ABSTRACT

MCCLURE, LEIGH R. Effects of Time of Day and Warm-Up on Lifting Kinematics. (Under the direction of Dr. Gary Mirka).

There is a real need to be able to understand the etiology of back injury. One area that has had only limited research is that of time of day effects. Previous studies have measured both the static (Adams et al., 1987) and dynamic (Fathallah et al., 1995) effects time of day has on the low back. These studies, however, measured maximum capabilities and did not relate their results to real world applications. The objective of the current study is to explore the effects that time of day and warm-up have on trunk kinematics during an industry inspired lifting task.

Nine male and three female subjects participated in the study. A series of four separate experimental sessions, two AM sessions held one hour after rising and two PM sessions held nine hours after rising, were performed. During one AM and one PM session the subject was led through a series of physical warm-up exercises prior to performing the lifting exertions. Upon conclusion of the warm-up, subjects completed a lifting task with two separate weight conditions, 3.6 kg and 10.9 kg. The lifting task consisted of lifting a box from the floor, rotating approximately 130º, and placing the load on an adjacent conveyer. Twenty consecutive lifts were completed for each load condition. The independent variables were SESSION (AM and PM), WARM-UP, and LOAD (low-3.6 kg and high-10.9 kg). The dependent variables considered in this study were peak trunk range of motion and peak trunk velocity in the sagittal and rotational planes, and the (x,y) coordinate positions of each knee in the anterior/posterior and lateral directions at the peak trunk position.

The experiment was of a split plot design and used MANOVA and subsequent univariate ANOVA to test for statistical significance. LOAD was the only independent variable that proved statistically significant, and was significant for trunk sagittal position, trunk sagittal velocity, and lateral knee position. Trunk sagittal position increased from 75 (±0.48)º to 78 (±0.50)º for the low and high conditions, respectively. Trunk sagittal velocity on the other hand decreased from the low (140 (±0.87)º/s) to the high (130 (±0.92)º/s) condition. Neither SESSION nor WARM-UP were found to affect these kinematics variables.

The lack of statistical significance could have occurred for several reasons. The current study chose to measure range of motion (ROM) while doing an industry inspired lifting task. In order to complete the task subjects were not necessarily required to use a full range of motion. Instead, they used only the range of motion needed to accomplish the task. Results showed that SESSION had little effect on this ROM. Subjects were also allowed to complete the lifting task in any way they chose, which introduced inter-subject variability to the experiment because no two subjects used the same lifting technique. Overall intra-subject lifting strategies did not change with regard to SESSION or level of muscle WARM-UP.

Effects of Time of Day and Warm-Up on Lifting Kinematics

by

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Dedication

To my parents, without whom I may not have been possible, I love you both!

Biography

Raised in Pittsburgh Pennsylvania, Leigh grew up with her two brothers, Kyle and Brant, and a series of pets. Loving support from her parents, Laura and Randy McClure, encouraged Leigh to excel in school. Math and Science were of particular interest to her which is why she decided to join the engineering department at the University of Pittsburgh. While at the university she earned a Bachelors of Science in bioengineering in 2004. The bioengineering curriculum helped her to realize that she had a passion for biomechanics and ergonomics.

During her last semester at the University of Pittsburgh Leigh decided to study abroad by participating in the Semester at Sea program. This is one of the best decisions she ever made. Leigh spent 100 days aboard the M.S. Explorer sailing around the world. She was fortunate enough to visit 11 amazing countries on 4 continents before returning to her life in Pittsburgh. Upon graduation Leigh decided to pursue a graduate degree at North Carolina State University in the field of Industrial and Systems Engineering, but not before she worked for 5 months at the Mining Injury Prevention Branch (MIPB) of the National Institute for Occupational Safety and Health (NIOSH). This experience helped to reaffirm her interest in ergonomics.

The curriculum at NC State University fostered her interest for ergonomics and introduced her to occupational safety. Her education at NC State has allowed Leigh to follow her passion and explore a few new interests. For this she will always be grateful.

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1. Introduction

1.1 Ergonomics

The overarching goal of occupational ergonomics is to fit the environment/task/technology to the worker. This means that one must take anthropometry, cognitive and physical human capabilities and limitations, and type of work into account when designing for the human user. The field has two major objectives. The first is to improve worker efficiency and effectiveness. The second is to enhance desirable human values. Improved safety, increased comfort, reduced stress and fatigue, increased user acceptance, greater job satisfaction, and an overall increase in quality of life are all examples of desirable human values (Sanders and McCormick, 1992). In order to effectively develop and implement ergonomic procedures and/or interventions one must have a firm grasp on the topic areas within ergonomics. These areas include: cognitive, organizational, and physical ergonomics. Cognitive ergonomics is the study of the ways in which the human brain acquires, processes, and responds to information. This area is also known as cognitive engineering, engineering psychology, and cognitive psychology (Sanders and McCormick, 1992). Organizational ergonomics is the study of the optimization of social and physical system organization. The goal of this branch of ergonomics is to save time and effort by organizing items in an efficient manner. Many times systems, or processes, are organized based on frequency of use, the more often an item is needed the easier it is to locate and use.

The current study is in the area of physical ergonomics. Physical ergonomics is the study of how the physical parts of the body interact with different components of the environment in order to complete a given task. The environment includes machines, tools, materials, temperature, lighting, noise, other workers, etc. Physical ergonomic principles allow one to evaluate job tasks and the demands they place on the worker, develop alternative work procedures and interventions to alleviate physical work demands, and even provide a basis for matching workers to job tasks (Chaffin et al., 1999).

1.2 Physical Ergonomics

Acute and cumulative trauma injuries and musculoskeletal disorders (MSD) cost industry tens of millions of dollars each year in medical and worker's compensation claims (Webster and Snook, 1994). In 2005 the Bureau of Labor and Statistics (BLS) reported 1.2 million injuries and illnesses that resulted in days away from work (BLS, 2005). Thirty percent (375,540) of the missed time injuries, in 2005, were a direct result of an MSD (BLS, 2005). According to the BLS, musculoskeletal disorders can be defined as an "injury or disorder of the muscles, nerves, tendons, joints, cartilage, or spinal discs" (BLS, 2005 p.7).

The part of the body most commonly injured is the trunk (including the back and shoulders). Trunk injuries were seen in thirty-five percent of lost time cases. Of the trunk injuries those specifically related to the back region made up sixty-three percent of the reported cases (BLS, 2005). Low back pain is a commonly reported type of pain among United States adults (Deyo et al., 2006). Many trunk injuries, especially low back pain, can be attributed to repetitive physical activity, especially manual material handling tasks. Among the most frequent jobs to report an MSD were material movers (BLS, 2005). Today, about 1/3 of industry jobs involve some type of manual material handling (MMH) (Garg, 1983).

It is easy to see that the back is a crucial area of focus when it comes to understanding the mechanics of injury. In order to quantify the mechanics of back injury one must first understand the structure of the back and how the bones, muscles and various passive tissues work together.

1.3 Anatomy of the Low Back

The back is a complex region of the human body. It is a system of bones, muscles, ligaments, and tendons that work together to aid in protection of the spinal cord and internal organs, and provide skeletal support, flexibility and movement. Some of the bones in the back include ribs, scapula, and the vertebral column. The vertebral column, more commonly referred to as the backbone, is a series of bones stacked one on top of the other. These bones are called vertebrae. The vertebrae are divided into four sections: the cervical, thoracic, lumbar, and sacrum regions. The cervical vertebrae are the smallest of the vertebrae. They make up the neck and one of their main purposes is to provide support to the head. In all there are 7 cervical vertebrae (C1-C7). The thoracic spine region supports the rib cage and has a limited range of motion. There are 12 vertebrae that make up the thoracic region (T1-T12), these bones span from the neck to just below the rib cage. The area with the largest vertebrae is the lumbar region. This is because the lumbar vertebrae bear most of the body's weight. There are 5 lumbar vertebrae (L1-L5) and the region is located in the lower back. The sacrum region is located at the inferior end of the backbone and consists of 5 fused vertebrae.

The spine also has a very important "S" shape that contributes to balance, flexibility, and the distribution and absorption of stress (Van de Graaff, 1992). The "S" shape contains two types of curves, primary and secondary. A primary curve, also called a kyphotic curve, is convex when looked at posteriorily while a secondary curve, also referred to as a lordotic curve, is concave. The spine alternates between these two types of curves. When observed posteriorily the thoracic and sacral regions have primary curves and the cervical and lumbar regions have secondary curves (Christensen, 1982).

The vertebrae are separated by a fibrocartilaginous disc. Structurally the discs are made of a soft gelatinous mass, called the nucleus pulposus, surrounded by a fibrous cartilage, called the annulus fibrosis (Christensen, 1982). These discs aid in spinal flexibility and absorb the stresses of spinal movement (Van de Graaff, 1992). The nucleus pulposus is made up of a loose framework of randomly distributed collagen fibers, proteoglycans, noncollageneous proteins, and water. The collagen fibers account for about 20% of the dry weight of the nucleus pulposus and water constitutes 70-80% of the total weight. The collagen fibers in the disc serve to confer mechanical strength to the tissue and their random organization aids in isotropic mechanical properties. Also the pressurization of the nucleus pulposus allows the discs to absorb and transmit compressive spinal loads. The characteristics of the annulus fibrosis are also important to the structure of the spine. The annulus fibrosis is comprised of highly aligned concentric rings of collagen fibers that surround the nucleus pulposus. Each fibrous ring is oriented at alternating angles to the ones beside it. This orientation is important because it is ideal for "withstanding large and complex loads in multiple directions"(Kurtz and Edidin, 2006 p.39).

Also aiding in spinal movement and strength are the back muscles. Back muscles are arranged in two groups: longitudinal and transverse. The longitudinal group of muscles runs vertically along the back. They span from the vertebrae to the angles of the ribs. These muscles extend the vertebral column. The muscles of the longitudinal group include: the erector spinae, the semispinalis, and the splenius (Christensen, 1982). The transverse group of muscles includes: the multifidi, the rotators, the interspinales, and the intertransversarii.

Placed one on top of the other (like sandwich layers) their primary purpose is to support the twisting action of the spinal column (Christensen, 1982).

Other structures that support the spine include ligaments and tendons. Ligaments and tendons are passive tissues that bolster spinal integrity by making connections between bones and muscles. Ligaments connect vertebral bones to each other while tendons connect bones to muscles. Both tissues are tough fibrous bands that add strength and flexibility to joints, in the case of ligaments, and aid in movement, in the case of tendons (Van de Graaff, 1992).

1.4 Time of Day and Preparatory Exercise Effects on Physical Performance

Two of the variables considered in the current study were time of day and preparatory exercise and these will be explored in the following sections. The emphasis in these sections will be on basic physiological and muscle responses. The occupational implications of these variables will be discussed in sections 1.6 and 1.7.

1.4.1 Time of Day

Of particular importance to the current study is the observation that tissues of the lower back change throughout the day. Upright standing places a load on the spine and causes the viscoelastic intervertebral discs to lose height by expelling fluid. This process of losing height by expelling fluid is caused by creep loading. Creep loading brings vertebrae closer together (Adams et al., 1987; Keller and Nathan, 1999). These diurnal changes cause the body to “shrink” about 15-20 millimeters over an 8 hour period (Keller and Nathan, 1999; Wing et al., 1991). Disc height reduction slackens ligaments and muscles by decreasing the amount they are stretched, thus making them less resistant to flexion later in the day (Adams et al., 1987). As creep takes place resistance to bending in the discs and ligaments reduces by 85% and 45%, respectively. Results like these indicate that flexion activities in the morning generate greater stresses in the lumbar spine than the same activities performed later in the day (Adams et al., 1990). Height changes are recouped when the body assumes a supine position for a full night of sleep. This cycle of losing and regaining body height is repeated on a daily basis (Adams et al, 1987; Keller and Nathan, 1999).

1.4.2 Preparatory Exercises

Another area of importance in the current study is describing a method for low back injury prevention. People commonly associate preparatory exercises with decreasing the likelihood of suffering an injury while performing a physical task (Koch et al., 2003; Stone et al., 2006). Preparatory exercises include both muscle warm-up and stretching activities.

1.4.2.1 Muscle Warm-up

There are several different theories as to how muscle warm-ups affect the body. The most popular theory is that effects are temperature related. By raising muscle temperature one decreases resistance in muscles and joints, increases the release of oxygen in the blood, speeds metabolic reactions, increases the nerve conduction rate, and increases thermoregulatory strain (Bishop, 2003). Simply put, warm-up is any sort of activity that prepares muscles for peak performance by raising their temperature (Reisman et al., 2005). Muscle temperature rises rapidly, generally within 3-5 minutes of the beginning of exercise (Saltin et al., 1968). Commonly used warm-up activities include: swimming, jogging, and biking (Bishop, 2003).

There are conflicting views in the literature when it comes to the physical benefit of warm-up exercises. Some studies show that they are helpful while others show no change or even a decrease in physical performance. One study found that a moderate intensity warm-up lasting 3-5 minutes is likely to significantly improve short term task performance (Bishop, 2003). Specifically task performance associated with improvements in time to task completion and power output. La et al. (2004) suggests that daily physical exercise programs are beneficial to workers involved in manual material handling. The preparatory exercises completed in the La et al. (2004) study served to reduce low back electromyographic (EMG) activity during completion of a lifting task. Others like Koch et al. (2003) found that the use of a warm-up had no significant effect on physical performance. They showed that none of their preparatory exercise treatments (stretching, high force, or high power warm-ups) had any effect on explosive task performance (ie. standing broad jump).

