Abstract

Freeman, Jacklyn Harrell. Evaluating the Effects of Age on the Variability in Lifting Technique.
(Under the direction of Dr. Gary A. Mirka)

As individuals age, they under go numerous changes that can affect their lifting technique. These changes include muscle strength and flexibility reductions, and decreases in postural control. The rate and degree of these declines vary from individual to individual, which can lead to variability in their lifting technique. The objective of this research was to evaluate the inter- and intra-subject variability of the trunk kinematics and ground reaction forces on the lifting technique used to perform a lifting task. Variability of the lifting technique is important to consider when evaluating the safety of lifting tasks. A higher variability of a lifting technique means that some individuals perform the lifting task using more extreme techniques than others. Thus, a lifting task with high variability can lead to a greater risk of injury if the variability is not taken into account when testing the safety of the lifting task. The hypothesis was that an older subject group would have a higher inter- and intra-subject variability than a younger subject group. It was hypothesized that older subjects would have greater inter-subject variability because of the varying experiences and backgrounds of the older subjects, which would lead to variances in the lifting technique between subjects. It was hypothesized that older subjects would exhibit greater intra-subject variability because older subjects are more likely to lose their balance during a lifting task and would experience weakened muscles faster than younger subjects, both of which would lead to variance in the lifting technique within a subject.

Two subject groups were used in this study – a younger subject group and an older subject group. Subjects were asked to perform lifting tasks that included two levels of load

and three levels of lifting asymmetry angle. Trunk kinematic data were captured using a Lumbar Motion Monitor, and ground reaction force data were captured with a force platform. The inter- and intra-subject variability of the trunk kinematic data and force platform data were calculated using equations derived from the Modified Levene's test. Two statistical models were created – one model for the inter-subject variability dependent variables and one model for the intra-subject dependent variables. Multiple Analysis of Variance (MANOVA) and subsequent univariate Analysis of Variance (ANOVA) techniques were used to analyze the effects of age, weight, and angle (and their interactions) on the dependent variables.

The results did not support the hypothesis, as age was neither a significant main effect nor a factor in any significant interactions for any of the dependent variables. For inter-subject variability, the MANOVA showed that weight*angle was significant and for intra-subject variability, the MANOVA showed that angle was significant. The general trend of increasing intra-subject variability was demonstrated with increasing angle.

One possible explanation for why age was not a significant factor in the inter-subject variability dependent variables is the relatively homogenous nature of the older subject group. An explanation for why age was not a significant factor in the intra-subject variability dependent variables is that since older subjects exhibit decreased flexibility, they were more constrained in how they performed the lifting task. Future work should consist of choosing a heterogeneous older subject group with varying backgrounds among subjects. Recording the flexibility and muscle strengths of all subjects would be beneficial for comparison between the older and younger subject groups.

Evaluating the Effects of Age on the Variability in Lifting Technique

By

Jacklyn Harrell Freeman

A thesis submitted to the Graduate Faculty of North Carolina State University
in partial fulfillment of the requirement for the Degree of Master of Science.

INDUSTRIAL ENGINEERING
Raleigh, North Carolina

May 2005

APPROVED BY:

David Kaber, PhD

Peter Mente, PhD

Gary A. Mirka, PhD
Chairperson of Advisory Committee

Biography

Jacklyn was born on December 20, 1980 and grew up in Wilmington, North Carolina. She grew up with her parents, JE and Susan Harrell and her brother Callie. Her dad is an Engineering Supervisor at Progress Energy and her mom teaches 4-year old preschoolers at Scotts Hill Christian Academy.

Jacklyn married her college sweetheart, Aaron, on January 17, 2004. They currently reside in Apex, North Carolina with their two cats. Jacklyn started her undergraduate studies at NC State in 1999 and received Bachelor of Science degrees in Biomedical Engineering and Biological Engineering in 2003. She stayed at NC State to obtain her Master's degree in Industrial Engineering with a concentration in Ergonomics and Safety. Jacklyn is looking forward to starting her new job at Milliken and Company in Greenville, South Carolina where she will be a Process Improvement Engineer.

Table of Contents

List of Figures v
List of Tables vii
1 Introduction 1
1.1 The Aging Workforce 1
1.1.1 Changes in Physical Capability 5
1.1.1.1 Muscle Strength 5
1.1.1.2 Psychological Changes 9
1.1.2 Balance 11
1.1.3 Flexibility 14
1.1.4 Changes in Risk of Injury 15
1.2 Link to Biomechanical Variability 19
1.2.1 Inter-Subject Variability 20
1.2.2 Intra-Subject Variability 23
1.3 Objective and Hypothesis 27
2 Methods 29
2.1 Participants 29
2.2 Apparatus 29
2.2.1 Lumbar Motion Monitor 29
2.2.2 Force Platform 30
2.2.3 Box and Platform 31
2.3 Experimental Design 32
2.3.1 Independent and Dependent Variables 32
2.4 Procedure 33
2.5 Data Processing 35
2.5.1 Lumbar Motion Monitor 36
2.5.2 Force Platforms 36
2.5.3 Inter-Subject Variability 36
2.5.4 Intra-Subject Variability 38
2.6 Statistical Analysis 39

2.6.1 Evaluating the Assumptions of the Analysis of Variance 39
2.6.2 Statistical Model 40
2.6.3 Analysis Process 42
3 Results 43
3.1 Inter-Subject Variability 43
3.1.1 Lumbar Motion Monitor 43
3.1.2 Force Platform..45
3.2 Intra-Subject Variability 45
3.2.1 Lumbar Motion Monitor 45
3.2.2 Force Platform..52
4 Discussion..54
5 Conclusion..65
References..66
Appendix A – ANOVA Assumptions..69

List of Figures

Figure 1: Lumbar Motion Monitor 30

Figure 2: Setup of Force Platforms 31

Figure 3: Setup of Force Platforms and Box....................32

Figure 4: Sagittally Symmetric Lift Starting Position....................35

Figure 5: 30º Lift Starting Position....................35

Figure 6: 60º Lift Starting Position....................35

Figure 7: Ending Position of Lift....................35

Figure 8: The Age*Weight Interaction on the Inter-Subject Variability of the Peak Coronal Velocity....................44

Figure 9: Effect of Age on the Intra-Subject Variability of the Peak Coronal Position....................46

Figure 10: Effect of Angle on the Intra-Subject Variability of the Peak Coronal Velocity....................47

Figure 11: Effect of Angle on the Intra-Subject Variability of the Peak Coronal Acceleration....................48

Figure 12: Effect of Angle on the Intra-Subject Variability of the Peak Rotational Position....................49

Figure 13: Effect of Angle on the Intra-Subject Variability of the Peak Rotational Velocity....................50

Figure 14: Effect of Angle on the Intra-Subject Variability of the Peak Rotational Acceleration....................51

Figure 15: Effect of Angle on the Intra-Subject Variability of the Peak Sagittal Position....................52

Figure 16: Effect of Angle on the Intra-Subject Variability of the Peak Vertical Downward Force of the Right Foot 53

Figure 17: The normal quantile plot of the residuals for the inter-subject variability of the peak coronal position....................69

Figure 18: The normal quantile plot of the residuals for the intra-subject variability of the peak coronal position....................70

Figure 19: Scatter plot of the residuals to test the independence between trials

for the inter-subject variability of the peak coronal position......................71
Figure 20: Scatter plot of the residuals to test the independence between trials for the intra-subject variability of the peak coronal position......................71
Figure 21: Scatter plot of the residuals as a function of the predicted values for the inter-subject variability of the peak rotational velocity........................72
Figure 22: Scatter plot of the residuals as a function of the predicted values for the inter-subject variability of the peak rotational velocity using the log transformation values..72
Figure 23: Scatter plot of the residuals as a function of the predicted values for the intra-subject variability of the peak coronal velocity............................73
Figure 24: Scatter plot of the residuals as a function of the predicted values for the intra-subject variability of the peak coronal velocity using the log transformation values..73

List of Tables

Table 1: ANOVA Results Relative to the Inter-Subject Variability of the Peak Kinematic Dependent Variables 43

Table 2: ANOVA Results Relative to the Inter-Subject Variability of the Peak Lateral, Anterior, and Vertical Downward Forces in the of the Right Foot 45

Table 3: ANOVA Results Relative to the Intra-Subject Variability of the Peak Kinematic Dependent Variables 45

Table 4: ANOVA Results Relative to the Intra-Subject Variability of the Peak Lateral, Anterior, and Vertical Downward Forces in the of the Right Foot 52

1 Introduction

1.1 The Aging Workforce

It has been well documented that people are living longer due to better nutrition, exercise, housing, and education (Wright and Mital, 1999). Health improvements from medical technology, healthier lifestyles, less physically demanding work, and better living conditions have also contributed to longer lives of individuals (Weston, 1999). Rix (2004) states that in 2002, 14.2 percent of the labor force, or 20.2 million, people were 55 years or older. Also, reporting from the Bureau of Labor Statistics, Schwerha and McMullin (2001) predict that by 2008, 30% of the American population and will be over 55 years old and will represent the group with the greatest annual growth rate. It has also been reported that since 1950, the percentage of the U.S. population 65 years of age or older has increased from 8 to 12 percent (Weston, 1999). Weston (1999) also reports that these demographic trends are due to a decline in fertility rates as well as a steady rise in life expectancy. For example, life expectancy measured from birth has increased almost 20 percent since 1940 while life expectancy measured at age 65 has increased even more. From this information, it seems that people are living longer and often remaining in the workforce for longer periods of time.

Rix (2004) reports that most older workers are wage and salary workers with traditional work arrangements and can be found in virtually every industry. For example, older men have been found to be mostly working in manufacturing, construction, transportation, communication, and public utilities (Rix, 2004). Workers are remaining in the workforce longer for a variety of reasons. According to Wright and Mital (1999), people are remaining employed longer not only by choice, but also because of Federal regulations raising the minimum age for retirement in order to receive full social security benefits. Rix

(2004) listed several reasons why a growing number of workers will delay retirement and stay in the workforce longer. These reasons include concerns about personal retirement savings and 401(k) plans. He notes that workers may be scared that they will outlive their retirement savings, with life expectancy at 65 being more than five years over what it was when the Social Security system was established. Workers may also work longer to fill their time during retirement due to their rising life expectancy. Layne and Pollack (2004) also report that the average retirement age is expected to increase. Their reasoning is that the older population is healthier than it has been before, age discrimination is declining, and the age for collecting full social security benefits is gradually increasing.

Even workers who retire may feel the need to work part-time or even full time after retiring. For example, Rix (2004) found that 6 in 10 retirees who were still employed viewed partial retirement as the ideal work arrangement. According to a survey conducted by the National Institutes on Aging, 73 percent of workers 51 to 61 years old report that they would like to continue doing some paid work after they retire. Also, Rix (2004) reports from a survey by AARP that 68 percent of workers 50 to 70 years old plan to work in retirement or expect never to retire. In addition, Weston (1999) found in a survey of older workers that there was a preference for gradual retirement because post-career employment offers a less demanding option to older workers who want to keep working. Individuals may also want to work longer because work can have a positive impact on an individual's quality of life while promoting better physical and mental well-being and proving an important social outlet accompanied by a sense of accomplishment and responsibility (Weston, 1999).

Since Herz (1995) believes that pension income greatly affects an individual's work and retirement decisions, she analyzed information on receipt of a pension and the current work activity in workers who have retired, in order to find trends in retirement ages and work after retirement. She found that both full- and part-time work among retired men, defined as those receiving income from a pension, less than 65 years old has increased in recent years. She attributes this finding in part to increases in expenses or reduced income among individuals who receive pensions. She feels that other reasons for retired individuals to continue working are declines in the value of pensions, or increases in health care costs.

Since individuals are staying in the workforce for longer periods of time, the follow question may arise: will these older workers be able to perform the work required of them, especially in manual material handling tasks. Williams and Crumpton (1997) note a concern that an aging worker experiences the same job demands as younger workers, but the aging worker also experiences changes in physical and mental abilities that come along with aging. Several researchers have conducted studies to determine the specific effects aging has on a worker and have attempted to quantify the differences between younger and older workers. Several areas of research include work ability, physical capacity, and balance. It is important to understand exactly what these changes are and how they affect an older worker's ability to perform his or her job so that employers can obtain maximum productivity from older workers while maintaining a safe working environment. Williams and Crumpton (1997) hypothesize that the physical and mental changes a person undergoes as he or she ages may affect their ability to perform well in the workplace. Their study utilized workers aged 50 to 55 years and investigated the work ability of these older workers. To determine work ability, Williams and Crumpton used the work ability index (WAI) that was developed in 1994 by the Finnish Institute of Occupation Health. The WAI is a subjective measure of a worker's work capacity determined by a series of questions in a survey. The questionnaire entails questions about the worker's physical, mental, and social capacities and is based on a point system ranging from 7 to 49 points. The Finnish Institute of Occupational Health proposes that the WAI can indicate when certain measures need to be taken to create a better work environment for the workplace. For example, a WAI of 7 to 27 would indicate poor work ability and would suggest that measures to restore good work ability should be taken. A score of 28 to 43 is classified as moderate work ability and suggests that measures should be taken to improve the WAI. The subjects in Williams and Crumpton's study consisted of 20 employees that were either clerks, administrators, instructors, or technicians. Each subject was given a questionnaire and asked to respond to questions dealing with their physical, mental, and social capacities. The answers to these questions determine each subject's WAI. Results indicate that the overall WAI scores of the participants ranged from 41 to 49. Eighty-five percent of the subjects had a good WAI ranging from 44 to 49 points while fifteen percent of the participants had a moderate WAI. Williams and Crumpton performed a linear approximation of their data and found that for workers aged 55 to 66 years, there was a small decrease in work ability as compared to when the workers were working in their younger years. The results of Williams and Crumpton imply that, since older workers have a decreased WAI, having the same workstation or job tasks as a younger worker may cause the older worker to be less productive or become fatigued quicker than the younger worker. Employers should take this into account and have some way to accommodate older workers.

The current study will focus on the physical changes that a person undergoes as he or she ages. Currently, the literature on these physical changes includes changes in physical capability, seen through muscle strength and aerobic capacity; balance, and flexibility.

1.1.1 Changes in Physical Capability

Much of literature on aging separates the changes in physical capability into the changes in muscle strength and physiological changes.

1.1.1.1 Muscle strength

It has been documented that aging can lead to progressive decreases in physical capability, which include decreases in muscle strength, aerobic power, thermoregulation, reaction speed, and acuity of the ocular and auditory senses (Shepard, 2000). Wright and Mital (1999) report that muscle strength is a primary measure of physical capacity, and that aging can lead to the gradual reduction in muscle strength capabilities. In their research, they found that these declines in muscle strength can make completing daily activities harder for older individuals. This is shown by the statistic that the percentage of individuals between the ages of 45 and 84 needing assistance in completing daily tasks doubles each succeeding decade. In their study, they sought to investigate the muscle strengths of an older population, and to compare these strengths to a younger group's strengths, while performing activities in an industrial and home environment. An older group (55-74 years) and a younger group (18-35) had to complete lifting tasks while the researchers determined the subjects' muscle strength capability through a dynamic psychophysical method of maximum acceptable weight of handling (MAWL). The results indicate that gender, age, lifting height, and lifting frequency all have a significant effect on MAWL. The interaction of age and gender also had a significant effect on MAWL. However, when data was separated by gender, the age effect on MAWL disappeared. Therefore, Wright and Mital conclude that the populations have similar psychophysical lifting capabilities. Even though Wright and Mital did not find a significant effect of age on manual lifting capability, they report that declines in isometric and isokinetic strengths due to aging may mean that older individuals are more prone to an early onset of fatigue.

