lifting patterns between obese people and normal weight people. The mean values, the intra-subject variability, the inter-subject variability, and the coordination of trunk kinematics parameters and ground reaction forces were considered during the lifting task. Two levels of load weight and two levels of asymmetric angle were set to detect the interaction with obesity. The results revealed that with respect to lifting, the rotational velocity increased 59.2%, the rotational acceleration increased 57.6%, the sagittal velocity increased 30.4%, sagittal acceleration increased 50.5%, and the coordination between sagittal trunk bend and external moment in the sagittal plane deviated 25.1% more from synchronization when BMI increased. The result did not support the idea that BMI had significant effect or was a factor in any significant interaction on intra- and inter-subject variability. In conclusion, considering the presence of the rapid rise of the obesity rates in the workforce, the result of this research indicated that BMI level should be considered carefully when evaluating the safety of the lifting task.
6 Reference


7 Appendices
Appendix A. ANOVA Assumption

Figure 30 represents the general trend of the normal quantile plot of the mean values.

Figure 30 The normal quantile plot of the residuals for the mean value of the peak sagittal velocity

Figure 31 represents the general trend of the residuals of the mean values for testing the independence assumption of ANOVA.
Figure 31 The scatter plot of the residuals to test the independence between trials for the mean value of the peak sagittal velocity

Figure 32 represent the general trend of the residuals of mean values for testing homogeneity of variances.

Figure 32 The scatter plot of the residuals versus predicted values for the mean value of the peak sagittal velocity
Figure 33 represent the general trend of the normal quantile plot of the intra-subject variability.

Figure 33 The normal quantile plot of the residuals for the intra-subject variability of the peak sagittal velocity

Figure 34 represent the general trend of the residuals of the intra-subject variability for testing the independence assumption of ANOVA.
Figure 34 Scatter plot of the residuals to test the independence between trials for the intra-subject variability of the peak sagittal velocity.

Figure 35 represents the general trend of the residuals of intra-subject variability for testing homogeneity of variances. Since the plot had an outward-opening shape, logarithmic transformation was adapted. Figure 36 is an example of the logarithmic transformation of the previous data.
Figure 35 The scatter plot of the residuals versus predicted values for the intra-subject variability of the peak sagittal velocity

Figure 36 The Scatter plot of the residuals versus predicted values for the intra-subject variability of the peak sagittal velocity using the logarithm transformation value
## 7.2 Appendix B. Degrees of freedom of the statistic model

Table 10 Degrees of freedoms of sources in the model for the mean value, the intra-subject variability, and the coordination

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<tr>
<td>wt</td>
<td>1</td>
</tr>
<tr>
<td>angle</td>
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</tr>
<tr>
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</tr>
<tr>
<td>BMI*angle</td>
<td>1</td>
</tr>
<tr>
<td>wt*angle</td>
<td>1</td>
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<tr>
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<tr>
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Table 11 Degrees of freedoms of sources in the model for the inter-subject variability

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