1.4.2.2 Stretching

One way to protect the delicate spine structures from damage is to reduce their stiffness by increasing muscle and joint flexibility. Muscle stiffness is associated with higher levels of muscle damage especially when performing eccentric contractions (McHugh et al., 1999). Stiffness is the ability of a tissue to resist a change in length and tissue stiffness decreases flexibility (Stone et al., 2006). One way to combat stiffness, by increasing range of motion (ROM), is to perform stretching exercises. Although it is generally believed that stretching, prior to exertion, will enhance ROM and improve performance there is not much data available on the effectiveness of such exercises (Bishop, 2003; Stone et al., 2006). Much of the available literature presents conflicting views on the effectiveness of this type of warm-up.

Cross and Worrell (1999) conducted a retrospective study on the effects of implementing a stretching routine on the incidence of musculotendinous strain injuries in the lower extremities. They studied a team of 195 college football players during their 1994 and 1995 seasons. Prior to the start of the 1995 football season Cross and Worrell (1999) added a stretching program to the practice schedule for the team. During the warm-up the players were instructed to stretch the targeted muscle group until they could feel a stretching sensation and then hold for 15 seconds, this was completed three times for each muscle group. The targeted muscle groups were the hamstrings, quadriceps, hip adductors, and gastrocnemius-soleus muscles. In order to analyze their results Cross and Worrell (1999) compared the medical records of the football players during the 1994 season to medical records from the 1995 season. From the records they reported the incidence of musculotendinous injury to the lower extremities. There were 155 injuries during the 1994 football season, 27.7% of which were musculotendinous injuries. The number of musculotendinous injuries was reduced in the 1995 season to 13.7% of the 153 total injuries. Results were evaluated for statistical significance using a chi-squared analysis. Chi-squared analysis revealed that this difference was statistically significant. "Musculotendinous strains were reduced 48.8% in 1995 compared with 1994 (43 versus 21 injuries)" (Cross and Worrell, 1999 p.13). Pre-season training programs remained the same from the 1994 to the 1995 seasons with the exception of adding the lower extremity stretching program. For this reason the authors of the study say it is safe to believe that the reduction in musculotendinous strain injuries is due to the implementation of the stretching program.

Others have found that warm-ups impacted performance negatively, particularly when it came to high power exertions using maximum power and strength. Cornwell et al. (2001) looked at the effects of passive stretching on high jump performance. Ten male subjects were asked to perform 2 types of vertical jump. One was a static jump with no lower extremity stretching. This jump was started in a squatted position and then the subject propelled themselves vertically in the air. The second jump was a countermovement jump that included an active pre-stretch. In the countermovement jump the subject started from an erect position squatted down and then immediately propelled their body vertically into the air. Each subject participated in 4 experimental test sessions. During each session both jumps were performed 3 times with a 10 minute rest break between the different styles of jump. On two of the testing days there was no passive stretching prior to testing and on the remaining two days a passive stretching exercise was conducted. Results indicated a significant decrease in both static and countermovement jump height and peak power after performing a passive stretching warm-up. Static and countermovement jump heights decreased by 4.4% and 4.3%, respectively. However, Cornwell et al. (2001) concede that the reduction in vertical jump height was only 1-2 cm and therefore the effects from stretching are likely to depend on the type of activity to follow.

1.5 Ergonomic Risk Factors for Low Back Injury

There is a real need to be able to quantify and understand the etiology of back injury. Back injury can be associated with very high loads, frequent bending and lifting, and also with repeated or prolonged low loading conditions (Marras et al., 1993; McGill, 1997). Hoogendoorn et al. (2000) found that degree of back flexion and load weight put workers at risk for low back pain. Maintaining 60º or more of flexion for more than 5% of the work day increases the risk of developing lower back discomfort as does lifting 25 kilograms or more 15 times per working day.

Overexertion has also been identified as a cause for low back injury because it means the job task has exceeded the capability of the worker (Cook and Neumann, 1987). The National Institute for Occupational Safety and Health (NIOSH) recognized that many workers were being injured due to significant strength exertions during job tasks (Chaffin et al., 1999). Thus in 1981 NIOSH developed and published "A Work Practices Guide for Manual Lifting". This guide limits the amount of weight a worker should lift based on the characteristics of the task (NIOSH, 1981).

Other studies focus in on this area in hopes to better our understanding of back injury prevention and treatment. Marras and Wongsam (1986) conducted a study that looked at the best way to predict and quantify back injury. They looked at back flexibility and velocity of movement and how they differed between groups. One group was made up of sixteen men with chronic low back pain (LBP). The other had eighteen participants who were all considered to be normal. Subjects completed a set of flexion, extension, and hyperextension tasks in the sagittal plane. Each of these tasks was completed at normal and maximal velocity. Results showed that men with LBP had a 50% slower flexion velocity than men who were considered normal. For this reason Marras and Wongsam (1986) suggest that "velocity data may be used as a quantitative measure of impairment" (Marras and Wongsam, 1986 p.217). People with already existing back impairment will tend to have a decreased trunk velocity when completing tasks as compared to those with normal back function.

Marras et al. (1993) completed another study looking at three dimensional trunk movements during repetitive manual material handling (MMH) tasks. Their aim was to see if analysis of trunk motion could be used to predict lower back disorders (LBD). They grouped 235 industry jobs into high and low risk LBD categories. Within these jobs they analyzed trunk motion characteristics. Results indicated that "velocity trunk motion components were the only trunk motion factors that were consistently different between risk groups in all planes " (Marras et al., 1993 p.620). Among the trunk motion factors velocity was the greatest predictor of injury and seemed to be the most “risk sensitive”. The larger the velocities during a repetitive task job the higher the injury risk for the worker. Collectively these two studies appear to indicate that trunk velocity may be a good predictor of low back injury risk.

1.6 Previous Research - Effects of Preparatory Exercises

Guo et al. (1992) conducted a study aimed at developing a stretching program for an industrial setting. Specifically they wanted to know if physical capacity (muscular strength, endurance time, and flexibility) was improved through a stretching/flexibility program, if flexibility training was better than a strength-flexibility program or vice versa, and if increasing the duration or the frequency of a stretch was better.

Guo et al. tested 24 hospital maintenance workers who were involved in various manual material handling tasks throughout their eight hour work shift. These subjects were split into four groups (1, 2, 3, and 4). Two groups (1 and 2) were trained for flexibility while the remaining two groups (3 and 4) were trained using strength-flexibility exercises. These groups were then divided again. Groups 1 and 3 increased the frequency of their stretching exercises while fixing the amount of time each stretch was held. Groups 2 and 4 did the opposite. They progressively increased the amount of time each stretch was held and fixed the number of times the stretch was completed. Training lasted four weeks and occurred five times per week. Subjects were tested for static strength, muscular endurance, and flexibility one week prior to the start of training and again one week after the completion of the training protocol. Due to non-adherence to the program three subjects were eliminated from the study (one from group 3 and two from group 4). Results showed that all groups had a statistically significant improvement in dynamic strength and endurance time from the pre to the post test. Most flexibility measure improvements were also statistically significant from the pre to the post test session. Increases in dynamic strength ranged from 28% to 59%. Endurance time improved a minimum of 99%, and flexibility improved 26%, 29%, 26%, and 20% for groups 1, 2, 3 and 4, respectively. Overall the study found a significant increase in physical capacity was achieved through the implementation of a flexibility training program. This improvement was seen regardless of progressive increases in stretch duration or stretch frequency. There was no significant difference between the results of the flexibility protocol versus the strength-flexibility training indicating that any sort of training protocol will improve worker physical capacity.

La et al. (2004) also conducted a study that examined the effects of physical exercise on worker well-being. They looked at the effectiveness of an exercise program at preventing low back pain, focusing on workers who regularly performed manual material handling tasks because they are among the most likely to suffer a back injury. Subjects were asked to perform a daily nine step exercise program for 6 months. The goal of these exercises was to increase both back muscle strength and flexibility. EMG signals were measured before and after completion of the 6 month program. In both testing sessions (before exercise and after 6 months of exercise) subjects were asked to lift 10 and 25 kilogram weights that were a horizontal distance of 35 and 55 cm away from the body. A total of eight subjects were tested. Results showed that EMG values were lower after completion of the exercise program. The force needed to complete the 10 kg lifting task decreased 12.39% after completing 6 months of daily exercise. Likewise muscle force for the 25 kg lifting task decreased by 9.66% after completing the exercise program. These findings provide support for the idea that maintaining a regular exercise routine is effective in increasing strength and flexibility. La et al. (2004) showed that a warm-up program conducted over time can be very beneficial to the worker.

1.7 Previous Research -Time of Day Effects on the Lower Back

Fathallah and Brogmus (1999) conducted a study looking at hourly trends in workers' compensation claims. The aim was to see if there was a trend in what time of day specific types of claims, LBDs and cumulative trauma disorders (CTDs), were recorded. They reviewed the 1994 workers' compensation claims from a large insurance provider. Over 600,000 claims were reviewed for LBDs within MMH related claims (about 12% of all claims) and CTDs (about 3.5% of all claims). Information included in each claim was cause, body part affected, and injury. The body parts of concern for the LBDs were the low back, disc, multiple trunk, sacrum and coccyx. Injury types to be considered for LBDs were hernia, rupture, strain, sprain, and inflammation. Body parts of interest for CTDs were multiple upper extremities, upper arm, elbow, lower arm, hand, finger(s), and thumb. Injury types for CTDs were inflammation, sprain, strain, carpal tunnel syndrome, and all other cumulative disorders. Within these subgroups the main information of interest was the time that the injury occurred and the estimated cost associated with claims in a given hour of the day. The numbers of workers working at any given time varies; Fathallah and Brogmus (1999) used this information to normalize the percentage of total claims and the percentage of total cost within each hour. They found that the number of injuries (LBD and CTD) generally increased from the 5 am hour until 10 am. CTD claims had a marked increase at the 9 am hour. The LBD claims showed an increase in this time period especially at the 9 and 10 am hours. After 10 am the number of injuries (LBD and CTD) steadily declined. There were slightly more LBD claims reported in the morning hours than the afternoon hours. One possible explanation for the increase in recorded back injuries in the morning hours could be due to biomechanical changes in the spine throughout the day (Fathallah and Brogmus, 1999). Intervertebral discs are subjected to creep loading which expels intervertebral fluid and slackens muscles and ligaments by decreasing the amount they are stretched. This process makes the spine less resistant to flexion later in the day. Studies have shown that morning flexion subjects the spine to higher moments than afternoon flexion because of the creep loading process (Adams et al., 1987; Wing et al., 1991). For this reason workers may be more likely to suffer a morning injury. Determining the time when workers are most likely to incur musculoskeletal injuries helps safety and ergonomic professionals better identify hazardous jobs and processes and develop appropriate safety measures. However, the study was limited to the time that claims were recorded which is not necessarily the same as the time that the claim was reported.

In another study Adams et al. (1987) investigated lumbar flexion angle in the morning compared to that observed in the afternoon. Using electronic incliniometers they measured lumbar curvature of 21 male and female subjects of varying ages (18–49 years). Incliniometers were attached, using double sided tape, to the L1 and sacrum levels of the spine to measure lumbar curvature. The output for each incliniometer was an angle measurement, θ_1 and θ_2. Lumbar curvature (C) was calculated by $C = \theta_1 + \theta_2$. Initial standing curvature was calculated before subjects were asked to fully flex. Total flexion was calculated by subtracting the initial standing curvature from the fully flexed curvature.

Subjects were tested shortly after rising from bed and again after they completed a full day of activities. The first five subjects were tested within 10 minutes of rising. Subsequent tests proved that experimental results would remain the same as long as the subject was tested within two hours of rising and upon entering the lab they lay supine for the same amount of time that elapsed between rising and their arrival in the laboratory. During both the morning and evening session the subjects were asked to sit on the floor with legs straight in front of them slightly apart and hands cupped behind their head. They were told to flex forward trying to touch their forehead to their knees all while keeping the knees straight. These precise instructions were useful in maximizing flexion and minimizing performance variability. When the subject reached their maximum forward bend the researchers recorded the measurement. This process was repeated three times during each session and the three values were averaged to calculate the lumbar curvature value.

All 21 subjects showed an increase in lumbar flexion from the early morning to the late afternoon session. This result was seen regardless of age, sex, or initial lumbar spinal curvature measurement and is supported by Franz-Bernhard et al. (1996). On average subjects experienced a statistically significant increase in flexion of $5.0^{\circ} \pm 1.9^{\circ}$. The average level of early morning lumbar flexion was 57º, while late afternoon flexion averaged 62º. Another interesting result to the study was that many subjects reported early morning flexion to be "hard work" and "uncomfortable". All in all Adams et al. (1987) found that "people can flex the lumbar spine more in the afternoon than in the early morning" (Adams et al., 1987 p.132). They also believe that much of this result can be explained by the diurnal fluid changes in the intervertebral spinal discs. This study was effective in documenting the increased range of lumbar flexion from morning to afternoon. However, Adams et al. (1987) only collected static readings and had no dynamic portion to their study.

Similar to the Adams et al. (1987) study, Fathallah et al. (1995) also considered the diurnal changes associated with spinal range of motion. However, they added a dynamic component to their experiment. They felt that the dynamic components of trunk flexibility were equally if not more important than the static components. The results presented by Marras and Wongsam (1986) and Marras et al. (1993) both indicated that trunk velocity was a key component in assessing LBDs and job risk factors, respectively. Twenty-one male college students participated. They were asked to attend three separate testing sessions held one hour after rising from bed (morning), five hours after rising (afternoon), and nine hours after rising (evening). During each session the subjects completed a series of six tasks: sagittal flexion and extension, left lateral bending, right lateral bending, left twisting, and right twisting. For tasks testing range of motion the subject was instructed to slowly complete the motion until he reached his maximum, hold it for one second and then slowly reverse direction. For tasks concentrating on velocity and acceleration the subject was instructed to move as quickly as possible through his range of motion without pausing. Experimental data was collected using a lumbar motion monitor, which measures position, velocity, and acceleration in the cardinal planes of motion.