Skelton *et al.* (1994) believe that maximal muscle strength, also known as the force of contraction, decreases with increasing age, and that the loss of maximal explosive power may be even greater. They conducted a cross-sectional study with the objective of investigating the effects of healthy aging on muscle strength, power, and related functional ability. This was done by measuring the isometric muscle strengths of the knee extensor and elbow flexor muscles in 100 subjects that consisted of 50 men and 50 women all between the ages of 65 and 89 years. Handgrip strength and leg extensor power were also measured. The functional ability tests were chosen for their relationship to either strength or power and consisted of rising from a chair, lifting a bag onto a fixed surface, and stepping up onto five boxes without the use of handrails. They found that isometric strength declined at a rate of 1-2% per year while leg extensor power declined at a rate of 3.5% per year. They also report that explosive power had a faster decline rate than knee extensor strength in men but not in women. The results also indicate a correlation between strength, power, and the chair rise and box stepping functional ability tasks. Skelton *et al.* suggest that reduced strength and power may lead to the inability to function in various daily living tasks and that a loss of muscle performance may be an inevitable accompaniment of aging.

Okada *et al.* (2001) conducted a study investigating the effects of a sudden deceleration resulting from postural disturbance in eight elderly men (67-72 years) and eight younger men (19-22 years). Even though their study focused on age-related differences in postural control, Okada *et al.* also looked at flexion and extension strength at the ankle and knee joints. Surface electromyography data was obtained from the anterior tibialis muscle and the medial head of the gastrocnemius muscle of the right leg. Their results indicated that when compared to the younger group, the older subject group had lower muscle forces in their extremities. Dorsal flexion, plantar flexion, knee extension, and knee flexion all were significantly less in the older subject group than in the younger group. These results are in accordance with Skelton *et al.*'s findings that muscle strength decreases with age.

Schibye *et al.* (2001) conducted a study that investigated the physical capacity, defined through aerobic power and muscle strength, of young and elderly workers, both with physically demanding jobs and without. The young subject groups consisted of workers aged 19-32 years with physically demanding jobs – waste collection, and a control group without physically demanding jobs. The elderly groups were aged 47-64 years and consisted of the same job categories as the young workers. The objective of this study was to determine if waste collection has a training or wearing effect on the workers' physical capacity by comparing aerobic power and muscle strength in the young and elderly waste collectors with a control group of young and elderly workers without physically demanding jobs. In the muscle strength assessment part of the study, maximal isometric muscle strengths were measured for back extension and flexion, shoulder elevation and abduction, and handgrip. The results with respect to muscle strength reveal a reduction in muscle strength in the elderly control group (non-physically demanding jobs). The handgrip strength decreased approximately 10% while the shoulder muscle strength decreased approximately 30-45% in the elderly control group when compared to the young control group. There was no significant difference found in the back and abdominal muscle strength. In the waste collector group, the only muscle strength decrease was found in the handgrip strength, which decreased approximately 10% in the elderly group. In general, when compared to the control groups, both the young and elderly waste collectors had larger muscle strengths. This could mean that a physically demanding job such as waste collecting may have a training effect on the strength of the shoulder muscles.

However, other researchers report that workers with physically demanding work may have a tendency of having lower muscle strength (Savinainen *et al.*, 2004). Savinainen *et al.* (2004) also conducted a study that examined the physical capacity and muscle strength of aging workers. Their study was a 16-year follow up study. Consisting of groups separated into workers with a perceived high workload and a perceived low workload, this study determined that there was an age related decline in the physical capacity of the workers. Specifically, the groups with a perceived high workload experienced a more pronounced decrease in physical capacity than the groups with a perceived low workload. There was also a decrease in muscular strength in the workers with a perceived high workload. Since Savinainen *et al.* found that older workers with a high-perceived workload experienced a diminished physical capacity, he concluded that physical work may not have a training effect on either musculoskeletal or aerobic capacities as others had suggested. Savinainen agrees with other researchers who suggest that high physical demands in a job may have a wearing effect on trunk muscles and the lower extremities, which would be a reason for the diminished muscle strength in aging workers whose jobs entail performing a lot of manual work such as lifting tasks in their job.

It has also been reported (Laughton *et al.*, 2003) that many older individuals experience weaker tibialis anterior and vastus lateralis muscles when compared to a group of younger individuals. With a decrease in the strength of the above muscles, older workers with manual material handling jobs may find their jobs becoming more difficult. The older workers may tire more easily then they did in the years before when they were younger. As stated by Shephard (1999), older employees have a harder time undertaking physically demanding jobs that include repeated carrying and lifting tasks. Rix (2004) also agrees that 20 percent of people 55 to 64 years old report some sort of activity limitation. From the available literature, it is evident that some researchers disagree on whether or not a physically demanding job has a training effect on the muscles used in the job.

There seems to be a general consensus in the current aging literature that as an individual ages, his or her muscle strength decreases over time. However, the current literature does not reach an agreement on the extent or rate of muscle strength decline. Researchers also disagree on whether or not a physically demanding job has a wearing effect on the muscles.

1.1.1.2 Physiological Changes

Shephard (2000) compiled a paper that investigated the influence of aging on productivity by examining certain physiological changes that accompany aging such as aerobic power and thermoregulation. He reports that aerobic power has been said to decline from 50 ml O_2/(kg*min) in young men to 25-30 ml/(kg*min) in 65 year olds. In self-paced heavy work, the critical intensity of effort of an average worker should be approximately 40% of the maximal oxygen intake. However, an older worker may use more than 40% of their maximal oxygen intake since the resting metabolism accounts for more than this 40% standard. Also, older workers may experience an age-related increase in body mass which tends to increase the cost of the tasks where body mass must be displaced. He also reports that people 46 to 65 years old have a reduced heat tolerance relative to younger adults, which can lead to more physiological strain during heat acclimation. With a lower heat tolerance, these older individuals may experience a reduced rate of sweating in hot environments that can lead to overheating. When fluid is lost due to sweating, blood flow to the muscles is reduced because a substantial fraction of the blood flow is directed to the skin instead of the working muscles. This loss of blood flow causes the worker not to be able to operate at 40% of his or her maximal oxygen intake in an eight-hour day without developing severe fatigue. Shephard found that when work is performed in a hot environment, the rise in core body temperature depends on the relative intensity of effort and not the absolute intensity of effort. This negatively affects older workers because their maximal oxygen intakes are lower than younger workers. Therefore, older workers have a higher intensity of effort than younger workers. These declines in thermoregulation can lead to decreased worker productivity due mainly to worker discomfort. When an older worker realizes his productivity is decreasing, he may try to work harder to catch-up, which can lead to fatigue, poor quality output, accidents, injuries, and absenteeism.

The aforementioned study conducted by Schibye *et al.* (2001) also tested aerobic capacity of young and elderly workers with physically demanding jobs and without physically demanding jobs. Aerobic power was indirectly estimated using a submaximal test on a bicycle ergometer. The maximal oxygen consumption was also measured from work intensity and heart rate. The results showed that both the type of work and the age of the worker have a significant effect on the worker's physical capacity. Specifically, both of the elderly groups (waste collectors and the control group) had an approximate 30% reduction in the maximal oxygen uptake compared to their respective younger group, which corresponds to approximately a 1% decrease of the maximal oxygen consumption per year. The weight related maximal oxygen consumption also decreases approximately 40% for the elderly waste collectors. The decrease in weight related maximal oxygen consumption may be due to the elderly waste collectors being heavier, since the elderly waste collector group had a significantly higher body mass index (BMI) than the younger group.

Gall and Parkhouse (2004) conducted another study that looked at the changes in physical capacity in aging power line technicians who perform heavy manual work in their jobs. They had three groups of workers – a young group (less than or equal to 39 years old), a middle-aged group (40-49 years old), and an older group (50+ years old). The older group was found to have significantly lower aerobic capacity, at almost a 30% reduction when compared to the young group. Also, a 17% reduction in musculoskeletal capacity was found in the older group during a one-handed pull down and standard handgrip test, as compared to the young group. They conclude that workers, whose jobs entail physical work, experience a rise in the rate of musculoskeletal disease from 36% to 45% between the ages of 50 an 54 years. This increase in musculoskeletal disease could be due to the reported decrease in physical capacity experienced by older workers.

In the current literature, there is not a consensus on what age defines older workers; however, there does seem to be a consensus, that as an individual ages, he or she experiences a decline in aerobic capacity and thermoregulation. Musculoskeletal capacity has also been shown to decline with age in some studies. These declines can lead to poor worker productivity since workers would not be working at their optimal ability.

1.1.2 Balance

It has been well documented that as individuals age, they experience a decrease in the ability to maintain balance or postural control. Okada *et al.* (2001) suggest that this decline in postural control is due in part to a decline in vestibular, somatosensory, and musculoskeletal functions. Young subject groups have been reported to correct postural disturbances by using a majority of ankle movements; whereas, older subject groups have been reported to use mainly hip movements to compensate for a postural disturbance. This could be due to a lack of somatosensory function since muscle spindles and joint receptors of the lower extremities and cutaneous receptors in the soles of the feet are a main source of somatosensory inputs used to maintain posture when confronted with a postural disturbance. To test this theory, the researchers deliberately disrupted somatosensory input in their younger subject group to find out if they would respond to the postural disturbance the same way that the older subjects did. When younger subjects experienced this disruption in somatosensory input due to ischaemia brought about by pressure cuffs on the ankles, they responded by correcting postural disturbances by using a hip dominant motion rather than an ankle dominant motion, which was the same way that the older subject group corrected a postural disturbance.

Laughton *et al.* (2003) conducted a study with 70 older adults and 15 younger adults comparing balance as observed through the postural control of each age group. They found that the older subject group demonstrated an increased amount of postural sway in the anteroposterior direction, which leads to the conclusion that the older group possesses less balance control than the younger population. When compared with the younger subjects, the older group also had greater muscle activation during quiet standing and increased levels of muscle co-activation in response to postural perturbation. This increased postural sway with increased muscle activation may suggest that elderly individuals try to maintain an upright posture by using a postural control mechanism of increasing their muscle activation. However, this study also found that the older group of subjects had more than twice as much biceps femoris activity during quiet standing than the younger subject group. The increase in bicep femoris activity may be caused by the flexed and rigid stance that the older group assumed, which moves the body's center of gravity anterior to the base of support. The older subject group would then activate their hamstring muscles to prevent their body's center of gravity from moving further forward. Therefore, the positive correlation between the increased muscle activation of the biceps femoris and the increased short-term postural sway in the older group reveals that their aforementioned strategy is ineffective in maintaining short-term postural control. Laughton *et al.* observe that the increase in muscle activation may be the cause of the increase in postural sway in the older subject group, and therefore, may compromise the older individual's ability to maintain an upright stability.

Postural control can also be determined by evaluating the center of foot pressure (CFP) and the body's center of mass (COM). Okada *et al.* (2001) conducted another study with a group of older and young subjects that looked at differences in postural control in response to a sudden deceleration due to a postural disturbance. These researchers found that there is a difference in the movement pattern technique used to correct postural disturbances between younger and older groups. Okada *et al.*'s data showed that the older group had slower and larger ankle and hip joint movements as well as a slower and larger CFP displacement when recovering from the sudden deceleration. A somewhat similar study conducted by Gu *et al.* (1996) also revealed that when faced with a postural disturbance, the older subject group exhibited larger hip torques and larger support surface anteroposterior shear forces than the younger subject group. This delayed and prolonged correction in postural disturbance may be due to a decreased vestibular input in the older group. The older subject group in Okada *et al.*'s (2001) study also revealed a delayed occurrence of head acceleration after the postural disturbance. These results show that the older subject group takes a longer time to recover after a postural disturbance and that the older group has to compensate more to regain balance than the younger group. In Gu *et al.*'s (1996) study, it was determined that the elderly were not as able to rapidly correct their imbalance like the young group. These results suggest that, the older subject group had reduced balancing and walking ability as compared to the younger subject group. Losing balance or postural control while performing a lifting task can alter the lifting technique used to perform the lifting task, and since older individuals are more likely to lose their balance, they may be more likely than younger individuals to alter their lifting technique during a lifting task.

1.1.3 Flexibility

Decreases in flexibility are also a concern with an aging workforce. The current literature on aging is limited in its coverage of flexibility. Hence, there is not much detail on the declines of flexibility as an individual ages. However, some studies include flexibility as a secondary focus in their study. In their 16-year longitudinal follow-up study, Savinainen *et al.* (2004) evaluated the flexibility of the spine in older subjects. These older subjects were separated into two groups. The first group consisted of workers that had a high-perceived workload and the second group consisted of workers that had a low-perceived workload. Flexibility of the spine was assessed while the subjects were in a standing position and was found by determining the increase in the length of the spine between the seventh cervical vertebra and the first sacral vertebra when subjects had their backs bent forward with knees straight. In their results, Savinainen *et al.* found that workers with a high-perceived workload experienced a decline in flexibility of the spine as compared to the flexibility in their spine when they were younger.

In Okada *et al.*'s (2001) study examining age-related differences in postural control due to sudden deceleration, the range of motion in the ankle and hip joints were also tested. To test range of motion, the researchers used a goniometer while the subjects actively moved their ankle and hip joints to the maximum extended and flexed positions. The results of this study indicated that the older subject group had a greater limitation of their hip and ankle joints, which can lead to a decreased range of motion in older workers.

The current literature on flexibility associated with aging is limited. However, some researchers have found decreases in flexibility in older subject groups. With these declines in flexibility, an older worker may not be able to complete the same job tasks, such as tasks that involve overhead work or tasks that require extremes in back extension or flexion, as a younger worker. Decreases in flexibility may also affect the lifting technique employed by older individuals during lifting tasks.

1.1.4 Changes in Risk of Injury

With all the physical changes that an aging worker undergoes, researchers have postulated that these older workers are at a higher risk for injury. Shephard (1999) argues that a decrease in muscle strength can lead to an increased susceptibility to lifting injuries as well as being predisposed to back strain. The weakening of muscles and the loss of balance control in the aging worker can lead to more stress on the older worker's body than the younger worker when performing the same job. Shephard (1999) reports that this greater exertion that is required to perform a job in the older worker can lead to an over-taxing of the heart and skeletal muscles which may lead to a decrease in productivity and demonstrations of worker fatigue such as missed work days, accidents, and an increased susceptibility to musculoskeletal injuries, heart attacks, and strokes.

According to Wright and Mital (1999), reduced muscle strengths in the older workforce may increase the risk of slips and falls in this population. Specifically, reductions in the strength of the tibialis anterior and vastus lateralis have the potential to impair an individual from being able to correct a shift in the body's center of gravity and effectively prevent a fall. These researchers also report that with decreases in muscle strengths, fatigue may occur earlier, which may lead to chronic fatigue. Research conducted by Laughton *et al.* (2003) states that increased levels of postural sway in older adults has been linked to an increased risk of falling. For example, these researchers report that when older adults who had fallen one or more times in a year were compared with older adults who had not fallen, it was found that the older fallers had a significantly greater average speed of sway than the non-fallers. Laughton *et al.* also (2003) found significantly greater anteroposterior sway in older adults who had fallen. Gu *et al.* (1996) documented that deterioration of postural control ability is thought to be a key factor in falls in the elderly. In their aforementioned study, these researchers noted the important connection between postural stability and being able to avoid falls. They report that previous studies have found that postural sway during quiet stance is greater in elderly adults compared to younger adults, and it is also larger in elderly adults who have a history of falling compared to elderly adults with no history of falling.

Layne and Pollack (2004) report that falls are a leading cause of morbidity for older individuals. They conducted a descriptive study with the objective of examining nonfatal occupational falls and slips and trips without a fall in older workers (55 years or greater) and comparing the risk of these injuries to those of the younger workers. To gather their data, Layne and Pollack used injury data reported to a national probability sample of hospital emergency departments. From a narrative of each fall or slip/trip without a fall incident of older workers, each incident was coded for extrinsic or intrinsic factors related to the falls. Extrinsic factors included floor contamination from water, ice, oil/grease, and wax; tripping over cords, furniture, and rugs or mats. Intrinsic factors that caused a fall included fainting, seizure, syncope, or dizziness. The results indicate that the most common cause of same-level falls to the floor were extrinsic factors such as floor contamination. Same level falls occur when an individual trips on an object or slips due to floor conditions. Older workers were not found to be at an increased risk of a fall injury, but when they did fall, they were more likely to be hospitalized after a fall injury than younger workers. The physician's diagnosis for slip, trip, or fall incidents among older workers was most commonly a contusion, abrasion, or hematoma, followed by a sprain or strain, followed by a fracture, followed by a laceration. It was also found that same level falls were the most common type of incident among older workers, and that same level falls were mostly due to floor contamination or tripping hazards.