From the data a percentage of maximum range of motion (PROM), percentage of maximum velocity (PVEL), and percentage of maximum acceleration (PAC) were calculated for each subject during each session and for each plane of motion. "The analysis showed no significant difference in PROM among sessions for any of the cardinal planes" (Fathallah et al., 1995 p.23). The dynamic variables only showed significance in the sagittal plane. The sagittal PVEL was only significantly different between the morning and evening sessions. PVEL increased from approximately 73% to about 85% from the morning to the evening session. Similarly, the sagittal PAC also followed an increasing trend and only showed significant difference between the morning and evening session.

The goal of the study was to quantify trunk range of motion, maximum velocity, and maximum acceleration changes that might occur over an eight hour work shift. Unfortunately there were few statistically significant results. They attributed the lack of significance partially to the experimental session times. Because Adams et al. (1987) tested subjects shortly after rising they may have been able to see larger changes in range of motion throughout the day. Fathallah et al. (1995) noted that testing subjects a full hour after rising may have interfered with the initial level of "stiffness" that people feel shortly after waking. Also they hypothesized that the results could be explained through the failure of core muscles, particularly the obliques and latissimus dorsi, to completely lie in any one of the cardinal planes of motion. Lastly, ligaments and other passive tissues may have caused variations in the dynamic motion data.

Fathallah et al. (1995) built off the Adams et al.(1987) study by including dynamic variables in their analyses. However, both of these studies focused only on the maximum capability component of spinal range of motion and never related their results to real world applications. For instance it would be advantageous to know how the diurnal changes of the spine affect workers completing a lifting task in the morning versus the afternoon. Also while previous studies have chosen to focus mainly on the effects that time of day has on the lower back, they have overlooked the effects this may have on the lower extremities, particularly the knees. By focusing on the knees as well as the back one may discover how lifting strategies change with time of day.

Another area of interest not explored by previous research is a method to counteract the lack of spinal flexibility measured in the morning hours. This is important because some industries may not be able to avoid lifting in the early morning when workers are stiff and more prone to low back injury. A series of warm-up exercises may better prepare workers for their lifting task by reducing spinal stiffness and increasing flexibility.

1.8 Research Objective

The objective of the current study is to explore the effects that time of day and warm-up have on trunk kinematics during an industry inspired lifting task.

1.9 Hypotheses

- It is hypothesized that there will be an increase in range of motion from the morning session to the afternoon session in both the sagittal and rotational planes of motion.
- It is hypothesized that velocities will increase in the afternoon session because muscles are warmed up and fluid has depleted from the intervertebral discs.
- It is hypothesized that the introduction of a warm-up will counteract morning "stiffness" and increase range of motion in the morning session.

2. Methods

2.1 Subjects

Nine male and three female subjects participated in the study. None of the subjects had any history of chronic back or lower extremity pain (hips, knees, and ankles), nor were they currently experiencing any back or lower extremity discomfort. The group had a mean (standard deviation) age of 25.8 (2.7) years, height of 179 (8.1) cm, and weight of 82.2 (19.3) kg. Participation in the study was voluntary and each subject signed an informed consent form approved by the North Carolina State Institutional Review Board (see Appendix 6.1).

2.2 Overview of Experiment

The study consisted of four separate experimental sessions: two AM sessions that were held one hour after rising and two PM sessions held nine hours after rising. The session times were chosen based on the research done by Fathallah et al. (1995), and were meant to mimic an eight hour work day. During one AM and one PM session the subject was led through a series of physical warm-up exercises prior to completion of any lifting task. Exercises were taken from previous strength-flexibility research by Guo et al. (1992). The routine was performed twice, took approximately seven minutes to complete, and consisted of various stretching activities and squats.

Upon conclusion of the warm-up, subjects completed a lifting task with two separate weight conditions. In the two sessions where warm-ups did not take place subjects were asked to complete lifting tasks shortly after entering the lab. During this experiment participants were asked to lift 3.6 kg (8 lbs) and 10.9 kg (24 lbs) boxes from the floor to a nearby conveyer. For each of these weight conditions twenty consecutive lifts were completed at a self-selected pace. The weight conditions are based on the NIOSH lifting equation recommendation for this specific task and represent the recommended weight limit (3.6 kg) and three times the recommended weight limit (10.9 kg). Experimental sessions for each subject were randomized, so the experiment was completed over multiple days.

2.3 Data Collection Equipment

The Lumbar Motion Monitor (LMM) was used to record the position, velocity, and acceleration of the lower back in the three cardinal planes of motion (frontal, rotational, and sagittal). The LMM is a type of exoskeleton that mimics spine motion (see Figure 1). It has been previously validated by Marras et al. (1992).

Figure 1: LMM and Magnetic motion sensor set-up.

Four motion sensors from a magnetic field based motion tracking system (Ascension Technology Corporation, VT, USA) were used to record the x, y, and z coordinates of the T12 and L5 levels of the spine as well as the anterior-posterior and lateral coordinates of the right and left knee. The collection rate for both devices was set at 60 Hz.

A survey was administered before and after the 10.9 kg lifting condition. The survey was used as a subjective measure of the difficulty of certain elements within the task. The survey was only given during the 10.9 kg lifting task because the researcher believed that the subjects were more likely to be able to differentiate the difference in difficulty (either physically or mentally) during the heavier lifting task. Prior to the 10.9 kg lifting task, in each of the experimental sessions, the subject was asked to rate their level of preparedness on a continuous scale. They placed a mark on a line from “not well prepared” to “very prepared”. This was the only question administered before the lift and the only question that the participant was able to see. Upon completion of the task the subject reflected upon their level of preparedness, the level of force necessary to perform the lifts, the rate at which they chose to lift the weights, and the range of motion required to complete the task. These questions also were rated on a continuous scale. Participants were neither able to see their answer to the question asked prior to the lift when answering the questions administered after the lift, nor were they able to view responses from previous sessions. The survey appeared as seen in Figure 2.

1) [Prior to Lifting] How well prepared do you feel for the lifting task?

____

Not well Prepared	Prepared	Very Prepared

2) [After Lifting] How well prepared were you to perform the lifting task?

____

Not well Prepared	Prepared	Very Prepared

3) How would you rate the level of lifting force required to complete the lifting task?

____

Low	Medium	High

4) How would you rate the lifting rate (lifts/minute) required to complete the lifting task?

____

Low	Medium	High

5) How would you rate the difficulty of postures and range of motion required to complete the lifting task?

____

Low	Medium	High

Figure 2: Task survey administered during the high load condition in each experimental session

2.4 Independent Variables

This study had three independent variables: SESSION (AM and PM), WARM-UP, and LOAD (low-3.6 kg and high-10.9 kg). Subjects were asked to participate in four sessions of this experiment tested at two very specific times of the day, one hour after rising from bed (AM) and nine hours after rising from bed (PM). One AM and one PM session had a WARM-UP component that was completed before the lifting task. The remaining AM and PM session had no sort of WARM-UP before the lifting task. Lastly, during each SESSION the participants were asked to perform the lifting task twenty consecutive times with each LOAD, low and high. The order in which these weights were lifted was randomized within each experimental session.

2.5 Dependent Variables

The dependent variables that were considered for this study were the peak range of motion and peak velocity for the sagittal and rotational planes, and the positions of each knee in the anterior/posterior and lateral directions at the peak trunk positions. Knee data was included in the experiment because it was hypothesized that a change in back lifting mechanics could consequently change the postures assumed by the lower extremities. For instance if a subject was lifting with a "cold" back they may be more inclined to perform a squat lift and increase their knee bend rather than using a stoop lift which requires the back to travel through a large range of motion. Knee data was necessary to evaluate the balance between back and knee bending.

Lateral plane motion of the torso for the experimental lifting task was minimal and therefore was not considered during data analysis. The large majority of the motion was seen in the sagittal and rotational planes. Angular velocity was also examined during the experiment because it has been shown to be an important variable for describing low back performance (Marras and Wongsam, 1986; Marras et al., 1993).

2.6 Experimental Protocol

2.6.1 Initial Session

During the first session each subject was shown the task they were going to complete and allowed to try it to make sure they were comfortable participating in the experiment. If subjects agreed to proceed they were asked to read and sign an informed consent form and given the opportunity to ask any questions they have about the experiment. After signing, subjects were asked to provide anthropometric data including age, height, and weight.

2.6.2 Sessions with a Warm-Up

Upon entering the lab the subject was led through a series of physical stretches and exercises taken from previous research conducted by Guo et al. (1992). These exercises were meant to increase back flexibility and provide a muscle warm-up. The exercises were completed as listed in Table 1. The physical routine was completed twice during sessions with a warm-up.

Table 1: Warm-up routine

Exercise	Repetitions	Directions
Lumbar Spine	3 times	• Subject starts the exercise from a flexion/extension erect position. • Bends the trunk forward around waist height with the hands reaching for the toes (lumbar spine flexion) and straight knees • Moves the trunk to an erect position • Places the hands around the waist • Bends the trunk backward as far as possible (lumbar spine extension) • The subject returns to the initial position
Lateral Bending	3 times on each side	• Subject begins from an erect position • Places both hands around the waist • Bends the trunk laterally to one side with straight knees • Moves the trunk to an erect posture • Bends it laterally to the other side • The subject resumes the initial position
Trunk Rotation	3 times on each side	• Subject begins from an erect positions • Places the hands around the waist • Rotates the trunk laterally to one side with straight knees • Moves the trunk to an erect posture • Rotates the trunk laterally to the other side • The subject resumes the initial posture
Knee Flexion/Extension	10 times	• Subject starts the exercise from an erect position • Subject bends the knees with straight back and hands around the waist • Subject resumes the initial position

After completion of the warm-up the subject was fit with a shoulder and pelvic harness, which attached to the Lumbar Motion Monitor (LMM). Once the LMM was in place the magnetic motion sensors were attached to the side of each knee using elastic straps. Motion sensors were also attached directly to the LMM at the T12 and L5 levels using double sided tape (see Figure 1). These sensors were used to synchronize the LMM and motion analysis data collection systems.

With the equipment in place the subject was shown where to stand and told to center their feet around the "+" marked on the floor. While standing in position the experimenter read these instructions:

> "You should complete this task at your fastest comfortable pace that you feel you could maintain for 1 hour. Throughout the lifting task please keep your toes pointed toward the conveyer at all times. To perform the lift pick up the load directly in front of you, twist until the back of your right hand touches the pole, and then place the load on the adjacent conveyer."

Subjects were instructed to lift twenty consecutive times at their own pace and lifting style. The only restriction placed on subjects was that they were asked to preserve the toes forward position throughout the entire task. The lifting task that each participant was asked to complete was to lift a box from the floor (vertical position = 25 cm , horizontal distance = 38 cm, asymmetry = 0º), turn approximately 130º until the back of their right hand lightly contacted a pole, and place the load on a nearby conveyer (vertical position = 101 cm, horizontal distance = 35 cm). (See Figure 3(a)-3(d)).

a) b) c) d)

Figure 3: (a) Initial lift position. (b) Beginning of lift. (c) Twist during lift. (d) End of lift

The subject performed twenty consecutive lifts for two weight conditions, low and high. Between lifting conditions each subject was given a brief rest period of roughly three minutes in duration. A survey (see Figure 2) was given to each participant before and after conclusion of the high load task. When the subject completed twenty consecutive lifts with each load the data collection devices were removed and the subject was free to go.

2.6.3 Session with No Warm-Up

Upon entering the lab the subject was immediately fitted with the LMM harnesses, the LMM, and magnetic motion sensors (see Figure 1). Magnetic motion sensors were attached to the sides of each knee as well as the T12 and L5 levels of the spine.

With the equipment in place the subject was shown where to stand and told to center their feet around the "+" marked on the floor. While standing in position the experimenter read these instructions:

> "You should complete this task at your fastest comfortable pace that you feel you could maintain for 1 hour. Throughout the lifting task please keep your toes pointed toward the conveyer at all times. To perform the lift pick up the load directly in front of you, twist until the back of your right hand touches the pole, and then place the load on the adjacent conveyer."

Subjects were instructed to lift twenty consecutive times at their own pace and lifting style for each load condition. The only restriction placed on subjects was that they were asked to preserve the toes forward position throughout the entire task. The lifting task that each participant was asked to complete was to lift a box from the floor (vertical position = 25 cm , horizontal distance = 38 cm, asymmetry = 0º), turn approximately 130º until the back of their right hand lightly contacted a pole, and place the load on a nearby conveyer (vertical position = 101 cm, horizontal distance = 35 cm). (See Figures 3(a)-3(d))

The subject performed twenty consecutive lifts for two weight conditions, low and high. Between lifting conditions each subject was given a brief rest period of roughly three minutes in duration. A survey (see Figure 2) was given to each participant before and after conclusion of the high load task. When the subject completed twenty consecutive lifts with each load the data collection devices were removed and the subject was free to go.

2.6.4 Final Session

At the completion of the final testing session subjects were asked to bend forward and try to touch the floor without bending at the knees. The distance from the middle fingertip to the floor was measured in order to determine the general level of subject flexibility. This is referred to as the fingertip-to-floor method and is an objective clinical method used to quantify lumbar range of motion, or flexibility (Franz-Bernhard et al, 1996). The average (standard deviation) level of flexibility among subjects was fingertips 8.3 (9.7) cm from the floor.

2.7 Data Analysis

Kinematics data were processed in a Matlab 7.0 code written for the experiment (see Appendix 6.2). The code plotted a graph of the LMM and the T12 motion sensor data to make sure the data sets were properly synchronized. Another graph was plotted that allowed the experimenter to section out each portion of the data that was determined to be part of the concentric lift. The concentric lift began when the subject’s hands contacted the load and ended when they released the load onto the conveyer. This was shown in the data by graphing the sagittal position of the back with the rotational back position. The lift data of interest started from peak sagittal angle until the peak rotational angle. These sections were able to be picked out from the data using the program and analyzed separately. The peak sagittal and rotational back angles and the peak sagittal and rotational velocities were found for each lift.

The Matlab code also calculated the anterior/posterior and lateral position of each knee sensor at the occurrences of the trunk sagittal and rotational plane peaks. Due to concerns related to magnetic interference the data for the left knee sensor (magnetic motion sensor #4) was eliminated from the experimental analysis.

All data was normalized based on a neutral standing position. The neutral standing position was considered to be the zero in all planes of motion. The offsets for each plane were added to the peak values in order to say that the subject started from the zero position. For example, if a subject had a neutral standing sagittal angle of -10 degrees then 10 degrees was added to each peak sagittal lift. The same procedure was followed for the rotational trunk peaks and the knee data. All were normalized to their respective neutral standing positions. Dynamic values were smoothed via the process built-in to the LMM software. All data values were compiled in an excel spreadsheet and analyzed for statistical significance. Sixteen lifts were analyzed for each subject for each experimental condition.

The answers to the survey questions were marked on a line which represented a continuous scale. The distance of the subject's mark along the scale was divided by the total line length in order to normalize the data (see Figure 4). These answers were then compiled and averaged among subjects for each experimental session.

1) [Prior to Lifting] How well prepared do you feel for the lifting task?

__________________________X__________________________

Not well Prepared	Prepared	Very Prepared

Total line length = 134 mm

Distance of X along the line = 67 mm

(67/134) x 100% = 50%

Figure 4: Example of survey data analysis

2.8 Statistical Analysis

The experiment was determined to be of a split plot design due to restrictions on lift order randomization. The model is as follows:

$$Y_{ijk} = \mu + \tau_i + \beta_j + (\tau\beta)_{ij} + \gamma_k + (\tau\gamma)_{ik} + (\beta\gamma)_{jk} + (\tau\beta\gamma)_{ijk} + \varepsilon_{ijk}$$

Where,

Y_{ijk} = Response variable

Whole Plot Factors

τ_i = Subjects (1-12)

β_j = Session (AM, AM with a warm-up, PM, PM with a warm-up)

$(\tau\beta)_{ij}$ = Whole plot error

Subplot Factors

γ_k = Weight conditions (low, high)

$(\tau\beta\gamma)_{ijk}$ = Subplot error

Analysis of variance (ANOVA) and multiple analysis of variance (MANOVA) were used to evaluate the effects of the independent variables and their interactions on the dependent variables.

Prior to any ANOVA or MANOVA analyses the assumptions of ANOVA were tested. Using the graphical methods described by Montgomery (2001) the normality, independence, and homogeneity of residuals were all tested. The normality assumption is tested by constructing a histogram of the residual values for each of the dependent variables.

If the distribution appears to have a normal shape centered on zero then the assumption is satisfied. A normal probability plot can also be constructed to further verify the normality assumption. If the residual error is normally distributed then all the data values will lie close to a straight line and remain within the boundaries (represented by dotted lines). The independence assumption makes sure the experiment is adequately randomized. It is tested by plotting the residuals in the time order of collection. As long as this graph of residuals versus time exhibits no trends or patterns then the assumption of independence is satisfied. Lastly, if the other assumptions are verified then the residuals should be structureless, or unrelated to any variables especially the predicted values. To test for homogeneity plot the residuals versus the predicted values. If there are no trends or patterns in the graph then the assumption is satisfied.

After the assumptions of ANOVA are confirmed but before ANOVA can be used to assess statistical significance, a MANOVA must be completed. MANOVA is used where there are multiple dependent variables. If the effects of a dependent variable or any of its interactions are significant in MANOVA then it is appropriate to conduct univariate ANOVA to further verify significance. Effects were considered significant in ANOVA and MANOVA if their p-value was less than or equal to 0.05.

3. Results

All LMM, magnetic sensor, and survey data were evaluated using a split plot design. The data analysis results are presented in four sections: assumptions of ANOVA, ANOVA of trunk and knee kinematic data, ANOVA of survey results, and data trends.

3.1 Assumptions of ANOVA

The tests for normality of residual, homogeneity, and independence were performed on the data set for the trunk and knee data and no violations of these assumptions were found. For examples of typical test results see Appendix 6.3. Assumptions of ANOVA were also tested for the survey data and no violations of these assumptions were found. For examples of typical responses see Appendix 6.4.

3.2 Results for Trunk and Knee Data

All data were statistically analyzed using MANOVA and univariate ANOVA. All F and p values, for each dependent variable, are presented in Table 2. Significant values are highlighted within the table.

Table 2: All F and p values for trunk and knee variables. While all data are presented only the highlighted boxes should be taken into consideration due to statistical significance.

	Session (S)	Warm-Up (W)	Load (L)	SxW	SxL	WxL	SxWxL
MANOVA	F=2.8 p=0.12	F=0.7 p=0.64	F=69.4 p<0.01	F=1.1 p=0.42	F=3.8 p=0.06	F=1.4 p=0.34	F=1.4 p=0.33
Trunk Sagittal Position	F= 0.8 p=0.37	F=0.7 p=0.42	F=43.4 p<0.01	F=0.02 p=0.88	F=7.7 p=0.01	F=0.1 p=0.73	F=0.01 p=0.92
Trunk Rotational Position	F=4.5 p=0.05	F=0.5 p=0.49	F=1.3 p=0.26	F=0.04 p=0.83	F=0.02 p=0.89	F=1.5 p=0.24	F=0.01 p=0.93
Trunk Sagittal Velocity	F=0.2 p=0.65	F=0.3 p=0.58	F=177.5 p<0.01	F=0.1 p=0.70	F=3.7 p=0.08	F=7.3 p=0.02	F=1.7 p=0.21
Trunk Rotational Velocity	F=3.4 p=0.09	F=1.0 p=0.33	F=1.3 p=0.27	F=1.2 p=0.29	F=0.09 p=0.77	F=6.5 p=0.02	F=0.01 p=0.91
Knee Anterior/Posterior Position	F=0.0 p=0.97	F=2.1 p=0.16	F=3.1 p=0.10	F=0.01 p=0.92	F=0.05 p=0.82	F=0.4 p=0.51	F=5.4 p=0.03
Knee Lateral Position	F=0.9 p=0.35	F=0.1 p=0.73	F=5.2 p=0.04	F=1.8 p=0.20	F=11.4 p<0.01	F=0.06 p=0.81	F=2.3 p=0.15

Interestingly, LOAD was the only independent variable that showed statistical significance. LOAD affected trunk sagittal position, trunk sagittal velocity, and the lateral position of the knee. Graphical representations of each of these effects are presented in Figures 5-7.

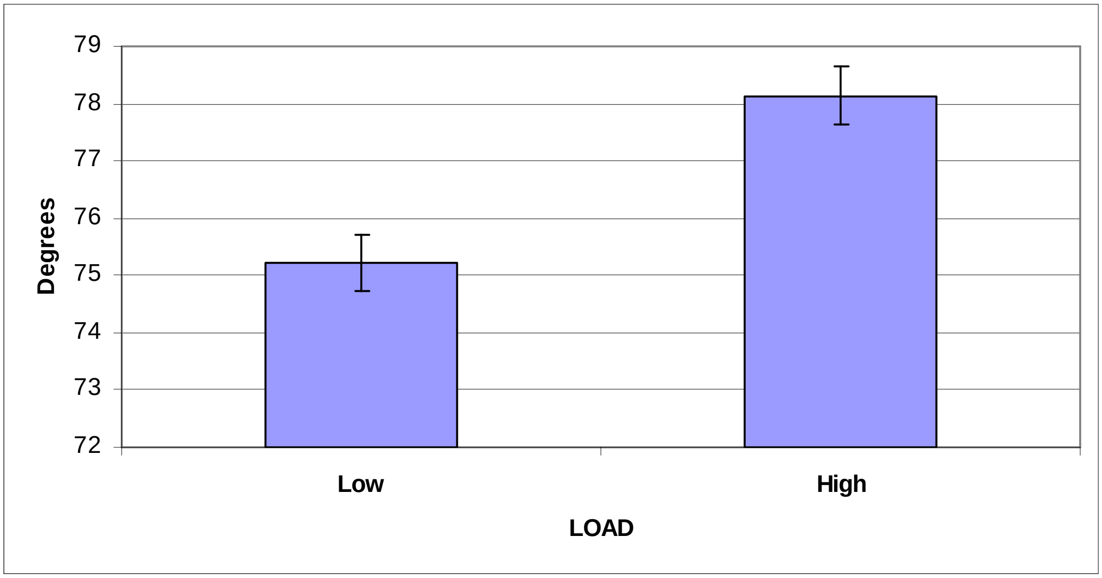

Figure 5: Effect of LOAD on sagittal trunk position with standard error bars

The average peak trunk position, in the sagittal plane, observed to complete the low load task was about three degrees less than that observed to complete the high load task. Trunk position in the sagittal plane was 75 (±0.48)º for the low load lifting task and 78 (±0.50) º for the high load task.

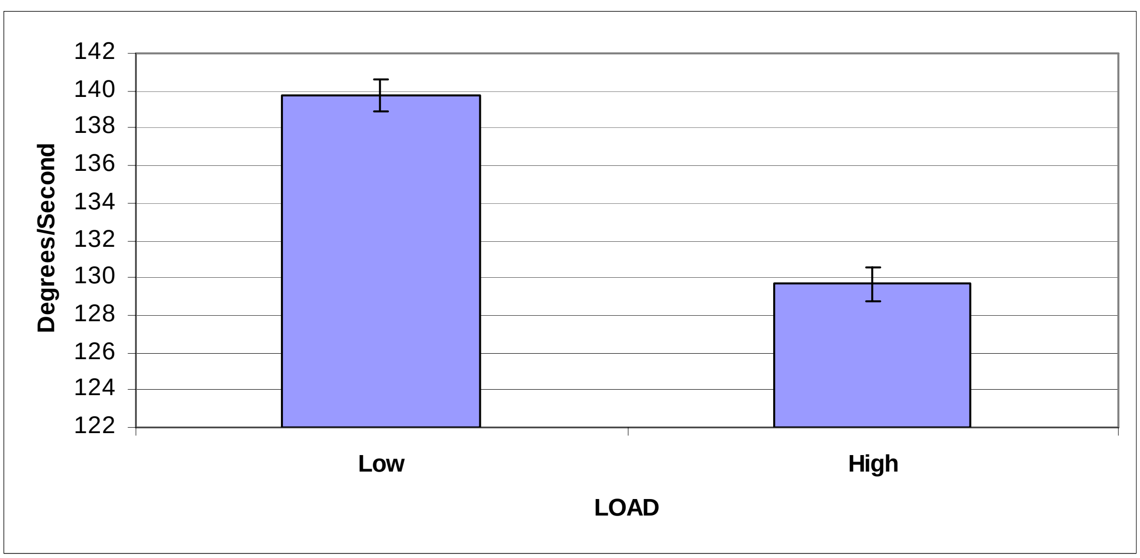

Figure 6: Effect of LOAD on sagittal trunk velocity with standard error bars

The average trunk velocity exhibited by the lumbar spine was higher in the low load lifting condition than in the high load condition. Sagittal trunk velocity for the low load lifts was 140 (±0.87)°/s. Sagittal trunk velocity for the high load lifts was 130 (±0.92)°/s. The low load lifts were performed an average of 10°/s quicker than each of the high load lifts.

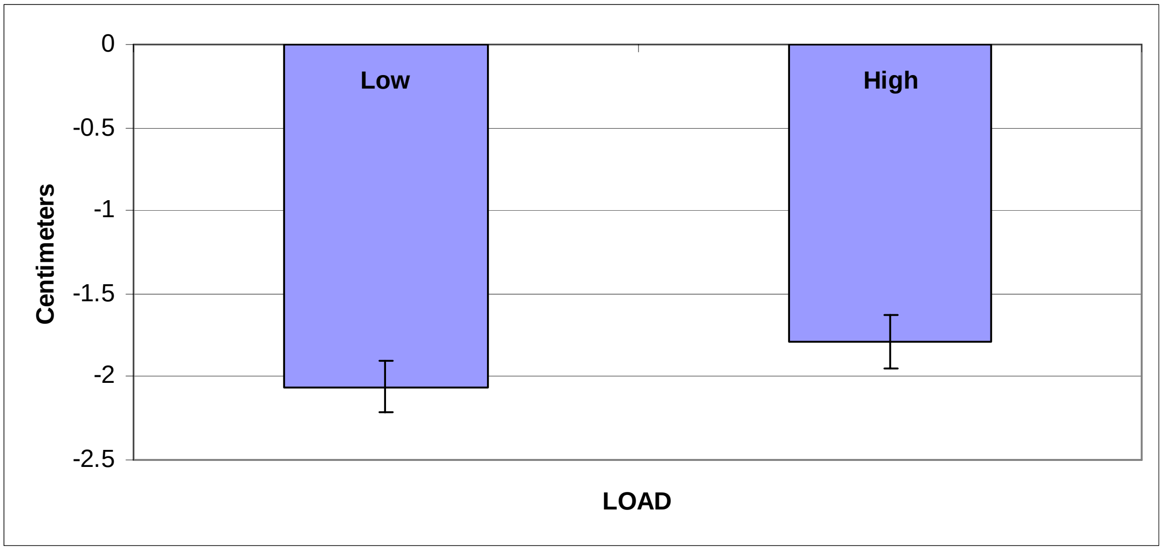

Figure 7: Effect of LOAD on lateral knee position with standard error bars

The knees tended to show more movement in the lateral plane during the low load condition. Negative values indicate a lateral position shift to the left while the trunk was twisting to the right. Average knee movement was -2.06 (±0.15) cm and -1.79 (±0.16) cm for the low load and high load, respectively.