Another study examining falls in older individuals (65 years or greater) was conducted by Stel *et al.* (2004). This study was conducted within a sub-sample of the Longitudinal Aging Study Amsterdam and specifically looked at individuals who had experienced a fall in the past year and the consequences of falls in older men and women. 204 community dwelling older individuals who had previously reported a fall within the preceding year were asked about the consequences of their fall including questions about physical injury, health service use, treatment, and functional decline. The results indicated that as a consequence of falling, 68.1% of fallers suffered physical injury with 5.9% suffering major physical injury, 23.5% used health services, and 17.2% needed treatment. 35.3% of fallers reported a decline in functional status with 16.7% reporting a decline in social activities and 15.2% reporting a decline in physical activity. More than 90% of the fallers had less physical activity for more than a week after their fall.

Mills and Barrett (2001) report that falls during walking are the primary cause of accidental injury in elderly individuals. Since there are two critical points in a person's gait that may predict falls, Mills and Barrett state that it is important to understand the effect aging has on the swing phase mechanics in a person's gait so that factors that predispose older individuals to falling or slipping may be identified. The two critical points in the gait cycle are the minimum toe clearance and heel contact, which occur during the swing phase and the swing to stance transition respectively. The potential for slip is greatest during mid-swing when the toe reaches a minimum height of approximately 10mm when at the same time, the anterior-posterior velocity of the foot is greater than 4m/s. These two researchers conducted a study with 10 young subjects (20-30 years) and eight older (65-75 years) subjects that examined the effect of aging on the swing phase mechanics of young and older individual's gait. Sagittal plane marker trajectories and force plate data were gathered while subjects walked at their preferred speeds. The results show that the swing duration of the older subject group was significantly less than that of the younger subject group. However, when the data was corrected for gait velocity, the difference in swing velocity was not significant. Independent of gait velocity, the older subjects had a significantly greater anterior-posterior heel contact velocity than the younger subject group. Another result showed that the older subjects also had a significantly lower angular velocity of the shank at the heel contact point. This result was also independent of gait velocity. In reference to joint kinematics, there were no significant differences between the young and older subjects for any of the joint angles or angular velocities, or the anterior-posterior hip velocity at the points where the toe leaves the ground, the heel makes contact, and the point of the minimum metatarsal-phalangeal joint clearance (MTPmin) (the point when the ball of the foot comes closest to the ground during the swing phase). The results from the kinetics show that the only difference between the old and young subjects was seen by a greater hip extension moment at MTPmin in the older group. Millis and Barrett feel that their results of the differences in swing mechanics between the two subject groups may be an effect of aging and can be used in predicting fall injuries in older individuals.

In summary, there is currently a void in the literature on studies that investigate the risks of injury on older individuals performing lifting tasks. However, locomotive studies have found that decreases in muscle strength and postural control have been shown to increase risk of injury. Decreases in muscle strengths can lead to an increase in lifting injuries as well as increases in slips and falls. Researchers have also shown a decline in postural control to be a key factor in fall injuries of the elderly. It has also been shown that older individuals are more likely to be hospitalized after a fall than younger individuals. Thus, older individuals need to be especially careful during locomotion and while performing lifting tasks.

1.2 Link to Biomechanical Variability

Since aging affects everyone differently, workers experience the biomechanical effects of aging in different amounts and at different rates, which can lead to both inter- and intra-individual variability in task performance. Inter-individual variability is defined as the variability between individuals; whereas, intra-individual variability is defined as the variability within an individual. With many ways to perform physical tasks such as lifting, it is evident that variability in the technique both between and within subjects will exist. The current literature that looks at the physical changes in the aging population and the correlating risk of injury does not focus on the variability of the older workers. Thus, variability is important to consider because the amount of variability associated with a lifting task may influence the risk of developing musculoskeletal disorders.

Granata *et al.* (1999) reported that different lifting tasks may exhibit different distributions of compressive loads. One task could have an average compressive load with a narrow distribution whereas another lifting task could have an identical average compressive load but with a wide distribution. Since the two tasks have the same mean compressive load, they may both be deemed safe. However, the technique with the wide distribution could have a significant percentage of the exertions exceeding some spinal tolerance levels. Hence, the task with the wide distribution may not be safe because of the large variability in the lifting technique, which could lead to injuries from some exertions exceeding safety limits. Thus variability in the lifting technique is important to consider when evaluating the safety of a lifting task. Currently, there is limited literature that focuses on the variability in the lifting techniques, especially the variability of the lifting techniques of older workers.

1.2.1 Inter-Individual Variability

Inter-individual variability is prevalent in manual material handing jobs that require lifting as people employ different lifting techniques. Examples of different lifting techniques include a back lift, semi-squat lift and a full squat lift (Burgess-Limerick, 2003). Different lifting techniques place different parts of the body at risk for musculoskeletal injuries through change in the loading at the joints of the body. For example, a back lift will place the worker at a higher risk for low back injury than will a semi-squat lift (Burgess-Limerick, 2003).

As individuals age, some may become or remain more active while others become more sedentary which can lead to a high inter-individual variability in the aging population. For example, Savinainen *et al.* (2004) states that different individuals experience differences in injury susceptibility and differences in risk factor exposures even when performing the same jobs. These differences can lead to older workers undergoing musculoskeletal and aerobic changes at different rates and to different degrees. Therefore, the older workforce will have greater variability in muscle strength and capacity as well as balance control and flexibility. Skelton *et al.* (1994) agree, and report in their study that there was considerable variance in strength in similar ages among the healthy elderly individuals. To further support this view, Gu *et al.* (1996) report the trend that older adults have more variance than younger individuals in their postural adjustments. Specifically, they found that older adults exhibited high variance in their kinematic responses to disturbances in their posture. Also, Shephard (1999) reveals that in physically demanding jobs, the toll that the work takes on the worker's body is heavily influenced by the worker's body mass. Since there is such a large variability in the body mass of older workers, the way in which a physically demanding job affects their body would be different than younger workers.

Another example of inter-individual variability is found in the study conducted by Williams and Crumpton (1997). As previously described, the work ability index was determined for 20 workers between the ages of 50 and 55. Since the results indicated 85% of the workers had a good WAI and 15% had a moderate WAI, it is evident that variability was present in the amount of work that each older participant in the study could perform. There could be many reasons for this variability such as differences in physical health, differences in attitude towards working, and differences in the way each worker performs his or her job.

In a study of inter-individual variability, which was not focused on aging, Granata *et al.* (1999) sought to quantify the variability in lifting motions, trunk moments, and spinal loads associated with repeated lifting tasks as well as to identify workplace factors that influenced the biomechanical variability in the lifting tasks. The subjects in this study were either experienced or inexperienced and performed either a sagittally symmetric lift or an asymmetric lift 60° to the right while lifting either a 13.6 or 27.3 kg box from knee height to an upright posture. The subjects were also told to either lift with a preferred lifting velocity or a faster than preferred lifting velocity. EMG data was collected from the left and right erector spinae, rectus abdomini, latissimus dorsi, external abdominal obliques, and internal abdominal obliques. Trunk motion data was collected from an electrogoniometer that measured sagittal, lateral, and twisting motions of the lumbar region of the trunk. The dynamic external loads were gathered from a force plate that the subject stood on during each lifting task. The results of this study related to variability showed that the largest source of variability in the trunk motion, lifting moments, and spinal load was actually inter-subject variability, coming from subject-to-subject differences. The variability associated with the dynamic sagittal trunk moment and spinal compression was largely due to the changes in the weight of the box. Interestingly, contrary to Granata *et al.*'s expectations, the experienced group had greater sagittal and twisting moment variability than the inexperienced group.

A lifting task can be completed using a variety of techniques, which will vary from individual to individual creating inter-individual variability in the lifting technique. Granata *et al.* (1999) found that the largest source of variability in trunk motion, lifting moments, and spinal loads during a lifting task is due to inter-subject variability. As individuals age, they undergo physical and physiological changes at different rates and to different degrees, which can also lead to inter-individual variability in the lifting technique of older workers. With this speculation of large inter-individual variance surrounding the lifting technique of older workers, this population may be at a greater risk for injury since the work tasks affect each individual so differently. It also may become harder to predict injuries among the older population with a great variability surrounding the lifting technique. However, no research has been conducted that quantifies the variability in the older workforce or that compares this variability to a younger workforce; thus there is a void in the literature of studies that investigate the inter-subject variability of the lifting technique of older workers.

1.2.2 Intra-Individual Variability

It is also thought that there would be intra-individual variability among the older population. Intra-individual variability can occur since an individual will not use an identical lifting technique for each lift in a given lifting task. Mirka and Baker (1996) noted that most biomechanical systems are multidimensional and indeterminate, which implies that there are many ways an individual can perform a movement or exertion. They further found that the most stressful tasks in a job were the most predictive of overexertion injury, not the average exertions. Hence, the benefit of a workplace parameter that reduces mean spinal compression but increases the variability would be questionable. Therefore, when assessing the risk of a lifting task, the variability of the lifting biomechanics must be considered as well as the mean values.

Granata *et al.* (1999) realized that different lifting tasks may have different distributions of compressive loads. For example, a task with an average compressive spinal load and a narrow distribution of loads will contain exertions with a very small chance of exceeding spinal tolerance levels. However, another task with the same mean compressive load, but with a wide distribution, may have a significant percentage of the subsequent exertions exceeding some spinal tolerance levels. But since the mean compressive loads were the same, ergonomic assessments may conclude that both tasks are equally safe. However, both of these tasks are not equally safe since workers would have greater risk of becoming injury while performing the lifting task with the wider distribution. The same can be said for individuals performing the same lifting tasks. Since there is variability in the way an individual performs the same lifting task, if a mean value is calculated, it may be determined that a job is equally safe, but that would not be the case because of the variability in how the individual performs the task. Granata *et al.* (1999) also noted that workplace factors that influence the biomechanical variability of a lifting task will also affect the risk of injury and associated musculoskeletal disorders.

Several studies have examined the intra-individual variability in younger workers and the potential impact that variability has on ergonomic and risk assessment. One such study was the previously mentioned study conducted by Granata *et al.* (1999). Not only did they evaluate inter-individual variability, but they also evaluated intra-individual variability. In this study, subjects performed lifting tasks while EMG data and trunk motion data were collected. Dynamic external loads were also gathered from a force plate that the subject stood on during each lifting task. Their results showed that the variability associated with the dynamic sagittal trunk moment and spinal compression was largely due to the changes in the weight of the box. The heavier box weight significantly reduced the variability of the sagittal extension velocities and accelerations. Twelve-twenty-four percent of the total trunk moment variability was due to trial-to-trial variations. The trial-to-trial variability in spinal load ranged from 14% in compression to more than 32% in lateral shear load, while the trial-to-trial variability accounted for 20-67% of the task acceleration variability. Greater variability was also found with twisting velocities, lateral accelerations, and twisting accelerations when the lifting task was asymmetric. However, the variability of the lateral velocities was reduced with an asymmetric lifting task. These results show that even with identical lifting tasks, the load on the spine greatly changes, which leads to the conclusion that performing identical tasks does not always produce the same kinetics or kinematics.

Since lifting tasks with the same weight, origin, and destination will not produce the same spinal loads, it is important to determine the biomechanical variability associated with the lifting task as well as workplace factors that influence the variability. An increased variability is harmful because the broad distribution has a greater chance of exceeding tissue tolerance and resulting in an injury (Granata *et al.*, 1999).

Mirka and Baker (1996) were interested in the variability in the external biomechanical forces exerted on the spine during lifting tasks. They conducted a study that investigated the variability of the kinematic parameters that describe human performance during sagittally symmetric lifting tasks and how that kinematic data transfers into variable torque about the L5/S1 joint in the sagittal plane. They also sought to determine the effect that workplace variables have on the magnitude of this variability. With independent variables of load weight and coupling level (ability to grip the load), Mirka and Baker had each subject repeat the lifting task with each combination of independent variables eight times while collecting the kinematic dependent variable parameter data of angular position, angular velocity, and angular acceleration of the lumbar trunk in the sagittal, coronal, and transverse planes. Mirka and Baker found that there was not only considerable variability in the peak value of angular position, velocity, and acceleration, but there was also variability in the location in time when peak value occurred. When the three types of kinematic data were compared, it was determined that the higher derivatives of motion contained more variability. When the trunk motion data were put into a dynamic biomechanical model, the results showed that the kinematic variability had the greatest impact on trunk kinetics. For example, the range of peak torques across the trials revealed that a torque at two standard deviations above the average was between 5 and 11% higher than the average of the peak sagittal torques. This showed that an average peak torque taken on an average lifting exertion may not well represent the type of loading that may occur under identical conditions because of changes in the lifting dynamics chosen by the subject. Also, higher variability was seen in the lifting tasks with a greater weight level.

Mirka and Baker (1996) believe that the biomechanical stress on the body associated with dynamic lifting tasks is affected by the worker's lifting strategy. Since workers choose their own lifting strategy in the workplace, there is definitely variability in such lifting tasks. They think a stochastic modeling approach would be a more accurate method of analyzing biomechanical systems because the variability in the lifting tasks can be accounted for. In addition to the variability found in the kinematics during a lifting task where environmental distractions were minimized, they state that in the workplace, environmental distractions will be greater; thus, leading to increased variability in the kinematics of human performance. In conclusion, these researchers believe that given a workspace with two alternative designs, the best choice to reduce back injury may be the design that, on average, generates the higher internal loads (to a certain degree), but has a lower variance about the mean, because the risk of extreme loads which increase the risk of low back injury will be reduced. It is important to note that the higher internal load is only to a certain value that must be determined by the analyst.

Mirka and Marras (1993) conducted another study that focused on the variability of the internal stresses on the spine during lifting tasks. In this study, EMG data was collected while subjects performed multiple repetitions of controlled trunk extensions in which the kinematics of the lifting motion were controlled. The results of the study showed that the muscle coactivation patterns had significant variance across multiple repetitions of the same controlled lifting task. It was also found that the torque exerted and the angular velocity from the lifting task affected this variability. After inputting the data into an EMG-assisted biomechanical model, it was found that the erector spinae variability affected the shearing forces on the spine.

The sum of this review of intra- and inter-individual variability indicates that if attention is focused only on average biomechanical stresses, valuable information that could predict low back stress and injury could be lost. Hence, it is important to determine variability when looking at risk for injury in addition to mean stress. With all of the known changes that an older individual undergoes, and the previous research conducted on variability in lifting tasks and human performance, a logical next step is to conduct a study that quantifies the inter- and intra-individual variability in older workers.

1.3 Objective and Hypotheses

The objective of the current study is to determine the differences in inter- and intra-subject variability in lifting mechanics between younger and older people. These lifting mechanics are assessed by considering trunk kinematics and ground reaction forces. The main hypothesis of the current study is that older people will have greater inter- and intra-subject variability in trunk kinematics and ground reaction forces during lifting than younger people. This hypothesis is in accordance with the result of the study by Granata *et al.* (1999) that found that variability is greater with varying experiences and backgrounds among subjects. In the current study, age is positively correlated with experience.

2 Methods

The objectives of this study are to quantify the differences in the inter- and intra-subject variability in the trunk kinematics and ground reaction forces of older individuals versus younger individuals.

2.1 Subjects

There were two subject groups in this study – a younger subject group and an older subject group. The younger subject group was defined for subjects ranging in age from 20 years to 31 years old, and the older subject group was defined for subjects between the ages of 55 and 66 years. Sixteen volunteers participated in this study with eight subjects in each group. Subjects were recruited from the North Carolina State student body, faculty, and local community. The criteria for subject selection was that each subject be male, have no chronic or current back problems or musculoskeletal problems of the upper extremity, and that the subject fit into one of the above age groups. The mean and (standard deviation) for the young subject group's age, height, and weight are as follows respectively: 25.75 (3.81) years, 178.94 (3.12) cm, and 83.00 (23.66) kg. The mean and (standard deviation) for the older subject group's age, height, and weight are as follows respectively: 59.9 (3.00) years, 179.06 (4.44) cm, and 89.25 (6.69) kg.