3.3 Results for Survey Data

Survey data was also analyzed using a split plot design. MANOVA and univariate ANOVA analyses were run to check for significance. All F and p values for the survey data are reported in Table 3.

Table 3: All F and p values for survey data

	Session (S)	Warm-Up (W)	SxW
MANOVA	F=1.3 p=0.34	F=0.9 p=0.52	F=0.3 p=0.89
Question 1	F=4.4 p=0.06	F=0.7 p=0.42	F=1.5 p=0.24
Question 2	F=0.2 p=0.66	F=2.2 p=0.16	F=0.03 p=0.86
Question 3	F=1.1 p=0.32	F=1.4 p=0.25	F=0.1 p=0.75
Question 4	F=0.0 p=0.95	F=0.0 p=1.00	F=0.08 p=0.78
Question 5	F=0.2 p=0.67	F=0.9 p=0.36	F=0.1 p=0.38

Oddly, despite subject claims that lifting was easier after completing a warm-up, there were no significant effects found in the analysis of the survey data.

3.4 Data Trends

Although not statistically significant there was a decreasing trend seen in the SESSION data for sagittal and rotational trunk position (see Figure 8). Sagittal and rotational trunk velocities, on the other hand, generally increased from the AM to the PM session (see Figure 9).

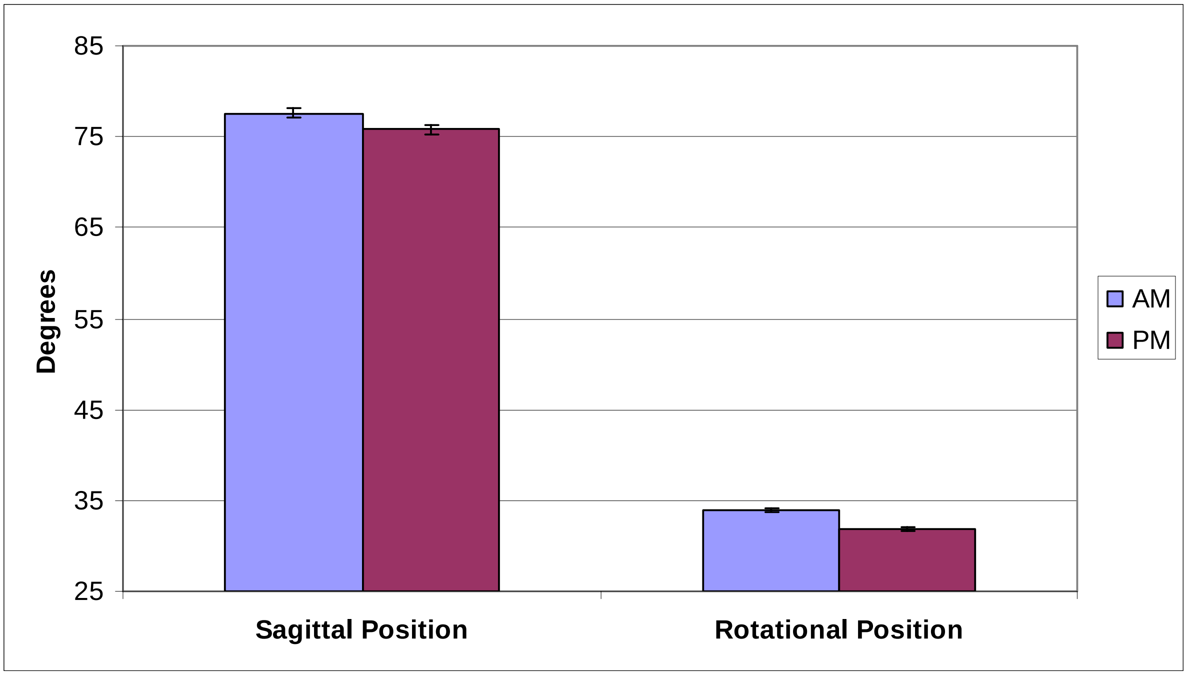

Figure 8: Effects of SESSION on sagittal and rotational trunk position trends with standard error bars

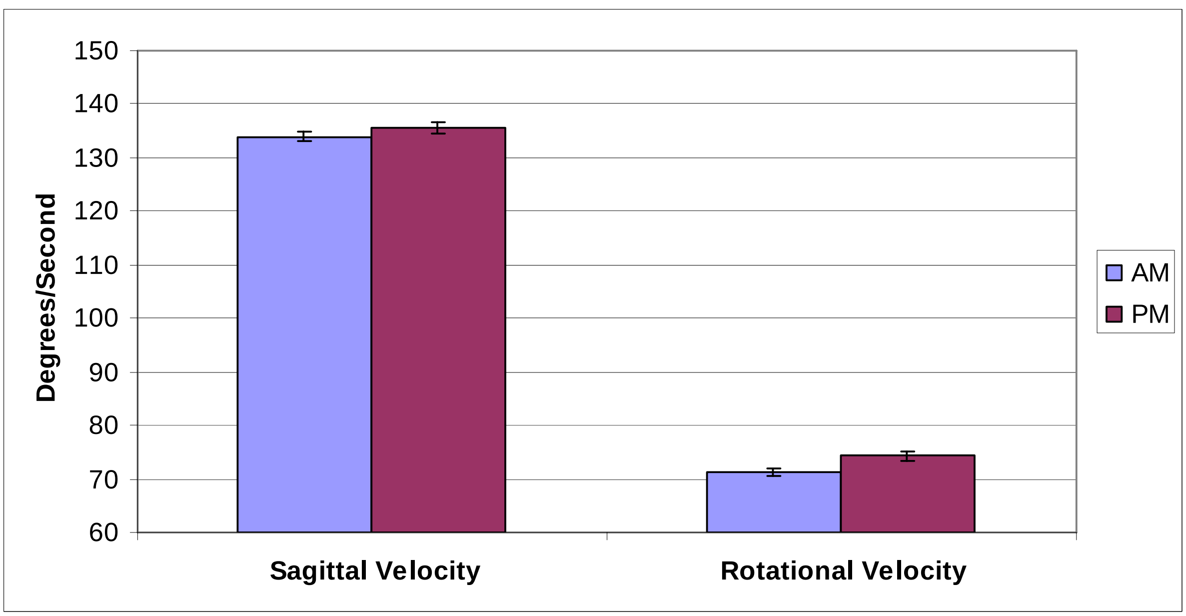

Figure 9: Effects of SESSION on sagittal and rotational trunk velocity trends with standard error bars

A statistically non-significant, increasing trend was seen in experimental sessions with a warm-up for both trunk position and velocity data, with the exception of rotational velocity, which decreased (see Figures 10 and 11).

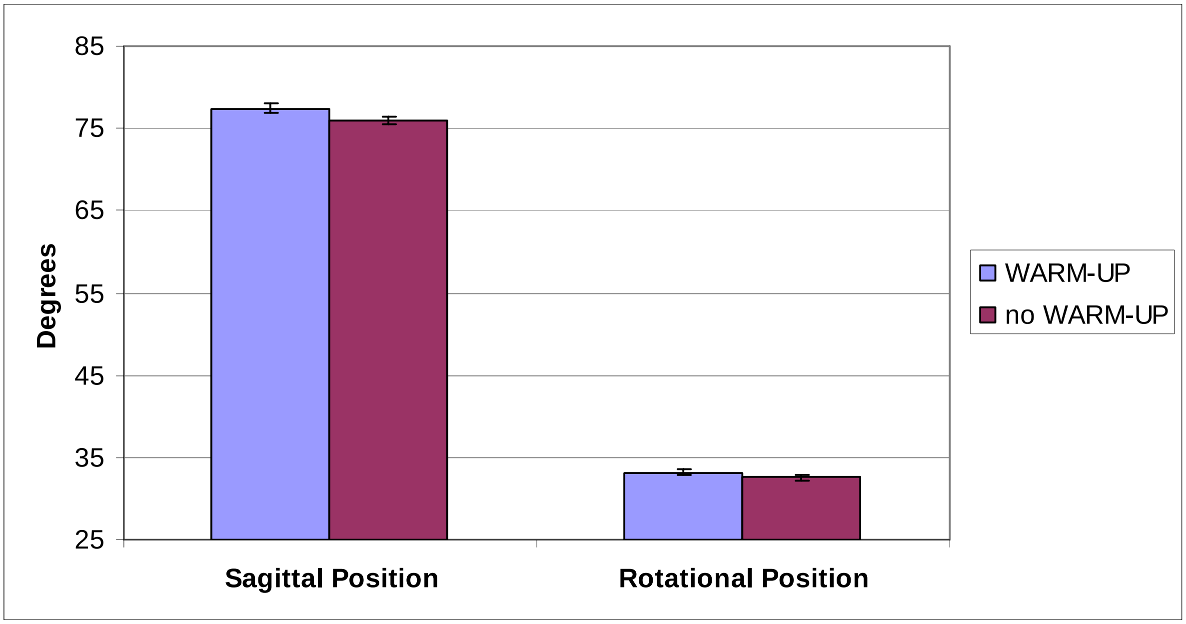

Figure 10: Effects of WARM-UP on sagittal and rotational trunk position trends with standard error bars

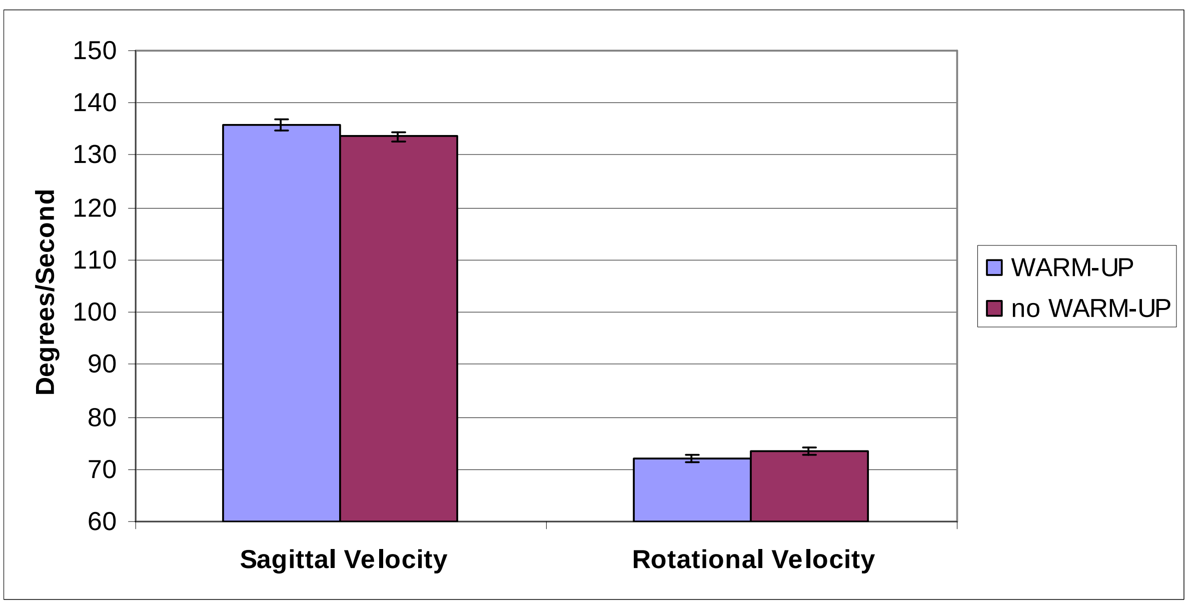

Figure 11: Effects of WARM-UP on sagittal and rotational trunk velocity trends with standard error bars

4. Discussion

The results of this study were not consistent with the original hypotheses. It was hypothesized that there would be an increase in trunk range of motion in the sagittal and rotational planes, from the AM to PM sessions. This hypothesis was supported by research conducted by Adams et al. (1987) who found that regardless of age, sex, or degree of spinal curvature the maximum spinal range of motion increased an average of $5^{o} \pm 1.9^{o}$ throughout the day. Similar results were reported by Adams et al. (1990), Krag et al. (1990), and Tyrrell et al. (1985). It is theorized that the increase in maximum range of motion is due to height loss in the intervertebral discs. Each day when one rises from bed spinal discs are fully saturated with intervertebral fluid. Gravity and creep loading expel fluid throughout the day. This fluid loss slackens ligaments and muscles and eliminates “stiffness”, thus resulting in an increase in maximum range of spinal motion. However, these expected results were not seen in this study. There could be several reasons for these results.

Previous studies have measured maximum range of motion and how it changes throughout the day. Subjects have been asked to flex in any one plane of motion to their maximum ability. The current study chose to measure ROM while doing an industry inspired task. In order to complete the task, subjects were not necessarily required to use a full range of motion. Instead they used only the range of motion needed to accomplish the task. Results showed that SESSION had little effect on this ROM. That is not to say that lumbar range of motion did not increase with SESSION, just that the increase was not necessary to complete the task and therefore any increase in ROM was not reflected in the task.