2.2 Apparatus

2.2.1 Lumbar Motion Monitor

The kinematics of the lumbar region of the back were captured using a device called the Lumbar Motion Monitor (LMM) (Marras *et al.*., 1992). The LMM was secured to the subject's back at both shoulder height and iliac crest height and measured the relative instantaneous angular position of the lumbar spine in the sagittal, coronal, and transverse planes. These data are collected at 60 Hz. These angular position data were then differentiated in software to obtain angular velocity and angular acceleration in the three planes. Figure 1 shows the LMM attached to a subject.

Figure 1: Lumbar Motion Monitor

2.2.2 Force Platform

The ground reaction forces at the feet were collected using two force platforms. The force platforms were set up side by side. A wooden frame was built around the force platforms using 3.81cm (1.5 inch) pieces of wood. The wooden frame kept the force platforms secure. Therefore, the force platforms were 3.81cm (1.5 inches) apart. Force platform data were collected at 100 Hz. Both force platforms were from Bertec Corporation, Model 4060A. Each force platform has a unique 6 x 6 calibration matrix and is calibrated individually. The calibration for each force platform is determined when the force platform is manufactured at Bertec Corporation. The calibration matrix is given for an amplifier gain of 1 for all channels. If a gain other than 1 is used, each signal is divided by the corresponding gain value before further processing. In the current experiment, a gain of either 10 or 20 was used. The first three rows of the calibration matrix have units of N/V and correspond to the forces. The second three rows have units of N*m/V and correspond to the moments. The force and moment values are calculated by pre-multiplying the signals with the calibration matrix. Both force platforms were auto-zeroed before subjects stood on the platforms. Figure 2 shows the setup of the force platforms.

Figure 2: Setup of Force Platforms

2.2.3 Box and Platform

The subjects were asked to lift a wooden box length by width by height of 35.56 cm by 35.56 cm by 30.48 cm (14 inches by 14 inches by 12 inches). The handles of the box were 19.05 cm (7.5 inches) from the bottom of the box. The handles had foam cushioning so that the subject's hands would not be injured while performing the lifting task. The empty box was 4.13 kg (9 pounds).

A wooden platform was designed and built to rest 1 inch (2.54 cm) above the right force platform or in the middle of the force platforms when at the sagittally symmetric position. The starting position of the wooden box was always on top of the wooden platform. This platform could easily be moved from the 0º starting position to the 30º starting position and the 60º starting position. The function of the platform was to minimize the moment arm from the subject to the box. This moment arm was kept constant from condition to condition and from subject to subject. The moment arm from the subject to the box was always 50.8 cm (20 inches). Figure 3 shows the box and the platform at the sagittally symmetric position. Cast iron weights were added to the box to obtain 4.59 kg (10 pounds) and 9.17kg (20 pounds).

Figure 3: Set-up of Force Platforms and Box

2.3 Experimental Design

2.3.1 Independent and Dependent Variables

The independent variables for this study included age, weight of load, and starting position of the load. There were two levels of age – younger and older, two levels of weight – 4.59 and 9.17 kg (10 pounds and 20 pounds), and three levels of starting position of the load - 0°, 30°, and 60°. 0° is a sagittally symmetric lift. Both the 30° and 60° starting positions were to the right of the subject. The asymmetric lifts were only to the right of the subjects because pilot data revealed no significant changes when the lifts were performed to the left side and then compared to data from lifts performed to the right of the subject.

The dependent variables for this study were the variability of the peak values of the kinematics of the lifting task captured by the LMM and the variability of the peak values of the ground reaction forces captured by a force platform. Specifically, the LMM captured the coronal position, velocity, and acceleration; rotational position, velocity, and acceleration; and sagittal position, velocity, and acceleration. The inter- and intra-subject variability were then calculated for the peak values for each observation that occurred during the concentric portion of the lifting motion. The variability of the peak coronal position, velocity, acceleration, peak rotational position, velocity, acceleration, and peak sagittal position, velocity, and acceleration became the dependent variables. The force platform captured the lateral, anterior, and downward vertical forces, and then the inter- and intra- subject variability of the peaks of these were calculated. After preliminary analysis of the data, it was determined that the right foot contained the most pertinent information because all lifts were performed to the right side; therefore, only the data from the right force platform, which contained data for the right foot, were used. The variability of the peak lateral, anterior, and vertical downward forces of the right foot became the dependent variables.

2.4 Procedure

Upon arrival of subjects to the place of the experiment, the researcher thoroughly explained and demonstrated the lifting tasks, and the subject was asked to sign an informed consent form approved by the North Carolina State institutional review board. This informed consent form also contained a description of the experiment. The subject was encouraged to ask questions whenever they arose. After signing the form (and receiving a copy for himself), height and weight of the subject was measured and recorded. This was followed by a brief (5 minute) warm-up/stretching activity that focused on the low back and shoulders. This stretching activity was performed to prepare the subject for the experimental tasks. A LMM was placed on the subject's back and the subject stood on the two force platforms while performing the lifting tasks. The subject was told to place his left foot on the left force platform and his right foot on the right force platform. The subject was told to keep his heels touching a white line located on top, near the middle, of the force platforms during the one minute of lifting. Keeping the heels on the white line allowed the 50.8 cm (20 in) moment arm from the subject to the box to be maintained. The subject was told he could place his feet at whatever width was comfortable and he could perform a free-style lift (either a leg lift or a back lift) using two hands. The subject was instructed not to move his feet during the trials.

Before the experimental trials started, the subject was told to practice lifting the box to ensure that he was comfortable with his lifting technique and the height to which the load was to be lifted. During the experimental trials, the subject lifted the wooden box, either 4.59 kg (10 pounds) or 9.17 kg (20 pounds), from a position on top of the wooden platform, which was elevated 12.7 cm (5 inches) off the ground, (either directly in front of the subject or off to the right at either 30° or 60°) to elbow height. The end position was always directly in front of the subject at the subject's elbow height. Figure 4 shows the starting position of a sagittally symmetric lift, Figure 5 shows a 30° lift, and Figure 6 shows a 60° lift. Figure 7 shows the ending position of the lift. After each lift, the researcher took the box from the subject and set it back at the starting position for the next lift. There were six total conditions (2 weights x 3 starting positions) and 6 consecutive lifts were performed under each task condition or within a trial. Each trial lasted for 1 minute; therefore, the subject performed 1 lift every 10 seconds. The researcher told the subject when to lift. A 30-second rest-break (standing without the load) was given after each trial. There were three repetitions of each trial for a total of 18 lifts/condition, and the order of the trials was randomized.

Figure 4: Sagittally Symmetric Lift Starting Position

Figure 5: 30° Lift Starting Position

Figure 6: 60° Lift – Starting Position

Figure 7: Ending Position of Lift

2.5 Data Processing

The LMM data and the force platform data had to be processed before it could be analyzed. Since the LMM and the force platforms do not output the variability of the dependent variables, this variability had to be calculated. The equations used to calculate the variability were from the modified Levene test (Levene, 1960; Montgomery, 2001). The modified Levene test uses the absolute deviation of the observations in each treatment from the median for that treatment. Microsoft Excel was used to calculate the variability of the variables output by the LMM and the force platforms.

2.5.1 Lumbar Motion Monitor

The LMM output data in the form needed to analyze the data, so processing was minimal. A Matlab program was written to process and analyze the data. This program allowed the necessary kinematic variables to be extracted from the data. The program was written so that the concentric portion of each lift was extracted for each kinematic dependent variable. The concentric portion of the lift was determined from the point of maximum sagittal position to when the subject stood upright (the point when the subject grabs the box to when the subject stands upright with the box – the lifting portion of the lift).

2.5.2 Force Platforms

The force platforms output the data in voltage form. In order to analyze the data, it was converted to forces. Therefore, a Matlab program with calibration equations for each force platform was developed to transform the data. This Matlab program also extracted the concentric portion of the lift for the ground reaction force dependent variables.

2.5.3 Inter-Subject Variability

The inter-subject variability for both the LMM variables and the force platform variables was calculated. Since the lateral, anterior, and downward vertical forces are related to the subject's weight, the force platform inter-subject variability data was normalized with respect to the subject's weight. This was done by dividing the lateral, anterior, and downward vertical forces by the subject's weight before the inter-subject variability was calculated. To calculate the inter-subject variability, first, within each subject, the average for a condition for each dependent variable was calculated from 18 values– six lifts per condition and three repetitions per condition. For each subject, there were a total of six averages per dependent variable since there were six conditions. The subjects' averages were separated into two groups – one group for the averages of the younger subjects, and another group for the averages of the older subjects. Then, for each condition, the median value of these averages from all subjects in an age group was calculated. Thus, this median value was calculated from eight values since there were a total of eight subjects in each age group and each subject has one average value for a condition. There were two sets of median values - one for each age group. For each dependent variable, there were six medians calculated since there were six conditions. Finally, the inter-subject variability was calculated by taking the absolute value of the average value for each subject for a condition minus the respective median value from all the subjects in the respective age group. This process was adapted from the modified Levene test, which is defined as the deviations from the median. This test was used because it is robust from departures from normality.

Example:

Subject 1 (Younger), Condition 1 –
Values for 1 dependent variable
Peak Coronal Position, 0º, 4.59 kg (10 pounds)

Rep. 1	Rep. 2	Rep. 3
0	2	3
0	2	5
0	1	4
2	1	3
0	1	4
0	1	4

Median of Subject 1, Condition 1 = 1.5

Subject 2 (Younger), Condition 1 -
Values for 1 dependent variable
Peak Coronal Position, 0º, 4.59 kg (10 pounds)

Rep. 1	Rep. 2	Rep. 3
1	0	2
2	1	2
2	1	1
2	0	1
2	1	1
1	1	0

Median of Subject 2, Condition 1 = 1

This process was continued for all subjects. Then the average of all the medians for a specific condition for all subjects in an age group was found, and the inter-subject variability was the absolute value of the average from all subjects in an age group for a specific condition minus the above median for one subject.

2.5.5 Intra-Subject Variability

The intra-subject variability for both the LMM variables and the force platform variables was calculated. This calculation, like the inter-subject variability calculation, was adapted from the modified Levene test. First, within each subject, the median was calculated from 18 values – six lifts per trial and three repetitions per trial. For each subject, there were a total of six medians per dependent variable since there were six conditions. For each subject, the actual values of the peak coronal position, velocity, and acceleration; peak rotational position, velocity, and acceleration; peak sagittal position, velocity, and acceleration; and the peak forces in the lateral, anterior, and vertical downward directions from the concentric portion of the lift for a particular condition (weight and starting position combination) were subtracted from the median from the respective condition, and then the absolute value was taken. Since there were six lifts per condition and three repetitions of each condition, there were 18 actual values for each variable for each condition. Therefore the same median value was used for each of the 18 actual values for a condition when subtracting the actual value from the median value. Thus, the intra-subject variability data set includes 18 values for each dependent variable for each condition for each subject.

Example:

Subject 1, Condition 1, Values for 1 dependent variable
Peak Coronal Position, 0º, 4.59 kg (10 pounds)

Rep. 1	Rep. 2	Rep. 3 (These are the actual values)
0	2	3
0	2	5
0	1	4
2	1	3
0	1	4
0	1	4

The median was determined from the above 18 values.
Median = 1.5
Intra-subject variability = Absolute value(1.5-0)=1.5
Intra-subject variability = Absolute value(1.5-0)=1.5
Intra-subject variability = Absolute value(1.5-0)=1.5
Intra-subject variability = Absolute value(1.5-2)=0.5

This process was continued until the intra-subject variability was calculated from all actual values.

2.6 Statistical Analysis

Multiple Analysis of Variance (MANOVA) and subsequent univariate Analysis of Variance (ANOVA) techniques were used to analyze the effects of age, weight, and angle (and their interactions) on the dependent variables. Before performing these analyses, the assumptions of the ANOVA procedure were tested using the graphical methods advocated by Montgomery (2001).

2.6.1 Evaluating the Assumptions of the Analysis of Variance

Assumptions of the ANOVA procedure (assumption of normality of residuals, independence of errors and homogeneity of variance) were evaluated using the graphical techniques advocated by Montgomery (2001). See Appendix A for examples of figures illustrating the tests performed to evaluate these assumptions.

The normality assumption was tested by developing a normal probability plot of the residuals for each dependent variable. If the error distribution is normal, the plot should resemble a straight line. The independence of errors assumption was tested by plotting the residuals in order of time of data collection. The residuals should be randomly distributed below and above the 0 value on the y-axis. If there are runs of positive and negative residuals, the independence assumption may be violated. This assumption was assessed to ensure there was proper randomization of the trials in the experiment. The homogeneity of variance assumption is used to make certain there is constant variance of the residuals. This assumption was tested by plotting the residuals versus the predicted values. In order for this assumption to be true, the residuals should be structureless and appear to be randomly distributed. If the statistical model is correct and the assumptions are satisfied, the residuals should have no structure and be unrelated to any other variable, including the predicted response (Montgomery, 2001).

In both the inter- and intra-subject variability data sets, approximately half of the dependent variables violated the assumption of constant variance of residuals. The variance of the observations increased as the magnitude of the predicted value increased. Therefore, a logarithmic transformation was performed on both data sets and a MANOVA and ANOVA were performed on the log-transformed data (Montgomery, 2001). Appendix A illustrates the test for homogeneity of variance and includes figures of the residuals versus the predicted values and the residuals versus the predicted values using the logarithmic transformation.

2.6.2 Statistical Model

Two models were created – one for the inter-subject variability dependent variables and one for the intra-subject variability dependent variables. Nominal numeric variables included age, weight, and angle. Continuous numeric variables included all the dependent variables. A nested-factorial design was used for both models. The nested factor was subject, which was nested in age and the factorial factors were angle and weight. The models were created by including all three main effects (age, weight, and angle) and all two-way interactions. The appropriate error terms were used as defined by Montgomery (2001) and are as follows: subject(age) is the error term for the age effect; weight*subject(age) for the weight and age*weight effect; angle*age(subject) for the angle and age*angle effect; and weight*angle*subject(age) for the weight*angle effect. The linear model for this design is:

$$y_{ijklm} = m + t_i + l_j + b_k + g_{l(k)} + tl_{ij} + lb_{jk} + tb_{ik} + lg_{jl(k)} + tg_{il(k)} + ltg_{ijl(k)} + e_m$$

where

t_i corresponds to angle and i = 1-3

l_j corresponds to weight and j = 1-2

b_k corresponds to age and k = 1-2

$g_{l(k)}$ corresponds to subject nested within age and l = 1-8

tl_{ij} corresponds to the interaction of angle and weight

lb_{jk} corresponds to the interaction of weight and age

tb_{ik} corresponds to the interaction of angle and age

$lg_{jl(k)}$ corresponds to the interaction of weight and subject nested within age

$tg_{il(k)}$ corresponds to the interaction of angle and subject nested within age

$ltg_{ijl(k)}$ corresponds to the interaction of weight and angle and subject nested within age

e_m corresponds to the error in the model

2.6.3 Analysis Process

A multiple analysis of variance (MANOVA) was performed on both models to determine the significant effects. Since there were multiple dependent variables, performing the MANOVA controlled the experiment-wise error rate. An analysis of variance (ANOVA) was performed on both models to determine which dependent variables were affected by the significant effects revealed by the MANOVA. Throughout the statistical analysis, a probability of less than 0.05 indicated a significant effect. To further explore any significant effect of an independent variable with more than two levels, a Tukeys HSD test was conducted for pairwise means comparisons.

3 Results

The results are presented in four sections. The first two sections are the results from the inter-subject variability split-up into results from the LMM and the force platform. The next two sections are the results from the intra-subject variability, also split into results from the LMM and the force platforms. Significant effects determined by the MANOVA are illustrated in each section.