Subjects were also allowed to complete the task in any way they liked as long as they preserved the toes forward position. The thought was that as spinal range of motion increased lifting technique may change, therefore different lifting strategies may be used during the AM and PM sessions. This turned out not to be the case and the free dynamic nature of the task introduced subject variability to the experiment. No subject completed the task in exactly the same way. Some subjects used their lower extremities to squat down to lift the weighted box while others stooped over and primarily used their trunk to lift. There were no consistent differences in techniques used in AM sessions versus PM sessions.

Another possibility for the non-significant results for SESSION could be due to expulsion of spine stiffening intervertebral fluid being eliminated prior to AM testing sessions. Tyrrell et al. (1985) indicate that 54% of the total diurnal change occurs in the first hour after rising. Perhaps by the time subjects arrived in the lab (1 hour after rising) it was too long after waking and enough intervertebral fluid had already been expelled that there was no effect seen in peak range of motion with time of day. Research suggests that fluid is expelled relatively quickly (Krag et al., 1990). Further Parkinson et al (2004) found that lumbar stiffness exhibited a biphasic response when performing repetitive lifting (subjects in the Parkinson et al. (2004) study lifted at a rate of 7 lifts per minute for 1.5 hours). Tissue stiffness initially decreased but was followed by an increase in stiffness. They conjectured that the initial response phase could be due to soft tissue creep, and the secondary response phase due to soft tissue swelling because of overuse. While this was probably not a factor in the current study, because subjects did not lift for an extended period of time, but the biphasic response is still an important time of day effect.

It was also hypothesized that velocity would increase from the AM to the PM sessions. An increase in velocity would indicate that stiffness had depleted from the spinal discs and the worker was able to complete the tasks at hand more quickly due to increased ROM. However, study results indicated that sagittal and rotational trunk velocities due to time of day were not statistically significant. Subjects completed the task as fast as they felt comfortable in the morning session. The pace they chose to use may have been their maximum for the task regardless of the SESSION. Results also showed that, on average, there was no significant increase in range of motion which indicated that lumbar flexion levels were the same in the AM and PM sessions. Because lumbar flexion levels remained the same so did velocity due to no increase in ROM that would allow for greater task completion speeds. Fatigue may have been a contributing factor to the velocity results. By the time subjects completed the PM session they would have experienced a full day of activity and may have simply been too tired to complete the task at a faster pace.

It was hypothesized that the introduction of a WARM-UP would serve to counteract morning stiffness and increase the range of motion used in AM testing sessions. Although literature is conflicted on the benefit of warm-up it is readily believed among athletes, coaches, and the general public that warm-up is a good way to prepare for physical activity (Koch et al., 2003 and Bishop, 2003). That it readies muscles for peak physical performance. Of the studies that have been conducted several have shown that this simply may not be true. Many times warm-up activities have little, no, or even adversely effect performance (Cornwell et al., 2001 and Koch et al., 2003). The results of this study seem to support the notion that warm-up plays little role in preparing the body for a physical task.

The goal of the warm-up activity was to prepare muscles and soft tissues for physical activity and increase spinal range of motion in order to counteract stiffness. As indicated by the non-significant results of the kinematics and survey data, WARM-UP had little effect on either physical readiness or the feeling of subjective preparedness. The lack of positive results could be due to the elimination of morning stiffness prior to the AM testing session. As previously mentioned intervertebral fluid may have been expelled before AM testing sessions began and thus no amount of stretching or warm-up would aid in increasing lumbar range of motion. This may indicate that performing a warm-up activity prior to a physical lifting task is not effective if the lifting task is performed greater than 1 hour after rising.

However, the WARM-UP for this study could be considered low intensity and was done over a short term period. Perhaps if the warm-up intensity and duration were increased then beneficial results would be apparent. Completing the warm-up activities over a long term period would also serve to improve physical health. Consistent exercise has been shown to have positive effects on worker well-being (La et al, 2004). While warm-up immediately prior to activity was not significant a regular exercise routine may have a significant effect on physical response. If one was to measure the response to physical warm-up over a longer period, results may be different.

Warm-up should perhaps be assessed and applied on an individual basis. Some subjects verbally told the experimenter that lifting seemed easier after a WARM-UP session, especially in the morning. However, although stated verbally, subjects' opinions were not reflected as such on their surveys. Subjects were not able to see their answers to survey questions of prior sessions nor were they allowed to compare the pre and post lift question.

If this were allowed, the survey may have more accurately reflected their opinions. Approaching the survey in this manner would have made question responses more relative.

The main effect of LOAD proved to be significant. LOAD was significant for trunk sagittal position, trunk sagittal velocity, and knee rotational position. The range of motion the trunk used for the low load was about three degrees less than that used during the high load. More sagittal flexion was used for heavier loads. Bending down farther got the center of mass closer to the load prior to lifting which may have made it easier to pick up. Cook and Neumann (1987) observed that locating a load closer to the center of mass of the body worked to reduce energy expenditure, thus making the task at hand less difficult. Sagittal velocity in the trunk was greater during low load tasks. Because these loads were lighter they could more quickly and easily be lifted and carried through the range of motion necessary to complete the task.

The current study was a performance-based assessment that looked at how time of day and warm-up affected lifting kinematics. Results showed that neither time of day nor introduction of a warm-up significantly effected kinematics data. These results are useful in industry because they suggest that lifting tasks can be completed regardless of time of day or warm-up level. There does not appear to be any increased risk associated with completing a lifting task, similar to the one performed in the study, in the morning as opposed to in the afternoon. Lifting strategies did not change with regard to time of day or level of muscle warm-up. Load size, however, should be taken into consideration. High load tasks require an increased range of motion and level of control, reflected by a decrease in task completion velocity.

4.1 Limitations

- This experiment included no static measurement of maximal range of motion. Adding this test would have been useful to see if there was a change in ROM with time of day that just was not reflected in the industry inspired task.
- The study used a low to mid intensity short term warm-up routine. Perhaps conducting a long term warm-up regimen would have a significant effect on improving AM range of motion and counteracting morning stiffness.
- Survey responses in the study were absolute in nature. Meaning that subjects were unable to view previous question responses. Conducting the survey in a more relative manner, by allowing subjects to view previous responses, may better reflect the psychophysical opinions of the subject.

4.2 Conclusions

Previous research studies have failed to relate the effects of diurnal spinal changes to their implications for industry. The current study chose to explore these effects as well as the effects that performing a warm-up has on time of day lifting kinematics. To test these effects an industry inspired lifting task was designed and data was collected over 4 experimental sessions (AM, AM with a warm-up, PM, and PM with a warm-up). Results showed that neither time of day nor warm-up significantly affected lifting kinematics. The industry inspired task designed for the current study did not require subjects to use a maximum range of motion. Instead subjects only used the range necessary to complete the task. This departure from measuring maximum range of motion to peak range of motion could be the reason for the lack of significant results.

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6. Appendix

6.1 Informed Consent Form

North Carolina State University
INFORMED CONSENT FORM for RESEARCH

Title of Study:
Principal Investigator: Leigh McClure Faculty
Sponsor: Dr. Gary Mirka

We are asking you to participate in a research study. The purpose of this study is to discover how time of day, load size, and calisthenic warm-up effect lifting posture and speed. YOU MUST BE 18 YEARS OF AGE OR OLDER to participate in this study.

Initial here____________ to indicate that you are over 18 years of age or older.

INFORMATION

If you agree to participate in this study, you will be asked to perform a lifting task during 4 separate sessions. There will be 2 morning sessions held 1 hour after rising, and 2 afternoon sessions held 9 hours after rising. The procedure is as follows: (1) Anthropometric measurements, including weight, may be taken. (2) Depending on the session you will be led through a series of calisthenic warm-up exercises. (3) You will be fitted with a shoulder and pelvic harness that will support the data collection device which will be mounted on your back. (4) Two magnetic motion sensors will be fixed to the back of the data collection device. Magnetic motion sensors will also be placed of the backs of both thighs and both shins. (5) You will be positioned facing a load, either 8 or 24 pounds, that you will be asked to lift from the floor and place on a table 20 times in a row. You will be able to lift using any style that you want but will be instructed to keep your toes pointed forward at all times. You should lift at your fastest comfortable pace that you feel you could maintain for 1 hour. After 20 lifts you will be given a rest period of 3 minutes and then asked to perform the 20 consecutive lifts again using the other load condition. (6) A brief survey will be administered before and after the 24 pound lifting task. (7) When the 2 lift sets are completed the sensors will be removed and you will be free to go.

RISKS

The carrying task should not induce significant muscle fatigue or discomfort in the muscles of your back, legs, arms, and abdomen. If at any point you do feel pain, please stop the task and alert the experimenter. If you have any chronic problems or recent injury or pain in your low back, hips, knees, or ankles, you should not participate in this experiment. If you do not have any trouble with muscles and joints (back, knee, wrist, neck, shoulder, etc.), please mark your initials here: _____.

If you experience any numbness, tingling, or sharp pains during the study please stop immediately and notify the researcher. If the researcher determines that it is in your best interest to stop, she will remove you from the study.

Finally, you may experience some low back muscle soreness for a couple days after the experiment similar to that felt after a strong workout.

BENEFITS

This experiment could benefit society by lowering the number of lifting induced injuries. Discovering how time of day, load size, and muscle warm-up effect lifting technique may allow for improved lift safety recommendations.

CONFIDENTIALITY

The information in the study records will be kept strictly confidential. Data will be stored securely. You will be represented as a letter number combination in the test data that will in no way be linked to your identity. No reference will be made in oral or written reports which could link you to the study.

COMPENSATION

There is no compensation for this study.

EMERGENCY MEDICAL TREATMENT

If you need emergency medical treatment during the study session(s), the researcher will contact the University's emergency medical services at 515-3333 for necessary care. There is no provision for free medical care for you if you are injured as a result of this study.

CONTACT

If you have questions at any time about the study or the procedures, you may contact the researcher, Leigh McClure at 919-515-7210. If you feel you have not been treated according to the descriptions in this form, or your rights as a participant in research have been violated during the course of this project, you may contact Dr.

Matthew Zingraff, Chair of the NCSU IRB for the Use of Human Subjects in Research Committee, Box 7514, NCSU Campus (919/513-1834) or Mr. Matthew Ronning, Assistant Vice Chancellor, Research Administration, Box 7514, NCSU Campus (919/513-2148)

PARTICIPATION

Your participation in this study is voluntary; you may decline to participate without penalty. If you decide to participate, you may withdraw from the study at any time. If you withdraw from the study before data collection is completed your data will be returned to you or destroyed at your request.

CONSENT

"I have read and understand the above information. I have received a copy of this form. I agree to participate in this study with the understanding that I may withdraw at any time."

Subject's signature_______________________________________ **Date** _________________

Investigator's signature__________________________________ **Date** _________________