3.1 Inter-Subject Variability

The following sections describe the results from the analysis of the inter-subject variability dependent variables from the LMM and the force platform. A MANOVA was conducted on the inter-subject variability dependent variables to control for experiment-wise error. The results from the MANOVA indicated that the interaction of weight*angle was significant and a subsequent ANOVA was conducted on this interaction to identify the dependent variables that were driving this significant response.

3.1.1 Lumbar Motion Monitor

Table 1 displays the results from the ANOVA of the weight*angle interaction for the inter-subject variability of the peak kinematic dependent variables.

Table 1: ANOVA Results Relative to the Inter-Subject Variability of the Peak Kinematic Dependent Variables

Independent Variables	Coronal Position		Coronal Velocity		Coronal Acceleration		Rotational Position		Rotational Velocity	
	F-Ratio	P-value	F-Ratio	P-value	F-Ratio	P-value	F-Ratio	P-value	F-Ratio	P-value
Weight*Angle	1.5	0.2401	1.3	0.2871	1.3	0.2888	1.7	0.2	1.87	0.1715

Independent Variables	Rotational Acceleration		Sagittal Position		Sagittal Velocity		Sagittal Acceleration	
	F-Ratio	P-value	F-Ratio	P-value	F-Ratio	P-value	F-Ratio	P-value
Weight*Angle	2	0.1533	1.39	0.2661	3.6	0.0401*	0.79	0.4647

An * indicates a significant effect (p-value of 0.05 or less).

According to the ANOVA, the weight*angle interaction is a significant effect on the inter-subject variability of the peak sagittal velocity. Figure 8 shows the weight*angle interaction on the inter-subject variability of the peak sagittal velocity. The figure demonstrates that at 0º, the inter-subject variability is statistically different ($p<0.05$) (shown through simple effects analysis), and decreases as weight increases with a 14.5% decrease from the 4.59 kg (10 pound) weight to the 9.17 kg (20 pound) weight. However, at 30º and 60º, the inter-subject variability between the 4.59 kg (10 pound) weight and the 9.17 kg (20 pound) weight is not statistically different. At both the 4.59 and 9.17 kg (10 and 20 pound) weights, the inter-subject variability is not statistically different between angles.

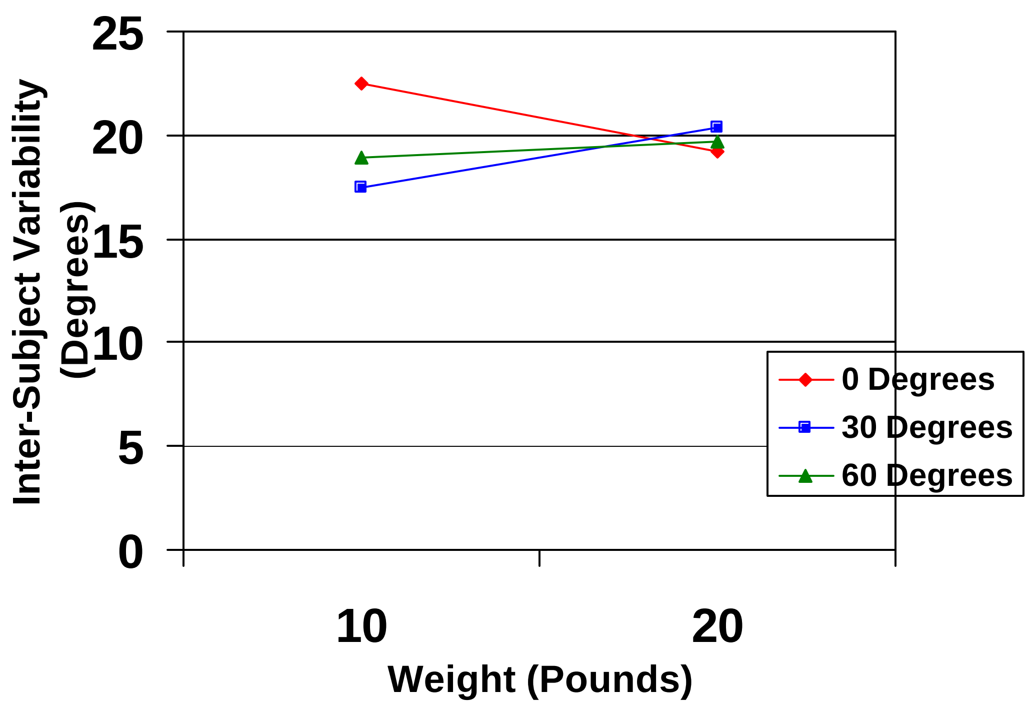

Figure 8: The Interaction of Weight*Angle on the Inter-Subject Variability of the Peak Sagittal Velocity

3.1.2 Force Platform

Table 2 displays the results from the ANOVA of the weight*angle interaction on the inter-subject variability of the peak lateral, anterior, and vertical downward forces of the right foot.

Table 2: ANOVA Results Relative to the Inter-Subject Variability of the Peak Lateral, Anterior, and Vertical Downward Forces in the of the Right Foot

Independent Variables	Lateral Force		Anterior Force		Vertical Downward Force	
	F-Ratio	P-value	F-Ratio	P-value	F-Ratio	P-value
Weight*Angle	0.84	0.4408	1.6	0.2186	1.84	0.1769

* indicates a significant effect (p-value of less than 0.05).

This table shows that, according to the ANOVA, the weight*angle interaction was not significant on any of the ground reaction force dependent variables.

3.2 Intra-Subject Variability

The following sections describe the results from the intra-subject variability dependent variables from the LMM and the force platform. A MANOVA was run on the inter-subject variability dependent variables to control for experiment-wise error. According to the MANOVA, angle was significant.

3.2.1 Lumbar Motion Monitor

Table 3 displays the results from the ANOVA on the intra-subject variability of the peak kinematic dependent variables influenced by angle.

Table 3: ANOVA Results Relative to the Intra-Subject Variability of the Peak Kinematic Dependent Variables

	Coronal Position		Coronal Velocity		Coronal Acceleration		Rotational Position		Rotational Velocity	
Independent Variables	F-Ratio	P-value	F-Ratio	P-value	F-Ratio	P-value	F-Ratio	P-value	F-Ratio	P-value
Angle	17.07	<.0001*	5.71	0.0084*	6.62	0.0044*	4.83	0.0158*	7.99	0.0018*

Table 3 (continued)

	Rotational Acceleration		Sagittal Position		Sagittal Velocity		Sagittal Acceleration	
Independent Variables	F-Ratio	P-value	F-Ratio	P-value	F-Ratio	P-value	F-Ratio	P-value
Angle	5.46	0.0099*	9.59	0.0007*	1.21	0.3131	0.25	0.7816

The * indicates a significant effect (p-value of less than 0.05).

This table indicates that angle was a significant effect on the intra-subject variability of the peak coronal position, velocity, acceleration; rotational position, velocity, and acceleration; and sagittal position. Figures 9 – 15 display the effects of angle on the dependent kinematic variables. Figure 9 illustrates a 74.3% increase in intra-subject variability from 0º to 30º and a 98.3% increase in intra-subject variability from 0º to 60º.

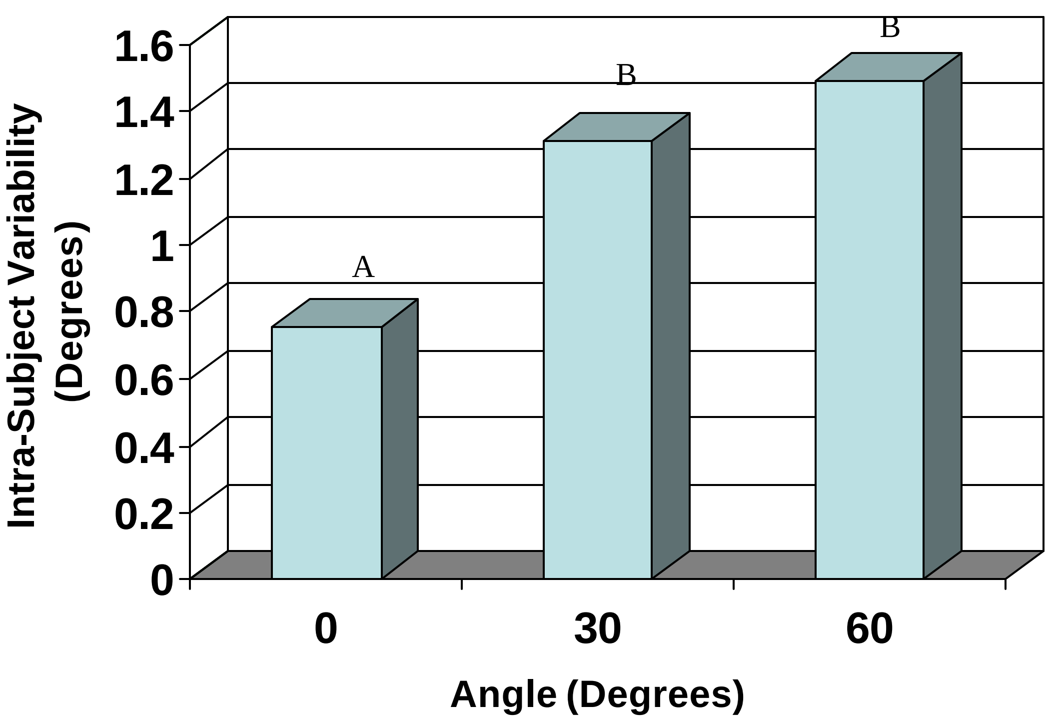

Figure 9: Effect of Angle on the Intra-Subject Variability of the Peak Coronal Position. According to Tukey's HSD, columns with different letters are statistically different (p<0.05) from one another.

Figure 10 illustrates increasing intra-subject variability in the peak coronal velocity as the angle increases with a 36.9% increase from 0º to 30º and a 49.6% increase from 0º to 60º.

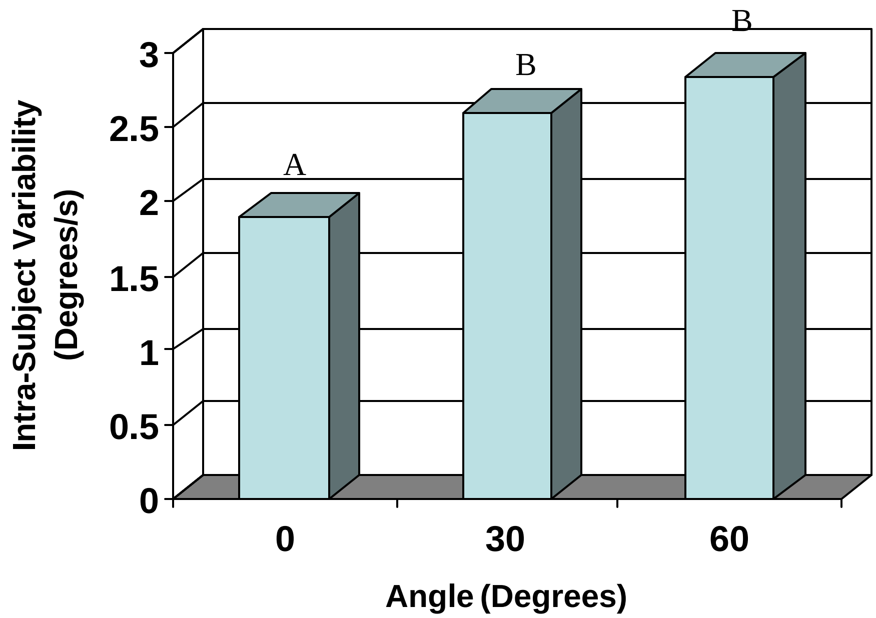

Figure 10: Effect of Angle on the Intra-Subject Variability of the Peak Coronal Velocity. According to Tukey's HSD, columns with different letters are statistically different ($p<0.05$) from one another.

Figure 11 displays an increasing intra-subject variability of the peak coronal acceleration, with a 32.6% increase from 0º to 30º and a 44.2% increase from 0º to 60º.

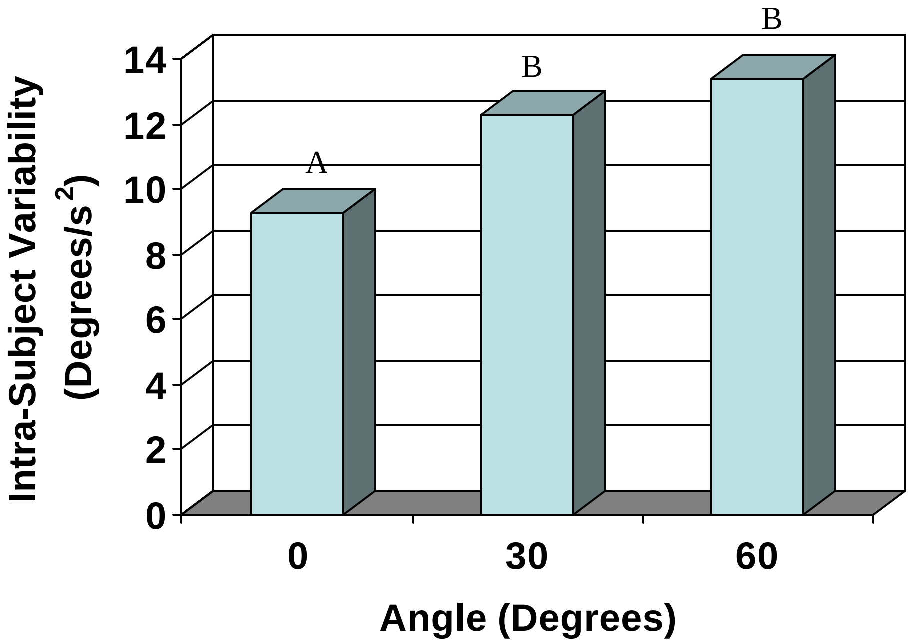

Figure 11: Effect of Angle on the Intra-Subject Variability of the Peak Coronal Acceleration. According to Tukey's HSD, columns with different letters are statistically different ($p<0.05$) from one another.

Figure 12 demonstrates an increasing intra-subject variability of the peak coronal acceleration with all angles being significant from one another. There was a 24.3% increase in intra-subject variability from 0º to 30º, and a 22.3% increase in variability from 30º to 60º.

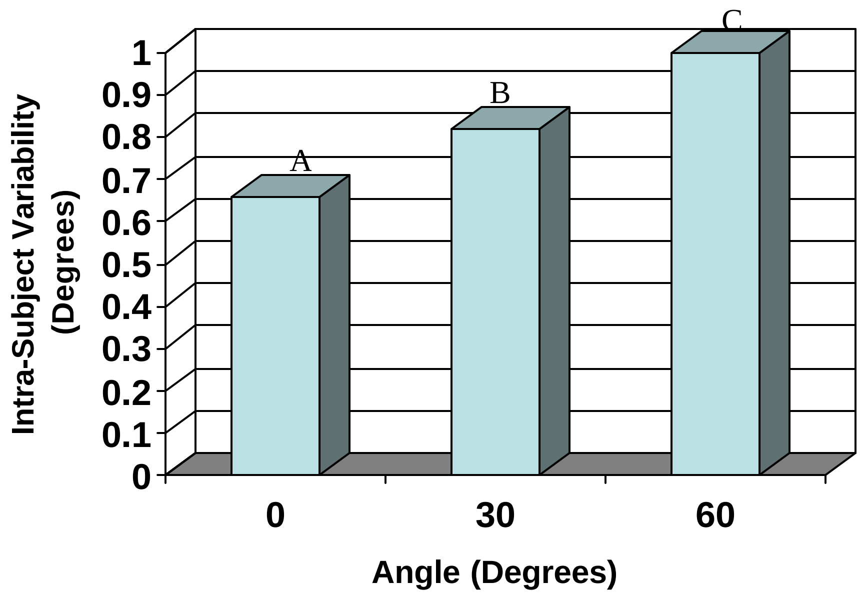

Figure 12: Effect of Angle on the Intra-Subject Variability of the Peak Rotational Position. According to Tukey's HSD, columns with different letters are statistically different ($p<0.05$) from one another.

Figure 13 displays a 31.6% increase in the intra-subject variability of the peak rotational velocity from 0º to 30º and a 49.3% increase in intra-subject variability from 0º to 60º.

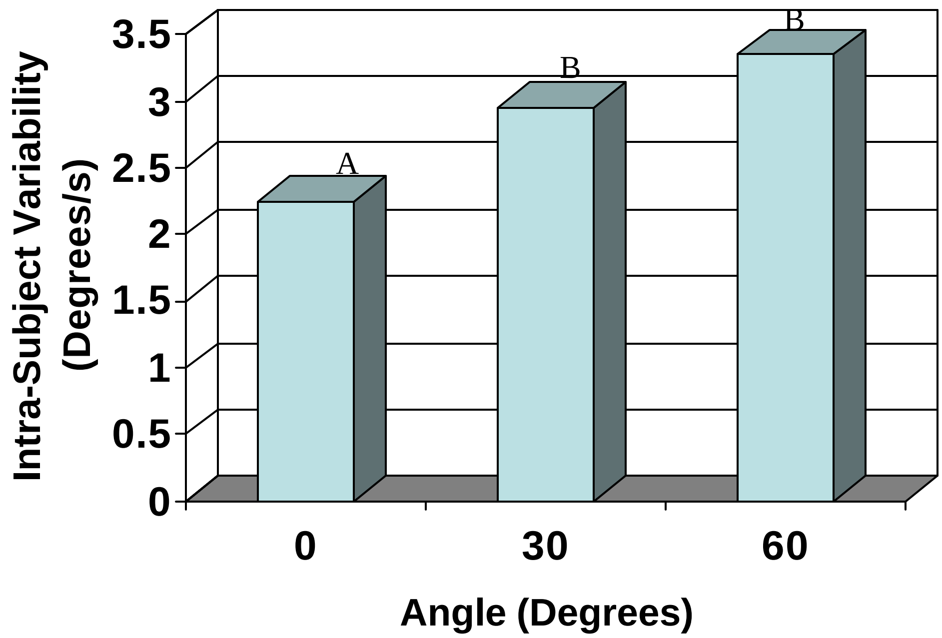

Figure 13: Effect of Angle on the Intra-Subject Variability of the Peak Rotational Velocity. According to Tukey's HSD, columns with different letters are statistically different ($p<0.05$) from one another.

Figure 14 illustrates a 30.2% increase in intra-subject variability of the peak rotational acceleration from 0º to 30º and a 33.7% increase from 0º to 60º.

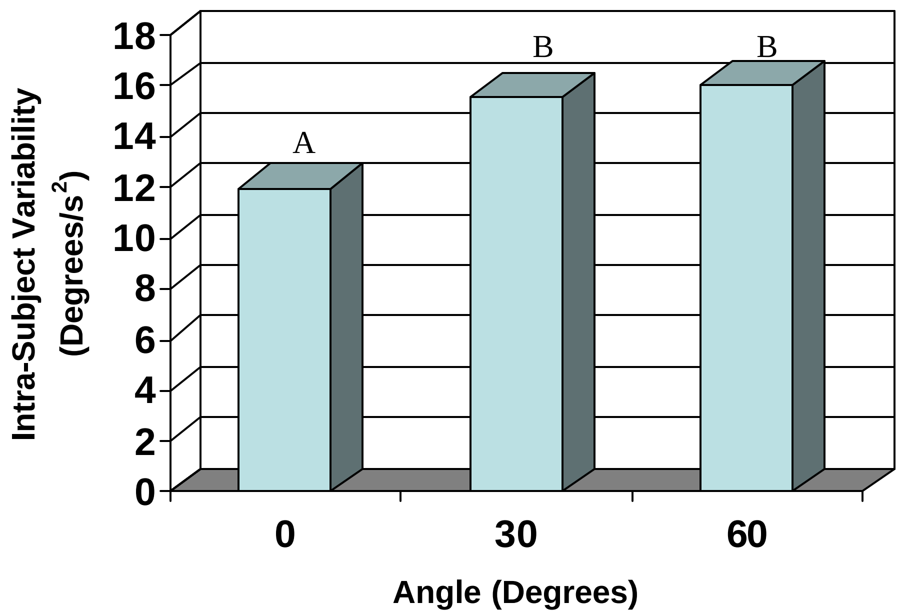

Figure 14: Effect of Angle on the Intra-Subject Variability of the Peak Rotational Acceleration. According to Tukey's HSD, columns with different letters are statistically different ($p<0.05$) from one another.

Figure 15 shows a decrease in intra-subject variability of the peak sagittal position with all angles being statistically significant from one another. There was a 27.4% decrease in intra-subject variability from 0º to 30º and a 43.7% decrease in intra-subject variability from 30º to 60º.

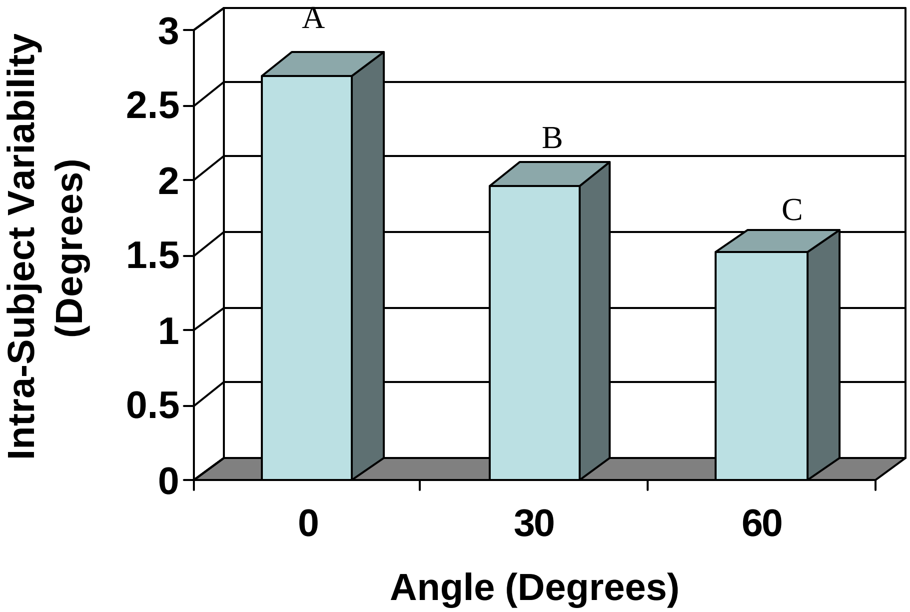

Figure 15: Effect of Angle on the Intra-Subject Variability of the Peak Sagittal Position. According to Tukey's HSD, columns with different letters are statistically different (p<0.05) from one another.

3.2.2 Force Platform

Table 4 displays the results from the ANOVA on the intra-subject variability of the peak lateral, anterior, and vertical downward forces of the right foot. (The results from the MANOVA indicated that angle was significant.

Table 4: ANOVA Results Relative to the Intra-Subject Variability of the Peak Lateral, Anterior, and Vertical Downward Forces in the of the Right Foot

Independent Variables	Lateral Force		Anterior Force		Vertical Downward Force	
	F-Ratio	P-value	F-Ratio	P-value	F-Ratio	P-value
Angle	2.86	0.0742	1.18	0.3215	5.4	0.0104*

An * indicates a significant effect (p-value less than 0.05).

According to ANOVA, angle was a significant effect only on the intra-subject variability of the peak vertical downward force of the right foot. Figure 16 displays this effect. This figure illustrates a 34% increase in the intra-subject variability of the peak vertical downward force of the right foot from 0º to 30º and a 73.6% increase in the intra-subject variability from 0º to 60º.

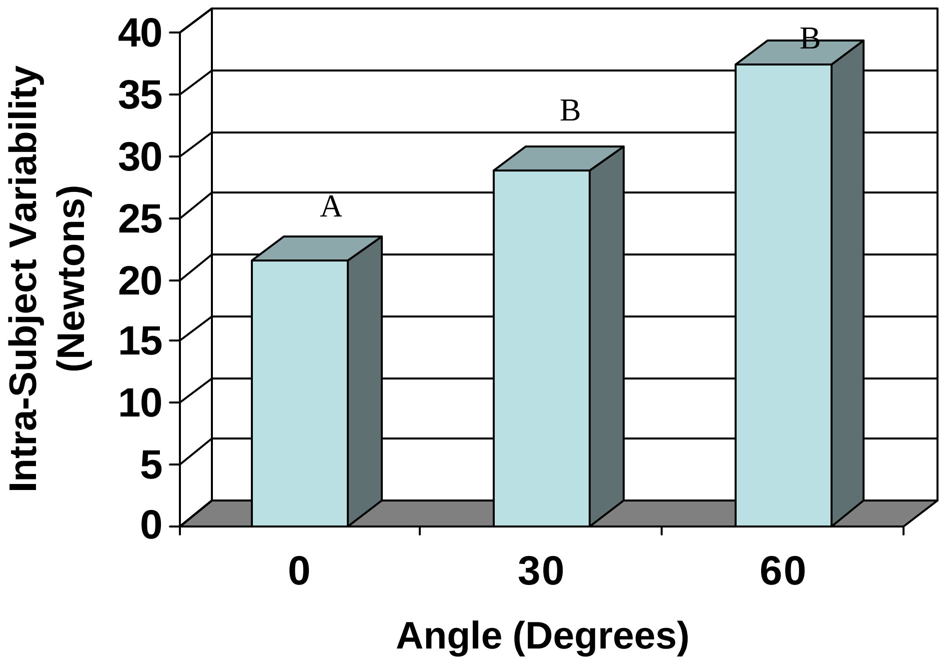

Figure 16: Effect of Angle on the Intra-Subject Variability of the Peak Vertical Downward Force of the Right Foot. According to Tukey's HSD, columns with different letters are statistically different ($p<0.05$) from one another.

4 Discussion

The overarching hypothesis of the current study was that older people would exhibit greater variability in trunk kinematics and ground reaction forces during lifting than younger people. It is logical to discuss the results of this work and their relationship to this hypothesis in two sections: 1a) The inter-subject variability of the trunk kinematics and ground reaction forces, and 1b) the intra-subject variability of the trunk kinematics and ground reaction forces. The following sections also discuss the implications of the current study, the limitations of the study, and ideas for future work.

It is important to note that in the study, independent variables besides age were considered (load weight and lifting asymmetry angle). These variables were selected with the intent to analyze their interactive effects with age; however, the results show that these other independent variables had effects on the variability of the trunk kinematics and ground reaction forces independent of age. These results will also be discussed.

Hypothesis 1a: Older subjects will have a greater inter-subject variability than younger subjects.

In the current literature on aging, there is a general consensus that muscle strength decreases with age. However, the rate at which muscle strength decreases varies from person to person. For example, Savinainen *et al.* (2004) states the same job can have varying effects on individuals that include differences in susceptibility to becoming injured and differences in physical risk factor exposures. Skelton *et al.* (1994) agree, and report that in their study, there was considerable variance in strength in similar ages among the healthy elderly individuals. These differences can lead to older workers undergoing musculoskeletal and aerobic fitness changes at different rates and to different degrees. Therefore, it would seem that a group of older workers would have a higher variance of muscle strength than a group of younger workers. This greater range of muscle strengths in the older group may affect the inter-individual variability in the way the group performs lifting tasks. Individuals with more muscle strength would perform lifting tasks differently than individuals with less muscle strength. Therefore, it was hypothesized that the older subject group would have a higher inter-subject variability than the younger subject group.

This hypothesis was not supported by the data in the current experiment since age was neither a significant main effect nor a factor in any significant interactions for any of the kinematic or ground reaction force dependent variables. In retrospect, there are several potential explanations for why age was not found to be significant. First, all the older subjects were in good health and the majority volunteered that they led active lives. Therefore, the muscle strength of the older subjects may not have been significantly heterogeneous. If there was not a wide range of muscle strengths among the older subjects, then the inter-subject variability of the lifting technique may not have increased. Previous research supports these explanations. For example, Wright and Mital's (1999) study comparing muscle strengths of older and younger individuals had an older subject group that was 55-74 years old (and a younger subject group aged 18-35 years). Even with this older age group, Wright and Mital did not find a significant effect of age on muscle strength. Wright and Mital cited the statistic that the percentage of individuals needing assistance in completing daily tasks doubles each succeeding decade between the ages of 45 and 84. The current study's older subject group was in the first two decades of the previous statistic, thus, the individuals might not have reached the age of needing assistance or the age of significant decreases in muscle strength. Wright and Mital's results, like the current study's, did not show a significant effect of age. They concluded that the older and younger age groups had a similar psychophysical lifting capability. Okada *et al.* (2001) also conducted a study that included comparing muscle strengths of older and younger individuals. They did find a significant effect of age on muscle strengths; however, the age group used for the older individuals was 67 to 72 years old and the younger individuals were aged 19 to 22 years.

Schroeder *et al.* (1998) compiled a comparison of life satisfaction, functional ability, physical characteristics, and activity level among older adults in various living settings. There were three populations of older adults that were analyzed including individuals (1): living in nursing facilities, (2): living in assisted-care facilities, and (3) those living independently in the community. A Physical Activity Questionnaire for the Elderly was given to all subjects, and the results indicated that the most active groups were the individuals living in the community and those living in assisted-care facilities. The least active group was those individuals living in nursing facilities. The subjects in the older subject group of the current study all fit into the category of community living individuals; therefore, they are among the most active older individuals; however, in a real industrial setting, there may be older workers who are not as active as the average older individual living in the community. Schroeder *et al.* (1998) report that individuals who maintain a high level of physical activity are usually stronger than their sedentary counterparts. The specific results from Schroeder *et al.*'s (1998) study of muscle strength show that the individuals who are living in the community had significantly greater leg press strength than both the individuals living in assisted-care facilities and those living in nursing facilities. Thus, the older subjects in the current study would have been stronger than older subjects who were not as active. This increased strength in the older subject group could be comparable to the younger subject group's strength, which would void the view that having a decreased strength in some individuals of the older group would increase the variability associated with how the older group performs the lifting tasks.

In the study by Savinainen *et al*. (2004), the older and younger workers were separated into groups that had a high perceived physical workload and a low perceived physical workload relative to the tasks they performed during the workday. The results showed that the older group of subjects with a high perceived workload had a decrease in muscle strength. Savinainen *et al.*. suggested that individuals with a job that entails a high physical demand may experience a wearing effect on their muscles, which would be a reason for the diminished muscle strength. In the current study, all subjects in the older age group were professors, which does not carry a lot of physical demand in the workload. Therefore, the subjects in the current study may not have experienced a wearing effect on their muscles and may not have had a significant decrease in muscle strength. Therefore, their muscle strength might not have been significantly different from the younger subject group's muscle strength, which would also affect the inter-subject variability. If there were not a wide range of muscle strength in the older subject group, then the inter-subject variability of the lifting technique might not have been large. Thus, the characteristics of the older subjects led to the data not supporting the hypothesis.

The weight*angle interaction was the only significant effect on the inter-subject variability dependent variables. This interaction was a significant effect on the inter-subject variability of the peak sagittal velocity. This result showed that at the 0° starting position, the inter-subject variability between the 4.59 and 9.17 kg (10 and 20 pound) weights was statistically different ($p<0.05$), with greater inter-subject variability at the 9.17kg (20 pound) weight. The result from the effect of the weight*angle interaction can be explained by subjects having more ways to lift the 4.59 kg (10 pound) weight at the 0° starting position since it was lighter and subject's would not have been as constrained by muscle strength. Yeung *et al.* (2002) conducted a study that evaluated the relative contribution of lifting task variables on physical effort required for the lift and the subject's perceived risk of injury. Their results indicate that the weight of the load has the most effect on the physical effort required to lift the load. They also determined that the more physical effort required to lift the load, the higher the perceived risk of injury. Therefore, subjects were not concerned as much with the risk of injury since they were lifting the lighter weight and lifting from the 0° starting position.

Hypothesis 1b: Older subjects will have a greater intra-subject variability than younger subjects.