6.2 Matlab Code

```
clear
%read in the neutral standing files to make sure that the markers didn't
%move too much between trials, also to get an average neutral standing
%position.
[Frames sS2_x sS2_y sS2_z sS2_ang sS3_x sS3_y sS3_z sS3_ang sS4_x sS4_y sS4_z
sS4_ang sS5_x sS5_y sS5_z sS5_ang sS6_x sS6_y sS6_z sS6_ang sS7_x sS7_y sS7_z
sS7_ang] = textread('S01_AM_bup.EXP','%f %f %f %f %f %f %f %f %f %f %f %f %f %f
%f %f %f %f %f %f %f %f %f %f %f','headerlines',9);

%plot to visually check neutral standing trials.
hwnd = figure('position', get(0, 'ScreenSize'));
figure (1)
plot(sS2_x, 'r')
hold on
plot(sS3_x, 'b')
hold on
plot(sS4_x, 'c')
hold on
plot(sS5_x, 'k')
title('neutral standing')
pause
close(hwnd);

%Finding the average neutral marker position.
T12_avex = mean(sS2_x);
T12_avey = mean(sS2_y);
T12_avez = mean(sS2_z);
L5_avex = mean(sS3_x);
L5_avey = mean(sS3_y);
L5_avez = mean(sS3_z);
LKnee_avex = mean(sS4_x);
Lknee_avey = mean(sS4_y);
LKnee_avez = mean(sS4_z);
RKnee_avex = mean(sS5_x);
RKnee_avey = mean(sS5_y);
RKnee_avez = mean(sS5_z);

%putting the average standing positions into a matrix
Neutral = [T12_avex T12_avey T12_avez;L5_avex  L5_avey  L5_avez;LKnee_avex
Lknee_avey LKnee_avez;RKnee_avex RKnee_avey RKnee_avez];

%directly reads in the ASCII task files, eliminates the header, and names each column
```

```
[Time1 Lat_pos1 Lat_vel1 Lat_acc1 Sag_pos1 Sag_vel1 Sag_acc1 Rot_pos1 Rot_vel1
Rot_acc1] = textread('AM_LO1.S01','%f %f %f %f %f %f %f %f %f %f','headerlines',14);
[Time2 Lat_pos2 Lat_vel2 Lat_acc2 Sag_pos2 Sag_vel2 Sag_acc2 Rot_pos2 Rot_vel2
Rot_acc2] = textread('AM_LO2.S01','%f %f %f %f %f %f %f %f %f %f','headerlines',14);
[Time3 Lat_pos3 Lat_vel3 Lat_acc3 Sag_pos3 Sag_vel3 Sag_acc3 Rot_pos3 Rot_vel3
Rot_acc3] = textread('AM_LO3.S01','%f %f %f %f %f %f %f %f %f %f','headerlines',14);
[Time4 Lat_pos4 Lat_vel4 Lat_acc4 Sag_pos4 Sag_vel4 Sag_acc4 Rot_pos4 Rot_vel4
Rot_acc4] = textread('AM_LO4.S01','%f %f %f %f %f %f %f %f %f %f','headerlines',14);

[Frames S2_x S2_y S2_z S2_ang S3_x S3_y S3_z S3_ang S4_x S4_y S4_z S4_ang S5_x
S5_y S5_z S5_ang S6_x S6_y S6_z S6_ang S7_x S7_y S7_z S7_ang] =
textread('S01_AM_lo.EXP','%f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f
%f %f %f %f %f %f %f','headerlines',9);
%Makes each file into a matrix (M,N,O and P)
M = [Time1 Lat_pos1 Lat_vel1 Lat_acc1 Sag_pos1 Sag_vel1 Sag_acc1 Rot_pos1 Rot_vel1
Rot_acc1];
N = [Time2 Lat_pos2 Lat_vel2 Lat_acc2 Sag_pos2 Sag_vel2 Sag_acc2 Rot_pos2 Rot_vel2
Rot_acc2];
O = [Time3 Lat_pos3 Lat_vel3 Lat_acc3 Sag_pos3 Sag_vel3 Sag_acc3 Rot_pos3 Rot_vel3
Rot_acc3];
P = [Time4 Lat_pos4 Lat_vel4 Lat_acc4 Sag_pos4 Sag_vel4 Sag_acc4 Rot_pos4 Rot_vel4
Rot_acc4];

%creating a blank matrix full of zeros
B = zeros([130 10]);

%combining all files to form one full matrix
ALL = [M;B;N;B;O;B;P];

%Naming matrix columns
Time = ALL(:,1);
Lat_pos = ALL(:,2);
Lat_vel = ALL(:,3);
Lat_acc = ALL(:,4);
Sag_pos = ALL(:,5);
Sag_vel = ALL(:,6);
Sag_acc = ALL(:,7);
Rot_pos = ALL(:,8);
Rot_vel = ALL(:,9);
Rot_acc = ALL(:,10);

%Gives the Max and Min values in each column in the matrix
Matrix_Maxs = max(ALL);
Matrix_Mins = min(ALL);
```

```
%Plot to show LMM versus FOB data, Use to make sure data is lining up
%properly
hwnd = figure('position', get(0, 'ScreenSize'));
% subplot(2,1,1);
plot(Sag_pos, 'r')
hold on

% subplot(2,1,2);
plot(S2_ang, 'b')
title('LMM and FOB Synching')
pause
close(hwnd);
hwnd = figure('position', get(0, 'ScreenSize'));

%Plot to show sagital and rotational angles
plot(Sag_pos, 'r')
hold on
plot(Rot_pos, 'g')
title('sag and rot angles')

%Keeps the plot on and allows you to select points on the graph and output
%the x and y coordinates for each point.  Hit 'enter' once you are finished
%selecting the points and red circles will show which areas you have
%selected.
hold on
[x,y] = ginput;
plot(x,y,'ro')

%transposes the x coordinates from a column to a row vetor to make it
%easier to read in the exported file
x_out = x';

%exports the x coordinates of the data that you select on the graph
dlmwrite('AM_LO_x.out',x_out, ';');

%determines how many rows are in x
xleng = length(x);

%Piecing out the individual segments
L = 1;
graphName = 'graph';

for n = 1:xleng/2;
   %LMM DATA
   %using a for loop to section out each selected portion of data
```

```
LP_seg = Lat_pos(round(x(L)):round(x(L+1)),:);
LV_seg = Lat_vel(round(x(L)):round(x(L+1)),:);
LA_seg = Lat_acc(round(x(L)):round(x(L+1)),:);

SP_seg = Sag_pos(round(x(L)):round(x(L+1)),:);
SV_seg = Sag_vel(round(x(L)):round(x(L+1)),:);
SA_seg = Sag_acc(round(x(L)):round(x(L+1)),:);

RP_seg = Rot_pos(round(x(L)):round(x(L+1)),:);
RV_seg = Rot_vel(round(x(L)):round(x(L+1)),:);
RA_seg = Rot_acc(round(x(L)):round(x(L+1)),:);

%finding the maxs, mins, and absolute maxs for each lift
LP_max(n)= max(LP_seg);
LV_max(n)= max(LV_seg);
LA_max(n)= max(LA_seg);

LP_min(n)= min(LP_seg);
LV_min(n)= min(LV_seg);
LA_min(n)= min(LA_seg);

[LP_max_abs(n),DD(n)]= max(abs(LP_seg));
[LV_max_abs(n),EE(n)]= max(abs(LV_seg));
[LA_max_abs(n),FF(n)]= max(LA_seg);

%Smoothed Velocity and Acceleration
%series of if then statments to smooth vel and acc.  If maxs happen at
%the very beginning or end of segment of data.
if EE(n) == 1
   LV_sm_max(n) = (LV_max_abs(n)+LV_seg(EE(n))+LV_seg(EE(n)+1))/3;
elseif EE(n) == length(LV_seg)
   LV_sm_max(n) = (LV_max_abs(n)+LV_seg(EE(n)-1)+LV_seg(EE(n)))/3;
else
   LV_sm_max(n) = (LV_max_abs(n)+LV_seg(EE(n)-1)+LV_seg(EE(n)+1))/3;
end

if FF(n) == 1
   LA_sm_max(n) = (LA_max_abs(n)+LA_seg(FF(n))+LA_seg(FF(n)+1))/3;
elseif FF(n) == length(LA_seg)
   LA_sm_max(n) = (LA_max_abs(n)+LA_seg(FF(n)-1)+LA_seg(FF(n)))/3;
else
   LA_sm_max(n) = (LA_max_abs(n)+LA_seg(FF(n)-1)+LA_seg(FF(n)+1))/3;
end

SP_max(n)= max(SP_seg);
```

```
SV_max(n)= max(SV_seg);
SA_max(n)= max(SA_seg);

SP_min(n)= min(SP_seg);
SV_min(n)= min(SV_seg);
SA_min(n)= min(SA_seg);

[SP_max_abs(n),I(n)]= max(abs(SP_seg));
[SV_max_abs(n),J(n)]= max(abs(SV_seg));
[SA_max_abs(n),K(n)]= max(SA_seg);

%Smoothed Velocity and Acceleration

if J(n) == 1
   SV_sm_max(n) = (SV_max_abs(n)+SV_seg(J(n))+SV_seg(J(n)+1))/3;
elseif J(n) == length(SV_seg)
   SV_sm_max(n) = (SV_max_abs(n)+SV_seg(J(n)-1)+SV_seg(J(n)))/3;
else
   SV_sm_max(n) = (SV_max_abs(n)+SV_seg(J(n)-1)+SV_seg(J(n)+1))/3;
end

if K(n) == 1
   SA_sm_max(n) = (SA_max_abs(n)+SA_seg(K(n))+SA_seg(K(n)+1))/3;
elseif K(n) == length(SA_seg)
   SA_sm_max(n) = (SA_max_abs(n)+SA_seg(K(n)-1)+SA_seg(K(n)))/3;
else
   SA_sm_max(n) = (SA_max_abs(n)+SA_seg(K(n)-1)+SA_seg(K(n)+1))/3;
end

RP_max(n)= max(RP_seg);
RV_max(n)= max(RV_seg);
RA_max(n)= max(RA_seg);

RP_min(n)= min(RP_seg);
RV_min(n)= min(RV_seg);
RA_min(n)= min(RA_seg);

[RP_max_abs(n),R(n)]= max(abs(RP_seg));
[RV_max_abs(n),S(n)]= max(abs(RV_seg));
[RA_max_abs(n),T(n)]= max(RA_seg);

%Smoothed Velocity and Acceleration
if S(n) == 1
   RV_sm_max(n) = (RV_max_abs(n)+RV_seg(S(n))+RV_seg(S(n)+1))/3;
elseif S(n) == length(RV_seg)
```

```
   RV_sm_max(n) = (RV_max_abs(n)+RV_seg(S(n)-1)+RV_seg(S(n)))/3;
else
   RV_sm_max(n) = (RV_max_abs(n)+RV_seg(S(n)-1)+RV_seg(S(n)+1))/3;
end

if T(n) == 1
   RA_sm_max(n) = (RA_max_abs(n)+RA_seg(T(n))+RA_seg(T(n)+1))/3;
elseif T(n) == length(RA_seg)
   RA_sm_max(n) = (RA_max_abs(n)+RA_seg(T(n)-1)+RA_seg(T(n)))/3;
else
   RA_sm_max(n) = (RA_max_abs(n)+RA_seg(T(n)-1)+RA_seg(T(n)+1))/3;
end

%finding the means for each segment of data
LP_mean(n)= mean(LP_seg);
LV_mean(n)= mean(LV_seg);
LA_mean(n)= mean(LA_seg);

SP_mean(n)= mean(SP_seg);
SV_mean(n)= mean(SV_seg);
SA_mean(n)= mean(SA_seg);

RP_mean(n)= mean(RP_seg);
RV_mean(n)= mean(RV_seg);
RA_mean(n)= mean(RA_seg);

%FOB DATA
%using a for loop to section out each selected portion of data
M2x_seg = S2_x(round(x(L)):round(x(L+1)),:);
M2y_seg = S2_y(round(x(L)):round(x(L+1)),:);
M2z_seg = S2_z(round(x(L)):round(x(L+1)),:);

M3x_seg = S3_x(round(x(L)):round(x(L+1)),:);
M3y_seg = S3_y(round(x(L)):round(x(L+1)),:);
M3z_seg = S3_z(round(x(L)):round(x(L+1)),:);

M4x_seg = S4_x(round(x(L)):round(x(L+1)),:);
M4y_seg = S4_y(round(x(L)):round(x(L+1)),:);
M4z_seg = S4_z(round(x(L)):round(x(L+1)),:);

M5x_seg = S5_x(round(x(L)):round(x(L+1)),:);
M5y_seg = S5_y(round(x(L)):round(x(L+1)),:);
M5z_seg = S5_z(round(x(L)):round(x(L+1)),:);

%finding the maxs and mins for the FOB data
```

```
M2x_max(n)= max(abs(M2x_seg));
M2y_max(n)= max(abs(M2y_seg));
M2z_max(n)= max(abs(M2z_seg));

M3x_max(n)= max(abs(M3x_seg));
M3y_max(n)= max(abs(M3y_seg));
M3z_max(n)= max(abs(M3z_seg));

[M4x_max(n),U(n)]= max(M4x_seg);
[M4y_max(n),V(n)]= max(M4y_seg);
[M4z_max(n),W(n)]= max(M4z_seg);

[M4x_min(n),U(n)]= min(M4x_seg);
[M4y_min(n),V(n)]= min(M4y_seg);
[M4z_min(n),W(n)]= min(M4z_seg);

%figuring out whether the max or the min is the absolute max value for
%sensor 4
abs_M4x_max = abs(M4x_max);
abs_M4x_min = abs(M4x_min);
if abs_M4x_max >= abs_M4x_min;
   M4x_amax = M4x_max;
else abs_M4x_min > abs_M4x_max;
   M4x_amax = M4x_min;
end

abs_M4y_max = abs(M4y_max);
abs_M4y_min = abs(M4y_min);
if abs_M4y_max >= abs_M4y_min;
   M4y_amax = M4y_max;
else abs_M4y_min > abs_M4y_max;
   M4y_amax = M4y_min;
end

abs_M4z_max = abs(M4z_max);
abs_M4z_min = abs(M4z_min);
if abs_M4z_max >= abs_M4z_min;
   M4z_amax = M4z_max;
else abs_M4z_min > abs_M4z_max;
   M4z_amax = M4z_min;
end

[M5x_max(n),AA(n)]= max(M5x_seg);
[M5y_max(n),BB(n)]= max(M5y_seg);
[M5z_max(n),CC(n)]= max(M5z_seg);
```

```
[M5x_min(n),AA(n)]= min(M5x_seg);
[M5y_min(n),BB(n)]= min(M5y_seg);
[M5z_min(n),CC(n)]= min(M5z_seg);

%figuring out whether the max or the min is the absolute max value for
%sensor 5
abs_M5x_max = abs(M5x_max);
abs_M5x_min = abs(M5x_min);
if abs_M5x_max >= abs_M5x_min;
   M5x_amax = M5x_max;
else abs_M5x_min > abs_M5x_max;
   M5x_amax = M5x_min;
end

abs_M5y_max = abs(M5y_max);
abs_M5y_min = abs(M5y_min);
if abs_M5y_max >= abs_M5y_min;
   M5y_amax = M5y_max;
else abs_M5y_min > abs_M5y_max;
   M5y_amax = M5y_min;
end

abs_M5z_max = abs(M5z_max);
abs_M5z_min = abs(M5z_min);
if abs_M5z_max >= abs_M5z_min;
   M5z_amax = M5z_max;
else abs_M5z_min > abs_M5z_max;
   M5z_amax = M5z_min;
end

%finding the means for the FOB data
M2x_mean(n)= mean(M2x_seg);
M2y_mean(n)= mean(M2y_seg);
M2z_mean(n)= mean(M2z_seg);

M3x_mean(n)= mean(M3x_seg);
M3y_mean(n)= mean(M3y_seg);
M3z_mean(n)= mean(M3z_seg);

M4x_mean(n)= mean(M4x_seg);
M4y_mean(n)= mean(M4y_seg);
M4z_mean(n)= mean(M4z_seg);

M5x_mean(n)= mean(M5x_seg);
```

```
M5y_mean(n)= mean(M5y_seg);
M5z_mean(n)= mean(M5z_seg);

%Finding the x and y knee values when the peak sag and rot back positions occur

M4x_SP(n)= M4x_seg(I(n));
M4y_SP(n)= M4y_seg(I(n));
M4z_SP(n)= M4z_seg(I(n));

M4x_RP(n)= M4x_seg(R(n));
M4y_RP(n)= M4y_seg(R(n));
M4z_RP(n)= M4z_seg(R(n));


M5x_SP(n)= M5x_seg(I(n));
M5y_SP(n)= M5y_seg(I(n));
M5z_SP(n)= M5z_seg(I(n));

M5x_RP(n)= M5x_seg(R(n));
M5y_RP(n)= M5y_seg(R(n));
M5z_RP(n)= M5z_seg(R(n));

%plot to show how the segments of data relate to eachother
%Sagital angle plot
subplot(3,1,1);
plot(SP_seg)
hold on
plot(I(n),SP_seg(I(n)), 'kp')
hold on
title('sagital angle')
hold off


subplot(3,1,2);
plot(M4x_seg)
hold on
plot(U(n),M4x_seg(U(n)), 'kp')
hold on
title('Left Knee')
hold off

subplot(3,1,3);
plot(M5x_seg)
hold on
plot(AA(n),M5x_seg(AA(n)), 'kp')
```

```
hold on
title('Right Knee')
hold off
pause
subp=1;
%this writes the graph as an JPEG to the file that you are working
%from. Graphs are named numerically...First #= Lift, Sencond #= figure
print ('-djpeg', [graphName int2str(n) int2str(subp)]);
close;

%Rotational Angle Plot
subp = subp+1;
subplot(3,1,1);
plot(RP_seg)
hold on
plot(R(n),RP_seg(R(n)), 'kp')
hold on
title('rotational angle')
hold off

subplot(3,1,2);
plot(M4y_seg)
hold on
plot(V(n),M4y_seg(V(n)), 'kp')
hold on
title('Left Knee')
hold off

subplot(3,1,3);
plot(M5y_seg)
hold on
plot(BB(n),M5y_seg(BB(n)), 'kp')
hold on
title('Right Knee')
hold off
pause
print ('-djpeg', [graphName int2str(n) int2str(subp)]);
close;

%Velocity Plot
subp=subp+1;
plot(SV_seg, 'r')
hold on
plot(RV_seg, 'y')
hold on
```