It was hypothesized that there would be higher intra-subject variability among the older population. Intra-subject variability is apparent because an individual will not use the same lifting technique for all lifting tasks. Since older subjects have a decreased muscle strength, reduced balance, and reduced postural control (Okada *et al.*, 2001), it was reasoned that they may demonstrate greater variability from lift to lift than a younger subject performing the same lifting task. This effect would generate intra-subject variability.

Overall, the intra-subject variability dependent variables were more responsive than the inter-subject variability. However, the hypothesis related to intra-subject variability was still not supported by the data because age was neither a significant main effect nor a factor in any significant interactions for any of the intra-subject dependent variables. One possible explanation for why the intra-subject variability was not greater in the older group is that the older subjects have less flexibility than the younger subjects, so the older subjects did not have as many different ways to perform the lift. With a lesser flexibility, the older subjects were constrained in the way they performed the lift; thus, an older subject performed the lifting task with more consistency than a younger subject. Therefore, an older subject's lifting technique would be less variable than what was hypothesized. Previous literature supports these explanations (Okada *et al.*, 2001; Savinainen *et al.*, 2004; McGill *et al.*, 1999).

In Okada *et al.*'s (2001) study, the flexibility of the hip and ankle joints was examined. The results demonstrated that the older subject group had less flexibility and range of motion at the hip and ankle than the younger subject group. This means that the older group was more limited than the younger group in the way that they could perform the lifting task. Therefore, the older subjects would have a small intra-subject variability because each subject would be limited in the way he could perform the lift, which would make him perform the lift in a more consistent manner than expected.

McGill *et al.* (1999) developed a database of three-dimensional trunk kinematics in the elderly spine. They also compared this database to a similar database of young individuals. Their results show the difference in flexibility of older and younger individuals. They found that the older individuals were slower moving and had a reduced range of motion in flexion and lateral bending. Specifically, the maximum flexion movement for the older group was 70% less than the maximum flexion movement for the younger individuals. The maximum lateral bending motion for the older group was 41% less than the maximum lateral bending motion for the younger group. These results indicate significantly less flexibility and range of motion of the older individuals. Therefore, relating these results to the older subjects in the current study, older subjects would have less ways to change their lifting technique and would be more likely to use the same lifting technique, lift after lift. This would make the intra-subject variability less than expected for the older group, and possibly consistent with the intra-subject variability of the younger group. The non-significant effect of age may reflect a balancing of these changes in range of motion with the age-related changes in strength and balance control, as discussed in the development of the original hypotheses.

Angle was the only significant effect found in the MANOVA for the intra-subject variability dependent variables. Angle was a significant effect in the intra-subject variability of the peak coronal position, velocity and acceleration, the peak rotational position, velocity, and acceleration, the peak sagittal position, and the peak vertical downward forces of the right foot. The trend of intra-subject variability with respect to angle was that the variability increased with increasing angle. The only dependent variable to deviate from this trend was the intra-subject variability of the peak sagittal position. This trend showed decreasing intra-subject variability with increasing angle.

One possible explanation for the trend with respect to the effect of angle is that the subject does not have as much opportunity to deviate from the sagittal plane when lifting the box at the 0º starting position as at the 30º and 60º starting position. Therefore, the subject does not need to move in the coronal plane or does not need to rotate their body to perform the lift, thus, the intra-subject variability would be less at the 0º starting position. The subject has to lift somewhat in the coronal plane and has to have some trunk rotation in order to perform the lift at the 30º and 60º starting positions. Therefore, the intra-subject variability would be greater at 30º and 60º.

The only dependent variable to deviate from this trend is the intra-subject variability of the peak sagittal position. This trend showed decreasing intra-subject variability with increasing angle. One possible explanation for this trend is that at 0º, the subject is not constrained on a lifting technique. It was easier for them to switch between back or leg lifts at 0º since the box was directly in front of the subject. However, as the angle increased, it became harder for the subject to perform a back lift because the subject had to twist his body to get to the box. Thus, the intra-subject variability of the peak sagittal position would be less at the 30º and 60º than at the 0º starting position.

These results are important to consider when assessing the safety of lifting tasks. Since all individuals have an inherent intra-subject variability in the their lifting technique, they will not employ the same lifting technique every time they perform a lifting task. Angle has an impact on the intra-subject variability of the lifting technique; therefore, it is essential to consider a variety of lifting techniques, especially when the lifting task does not involve a sagittally symmetric lift, when determining if a lift meets safety standards.

Low back pain and low back disorders are caused by both chronic and acute exposure to risk factors. However, an individual that has had a career involving manual material handling tasks has been chronically exposed to risk factors for low back pain since he constantly performed stressful exertions day in and day out during his job. Over time, this individual is more likely to have back strain because the tolerance to stress has decreased due to his chronic exposure to the risk factors for back injuries. It could happen that an injury occurs during heavy lifting and acute exposure; however, the injury may actually be caused by this cumulative trauma. Thus, it is important to consider the variability in a lifting task so that the lifting tasks can be evaluated for safety for those individuals who have had chronic exposures to low back pain risk factors.

Implications of this Research

The current study has rather broad implications for manual material handling jobs. There are many different industries and types of jobs that require employees to perform lifting tasks throughout their workday. Examples include loaders, receivers, and stockers in department stores and warehouses. Assembly line workers also have to perform lifting tasks, which are repetitive throughout the day. These tasks should be evaluated and deemed safe for all workers in order to prevent over-exertion injuries. A lifting task surrounded by high variability may lead to a greater risk of injury to the worker if it is not properly checked for safety. Since most ergonomic assessments are based on average values, greater variability would mean that more values, in this case, trunk kinematics and ground reaction forces, may be at extreme levels, which have the possibility of leading to musculoskeletal disorders, such as low back pain.

Therefore, it is important that whenever an ergonomist is evaluating the safety of a lifting task, he or she takes into account the different lifting techniques an employee may use. Different weights and angles should also be taken into account. An ergonomist should study the way an individual performs the lifting task several times during the same day and also during different workdays. This is important because of the presence of intra-subject variability surrounding the lifting technique. In order for a lifting tasked to be deemed safe for employees, it must be safe for all workers and for a variety of lifting techniques. If performing the lifting task with a certain technique is not safe, for example using a back lift, then workers should be adequately trained and advised not to use that particular technique. It is recommended that special attention be placed on the lifts with more extreme starting positions, such as at 60º since results from the current study show that at the more extreme angles, the variability was greater.

Limitations

The first limitation of the present study is that the research experiment was conducted in a laboratory setting. Consequently, the lifting task was very controlled. For example, the subject was told not to move his feet during the lifting task; however, in a work environment, the worker would move his feet during the lift. Foot movement could change the ground reaction forces, and thus change the amount of variability associated with the ground reaction forces. The results obtained were quite possibly less variable than what would have been observed had the subjects been in a real industrial setting. The subjects only performed 6 lifts at a time and then had a break. In a real-life situation, workers might perform a lot more lifts before having a break. As more lifts are completed, the amount of variability associated with the lifting technique may change. As a worker becomes fatigued, his lifting technique could change, which would result in a higher intra-subject variability. Time, cost, and the need to gather "clean" accurate data were all reasons why the study was performed in a laboratory setting.

A second limitation was the difference in the age groups. Most of the current literature on aging had an older subject group than the current study. With even older subjects, it is a possibility that there would be a different amount of variability than what was observed. Having an even older subject group might have led to significant main effects of age in the inter-subject variability dependent variables.

A third limitation was the relatively homogenous nature of the older subject group. Since subjects were recruited from the university faculty and students, all older subjects happened to be Professors who led active lifestyles. Had special attention been placed on choosing older subjects with a wider range of activity levels, the variability might have been affected. Professors in general have not had careers entailing manual material handling tasks. Thus, they have not experienced the wear and tear on their muscles like individuals who have had a career performing manual material handling tasks. Having an older subject group that included subjects with and without experience in manual material handling tasks might have affected the results of the inter-subject variability.

Future Research

Future research should address the limitations of the current work. This should include having a wider gap between age groups and a more diverse group of older individuals. Having subject groups that include active and inactive subjects would give a better representation of the actual workforce and may change the significant results of inter-subject variability. The length of time the subjects perform the lifting task should be increased. It would be advantageous to test the effects of fatigue on the inter-and intra-subject variability. It would also be beneficial to record subject flexibility, range of motion, and muscle strength, including maximal leg exertions, so that explanations of the results can be supported by these values.

5 Conclusion

The objective of this research was to evaluate the inter- and intra-subject variability of trunk kinematics and ground reaction forces on the lifting technique used to perform a lifting task. Two subject groups were used in this study – a younger subject group and an older subject group. It was hypothesized that the older subject group would have a higher inter- and intra-subject variability than the younger subject group.

Subjects performed lifting tasks while trunk kinematic data and ground reaction force data were collected. There were two levels of load weight and three levels of lifting asymmetry angle. The inter- and intra-subject variability of the trunk kinematics and ground reaction forces were calculated using equations from the Modified Levene's test.

The results did not support the hypothesis, as age was neither a significant main effect nor a factor in any significant interactions for any of the inter- or intra-subject variability dependent variables. For inter-subject variability, the MANOVA showed that weight*angle was significant and for intra-subject variability, the MANOVA showed that angle was significant. The general trend of increasing intra-subject variability was demonstrated with increasing angle.

In conclusion, although age was not found to have a significant effect on the inter- or intra-subject variability of the trunk kinematics or ground reaction forces, weight*angle was significant on an inter-subject dependent variable, and angle was a significant effect on several of the intra-subject dependent variables. This means that with different load weights and lifting asymmetry angles, individuals choose different lifting techniques when performing a lifting task. Therefore, all these techniques should be considered when evaluating the safety of a lifting task.

References

Burgess-Limerick, R. (2003) "Squat, Stoop, or Something In Between?" *International Journal of Industrial Ergonomics*. 31(3), 143-148.

Gall, B., and Parkhouse, W. (2004) "Changes in Physical Capacity as a Function of Age in Heavy Manual Work." *Ergonomics*. 47(6), 671-687.

Granata, K.P., Marras, W.S., and Davis, K.G. (1999) "Variation in Spinal Load and Trunk Dynamics During Repeated Lifting Exertions." *Clinical Biomechanics*. 14, 367-375.

Gu, M.J., Schultz, A.B., Shepard, N.T., and Alexander, N.B. (1996) "Postural Control in Young and Elderly Adults When Stance is Perturbed: Dynamics." *Journal of Biomechanics*. 29(3), 319-329.

Herz, D.E. (1995). "Work After Early Retirement: An Increasing Trend Among Men." *Monthly Labor Review*. Online. http://stats.bls.gov/opub/mlr/1995/04/art2abs.htm. Accessed August 23, 2004.

Laughton, C.A., Slavin, M., Katdare, K., Nolan, L., Bean, J.F., Kerrigan, D.C., Phillips, E., Lipsitz, L.A., Collins, J.J. (2003) "Aging, Muscle Activity, and Balance Control: Physiologic Changes Associated with Balance Impairment." *Gait and Posture*. 18, 101-108.

Layne, L.A. and Pollack, K.M. (2004) "Nonfatal Occupational Injuries From Slips, Trips, and Falls Among Older Workers Treated in Hospital Emergency Departments, United States, 1998." *American Journal of Industrial Medicine*. 46, 32-41.

Levene, H. (1960). "Robust Tests for Equality of Variance." *Contributions to Probability and Statistics*. Z. Olkin, ed. Stanford University Press, Palo Alto, CA, 278-292.

Marras W.S., Fathallah, F.A., Miller, R.J., Davis, S.W., Mirka, G.A. (1992), "Accuracy of a Three-Dimensional Lumbar Motion Monitor for Recording Dynamic Trunk Motion Characteristics", International Journal of Industrial Ergonomics, 9, 75-87.

McGill, S.M., Yingling, V.R., and Peach, J.P. (1999) "Three-Dimensional Kinematics and Trunk Myoelectric Activity in the Elderly Spine – A Database Compared to Young People." *Clinical Biomechanics*. 6, 389-395.

Mills, P.M. and Barrett, R.S. (2001) "Swing Mechanics of Healthy Young and Elderly Men." *Human Movement Science*. 20, 427-446.

Mirka, G.A. and Baker, A. (1996) "An investigation of the variability in human performance during sagittally symmetric lifting tasks." *IIE Transactions*. 28, 754-752.

Mirka, G.A. and Marras, W.A. (1993) "A Stochastic Model of Trunk Muscle Coactivation During Trunk Bending." *Spine.* 18(11), 1396-1409.

Montgomery, D.C. (2001) *Design and Analysis of Experiments*. 5th Edition. Wiley, New York.

Okada, S., Hirakawa, K., Takada, Y., and Kinoshita, H. (2001) "Age-Related Differences in Postural Control in Humans in Response to a Sudden Deceleration Generated by Postural Disturbance." *European Journal of Applied Physiology*. 85, 10-18.

Rix, S. (2004) "Aging and Work: A View from the United States." AARP Public Policy Institute. UNC Institute on Aging. Online. http://www.aging.unc.edu/groups/work/resources.html. Accessed August 25, 2004.

Savinainen, M., Nygard, C.H., and Ilmarinen, J. (2004) "A 16-Year Follow-Up of Physical Capacity in Relation to Perceived Workload Among Ageing Employees." *Ergonomics.* 47(10), 1087-1102.

Schibye, B., Hansen, A.F., Sogaard, K., and Christensen, H. (2001) "Aerobic Power and Muscle Strength Among Young and Elderly Workers With and Without Physically Demanding Work Tasks." *Applied Ergonomics.* 32, 425-431.

Schroeder, J.M., Nau, K.L., Osness, W.H., Potteiger, J.A. (1998) "A Comparison of Life Satisfaction, Functional Ability, Physical Characteristics, and Activity Levels Among Older Adults in Various Living Settings." *Journal of Aging and Physical Activity.* 6, 340-349.

Schwerha, D.J. and McMullin, D.L. (2002) "Prioritizing Ergonomic Research in Aging for the 21st Century American Workforce." *Experimental Aging Research.* 28, 99-110.

Shephard, R.J. (1999) "Age and Physical Work Capacity." *Experimental Aging Research.* 25, 331-343.

Shephard, R.J. (2000) "Aging and Productivity: Some Physiological Issues." *International Journal of Industrial Ergonomics.* 25, 535-545.

Skelton, D.A., Greig, C.A., and Davies, J.M. (1994) "Strength, Power, and Related Functional Ability of Healthy People Aged 65-89 Years." *Age and Ageing.* 23(5), 371-382.

Stel, V.S., Smit, J.H., Plumijm, S.M.F, and Lips, P. (2004). "Consequences of Falling in Older Men and Women and Risk Factors for Health Service Use and Functional Decline." *Age and Ageing.* 33(1), 55-68.

Weston, J. (1999) "Promoting Longer Work Lives: Why It Matters." *New Opportunities for Older Workers.* Chapter 1. Committee for Economic Development. Online. http://www.ced.org/docs/report/report_older.pdf. Accessed August 25, 2004.

Williams, S.N., and Crumpton, L.L. (1997) "Investigating the Work Ability of Older Employees." *International Journal of Industrial Ergonomics.* 20, 241-249.

Wright, U.R., and Mital, A. (1999) "Maximum Weights of Handling Acceptable to People Aged 55-74 Years: Part I. Lifting." *Journal of Occupational Rehabilitation.* 9(1), 3-13.

Yeung, S.S., Genaidy, A.M., Huston, R., and Karwowski, W. (2002) "An Expert Cognitive Approach to Evaluate Physical Effort and Injury Risk in Manual Lifting – A Brief Report of a Pilot Study." *Human Factors and Ergonomics in Manufacturing*. 12(2), 227-234.

Appendix A – ANOVA Assumptions

Figures 17 and 18 represent the general trend of the normal quantile plot. Figure 17 is an example of the inter-subject variability data and Figure 18 is an example of the intra-subject variability data.

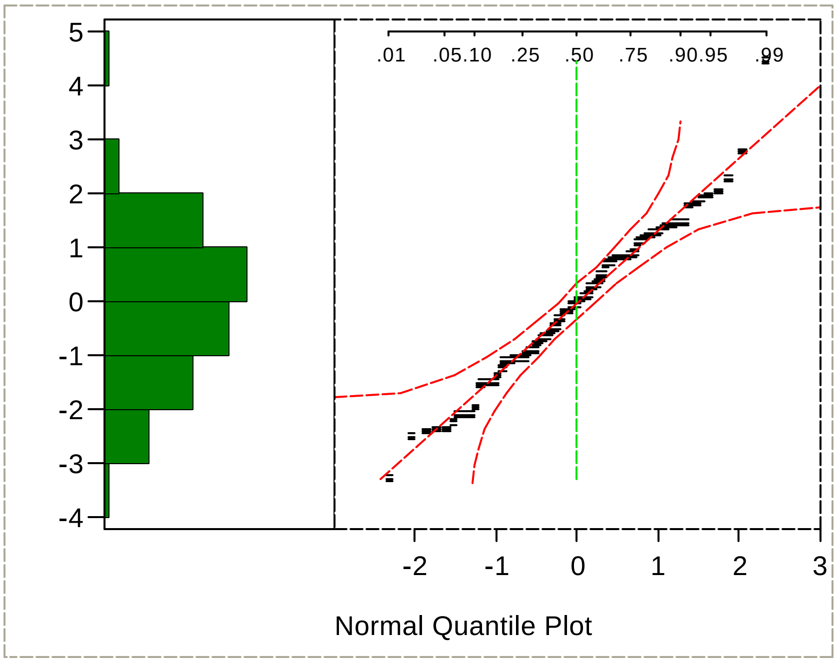

Figure 17: The normal quantile plot of the residuals for the inter-subject variability of the peak coronal position

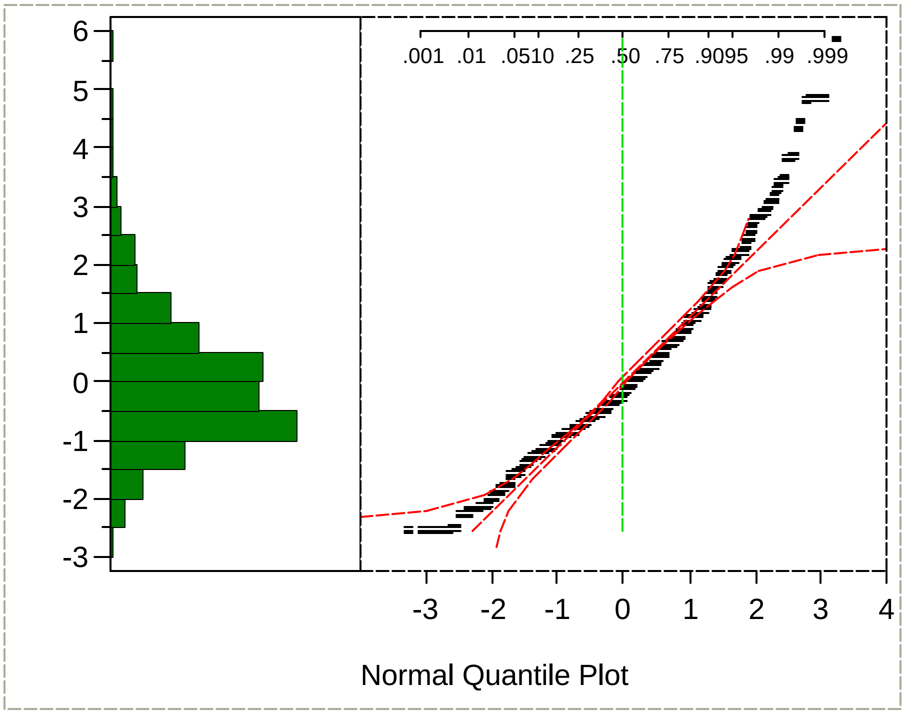

Figure 18: The normal quantile plot of the residuals for the intra-subject variability of the peak coronal position

Figures 19 and 20 represent the general trend of the residuals for testing the independence assumption of ANOVA. Figure 19 is an example of the inter-subject variability data and Figure 20 is an example of the intra-subject variability data.

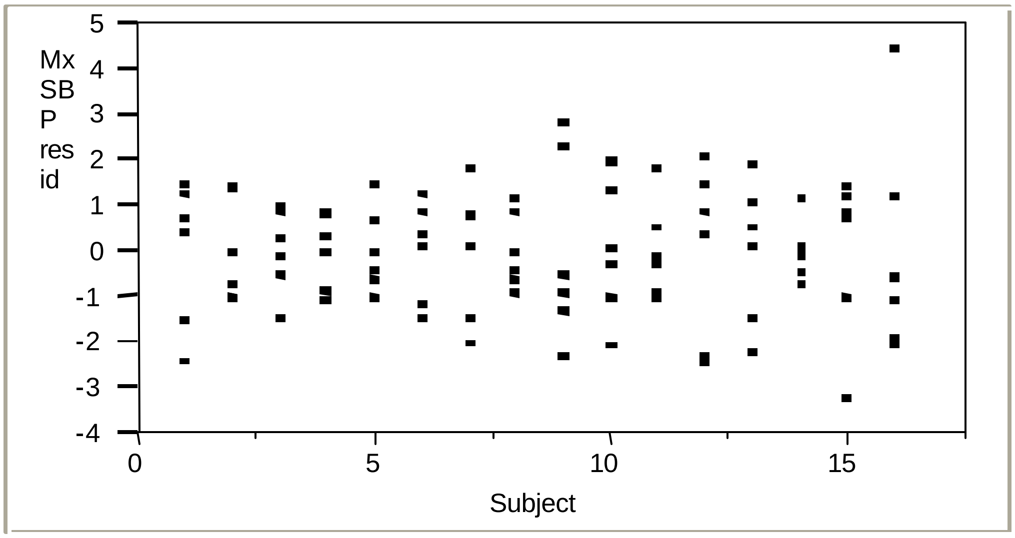

Figure 19: Scatter plot of the residuals to test the independence between trials for the inter-subject variability of the peak coronal position

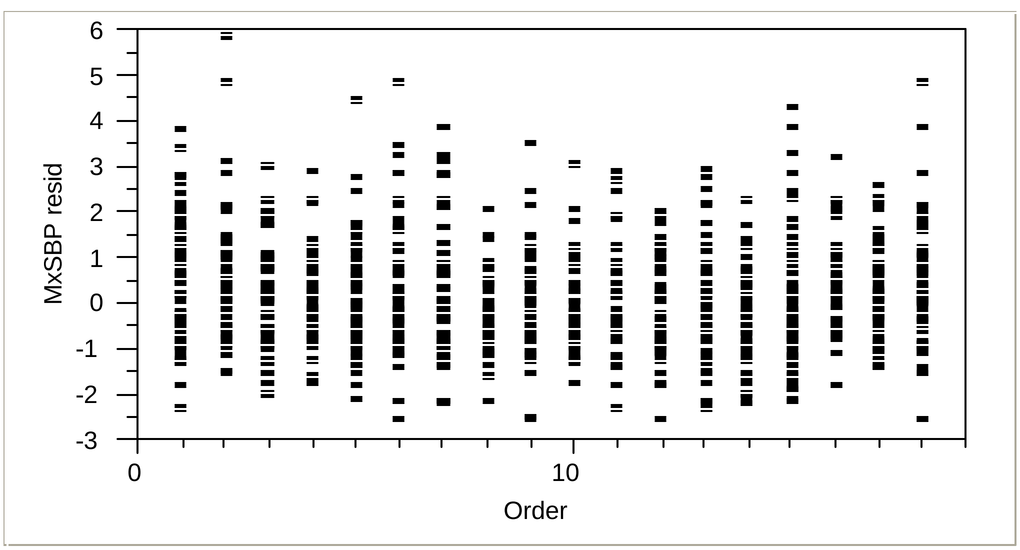

Figure 20: Scatter plot of the residuals to test the independence between trials for the intra-subject variability of the peak coronal position

Figures 21-24 illustrate the test for homogeneity of variances. Figure 21 is an example of the inter-subject variability dependent variables that needed to undergo a logarithmic transform. Figure 22 is an example of the logarithmic transformation of the pervious data. Figure 23 is an example of the intra-subject variability dependent variables that needed to undergo a logarithmic transform. Figure 24 is an example of the logarithmic transformation of the previous data.

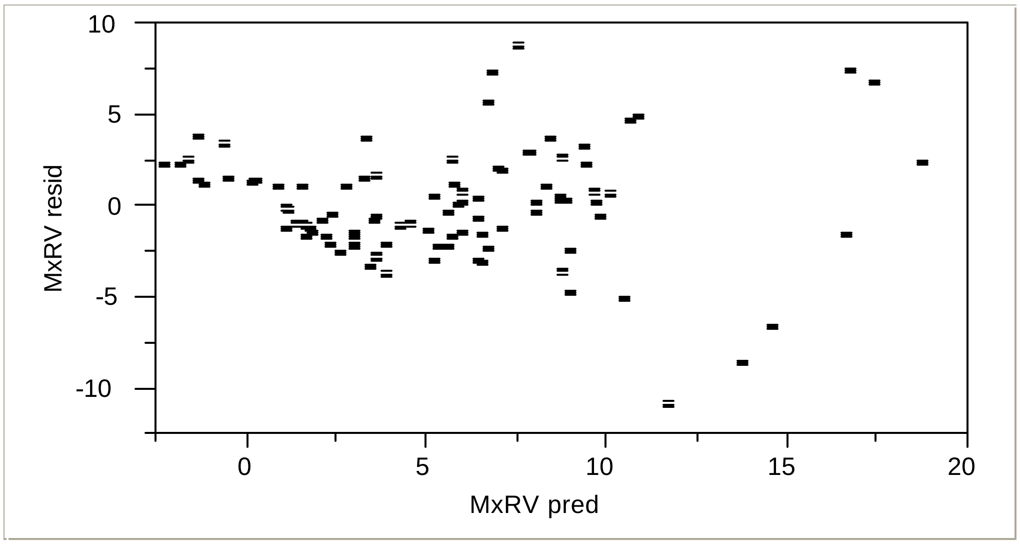

Figure 21: Scatter plot of the residuals as a function of the predicted values for the inter-subject variability of the peak rotational velocity

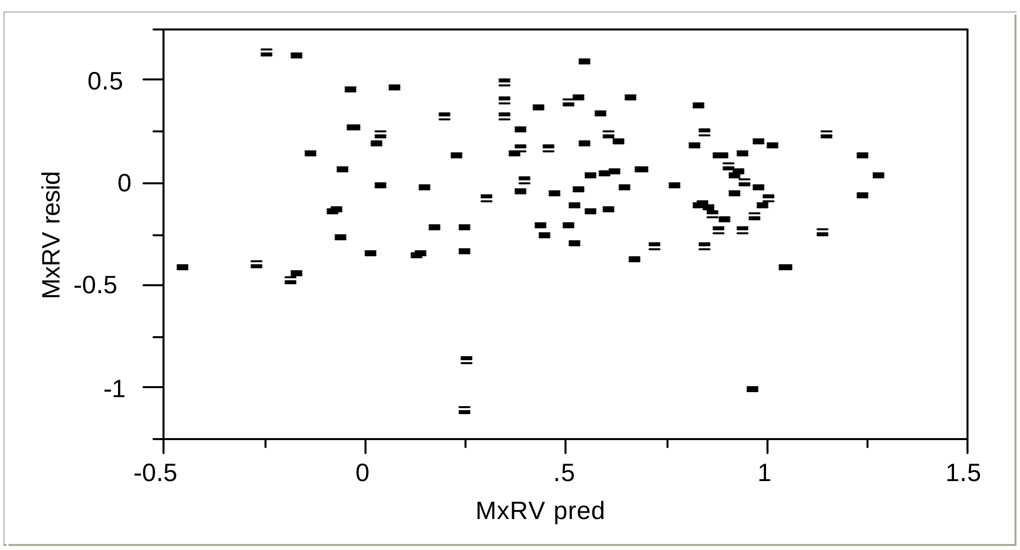

Figure 22: Scatter plot of the residuals as a function of the predicted values for the inter-subject variability of the peak rotational velocity using the log transformation values

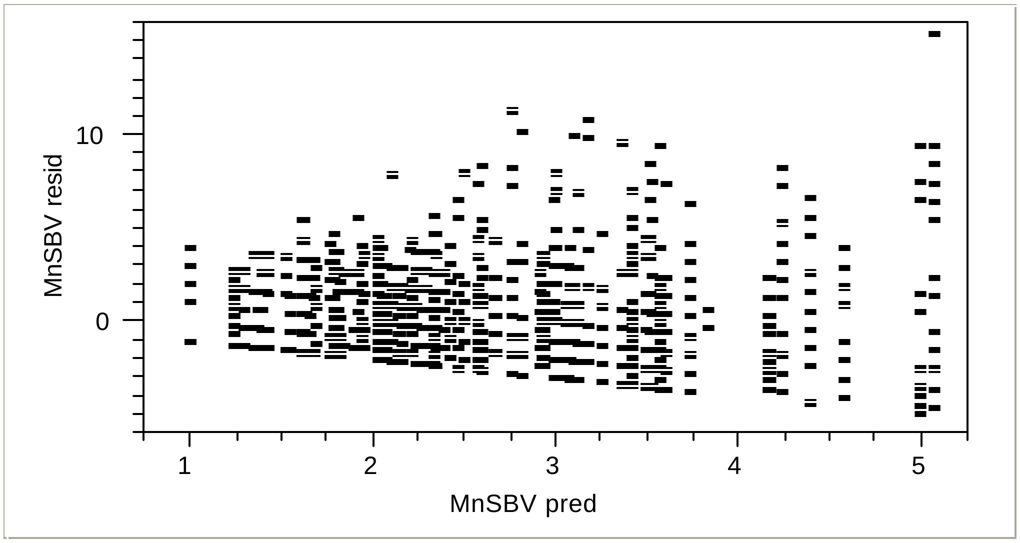

Figure 23: Scatter plot of the residuals as a function of the predicted values for the intra-subject variability of the peak coronal velocity

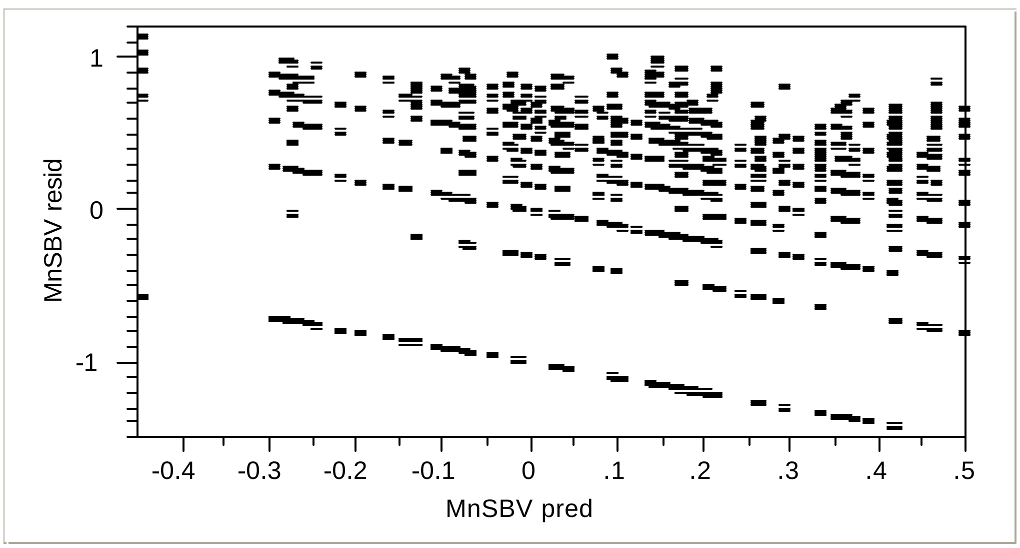

Figure 24: Scatter plot of the residuals as a function of the predicted values for the intra-subject variability of the peak coronal velocity using the log transformation values