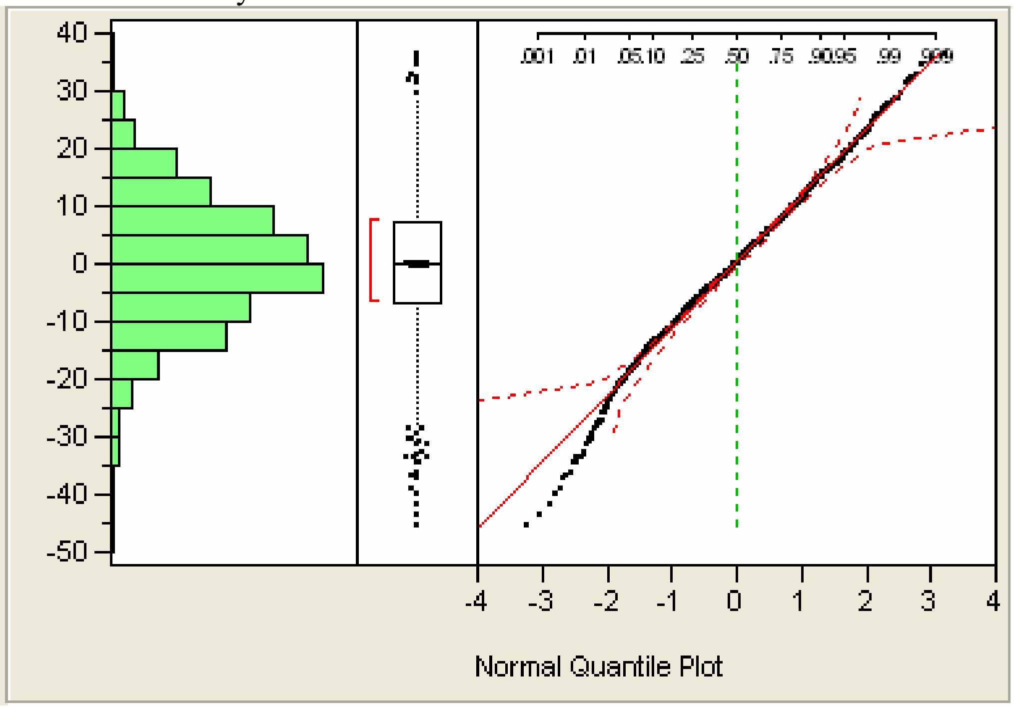
```
    plot(J(n),SV_seg(J(n)), 'rp')
    hold on
    plot(S(n),RV_seg(S(n)), 'yp')
    hold on
    legend('SV_s_e_g', 'RV_s_e_g')
    hold off
    pause
    print ('-djpeg', [graphName int2str(n) int2str(subp)]);
    close;

    L = L+2;
end

%Making the maxs, mins, and absolute maxs into matricies that can be
%copied into JMP and/or EXCEL and analyzed
Max_Pos = [LP_max; SP_max; RP_max];
Max_Vel = [LV_max; SV_max; RV_max];
Max_Acc = [LA_max; SA_max; RA_max];

Min_Pos = [LP_min; SP_min; RP_min];
Min_Vel = [LV_min; SV_min; RV_min];
Min_Acc = [LA_min; SA_min; RA_min];

Abs_Max_Pos = [LP_max_abs; SP_max_abs; RP_max_abs];
Abs_Max_Vel = [LV_max_abs; SV_max_abs; RV_max_abs];
Abs_Max_Acc = [LA_max_abs; SA_max_abs; RA_max_abs];

Ave_Pos = [LP_mean; SP_mean; RP_mean];
Ave_Vel = [LV_mean; SV_mean; RV_mean];
Ave_Acc = [LA_mean; SA_mean; RA_mean];

Smooth_Max_Vel = [LV_sm_max; SV_sm_max; RV_sm_max];
Smooth_Max_Acc = [LA_sm_max; SA_sm_max; RA_sm_max];

%FOB knee data
%Max and mean data for knee sensors
Knee_max_L = [M4x_amax; M4y_amax; M4z_amax];
Knee_max_R = [M5x_amax; M5y_amax; M5z_amax];

Knee_mean_L = [M4x_mean; M4y_mean; M4z_mean];
Knee_mean_R = [M5x_mean; M5y_mean; M5z_mean];

%Knee location during max back position and rotation
KLeft_SP = [M4x_SP; M4y_SP; M4z_SP];
KLeft_RP = [M4x_RP; M4y_RP; M4z_RP];
```

```
KRight_SP = [M5x_SP; M5y_SP; M5z_SP];
KRight_RP = [M5x_RP; M5y_RP; M5z_RP];
```

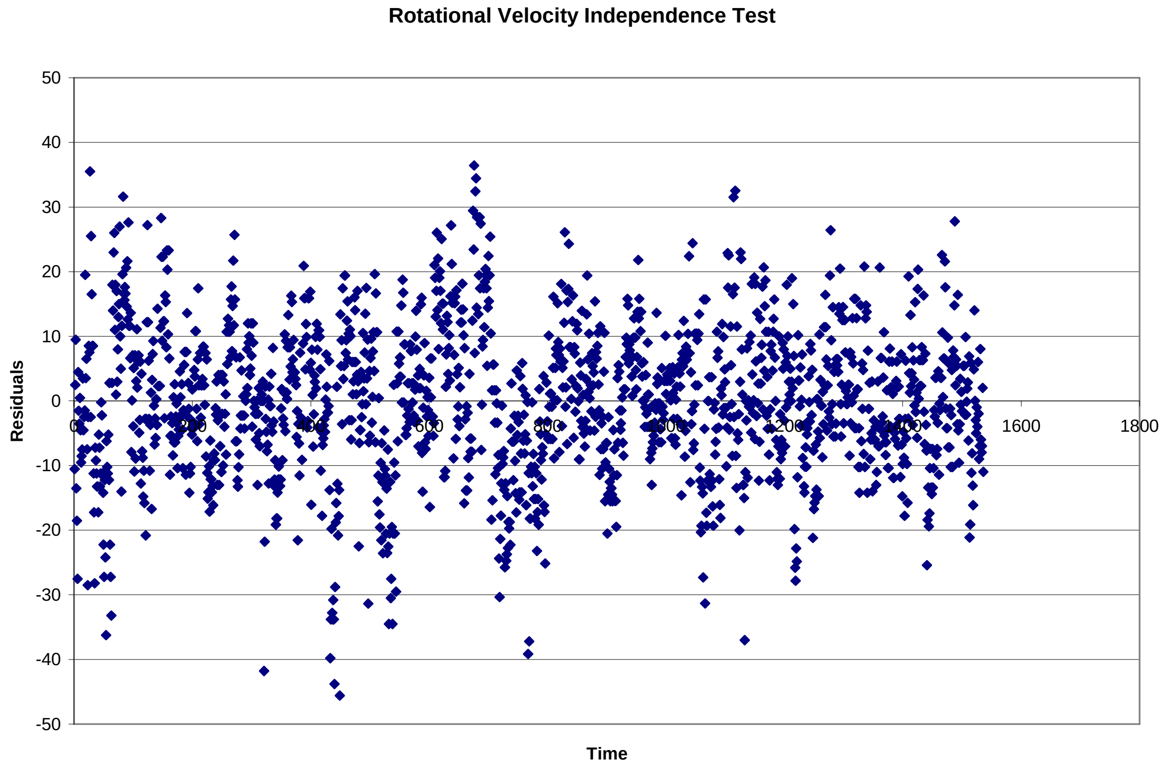
6.3 Assumptions of ANOVA (typical results) for Trunk and Knee Data

Normality of Residual

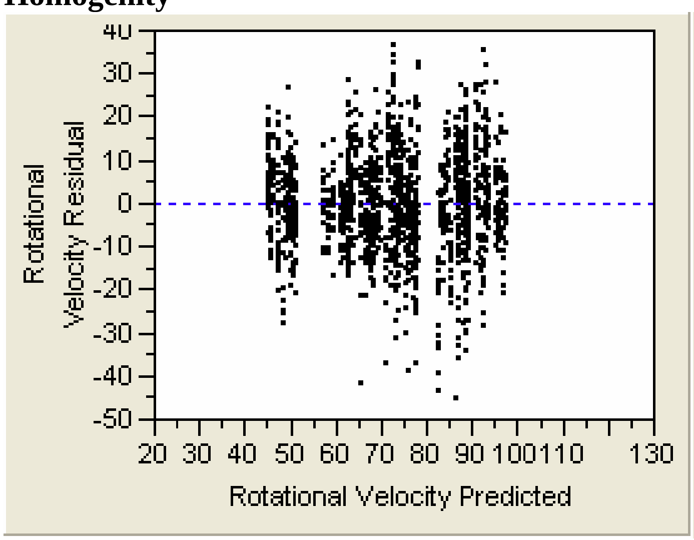
Rotational Velocity Results



Independence



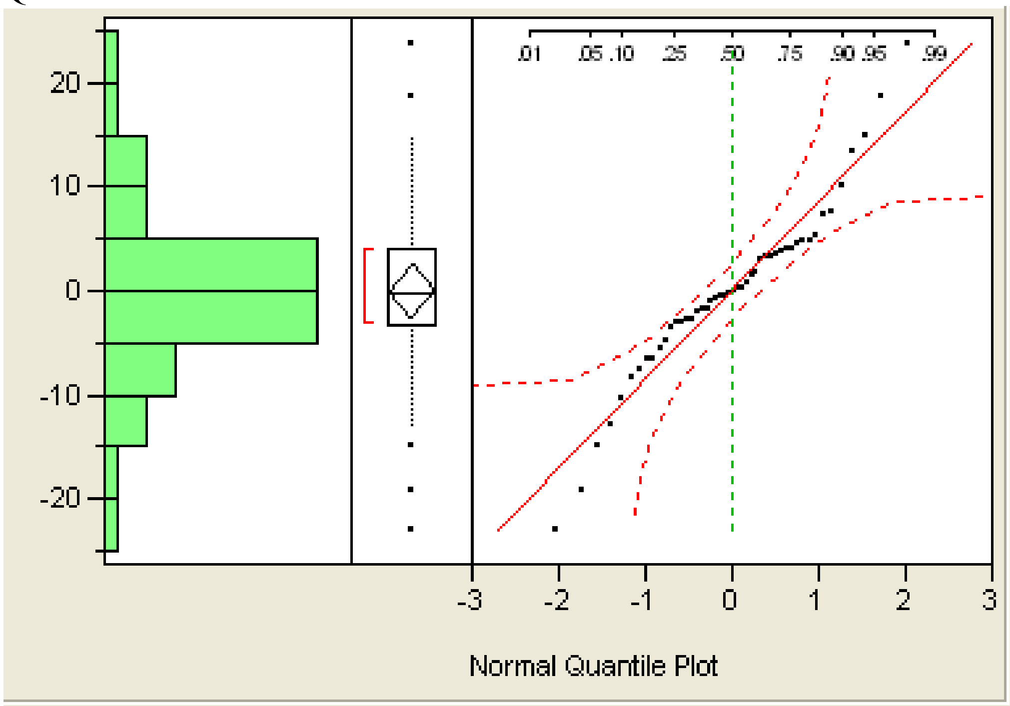
Homogenity



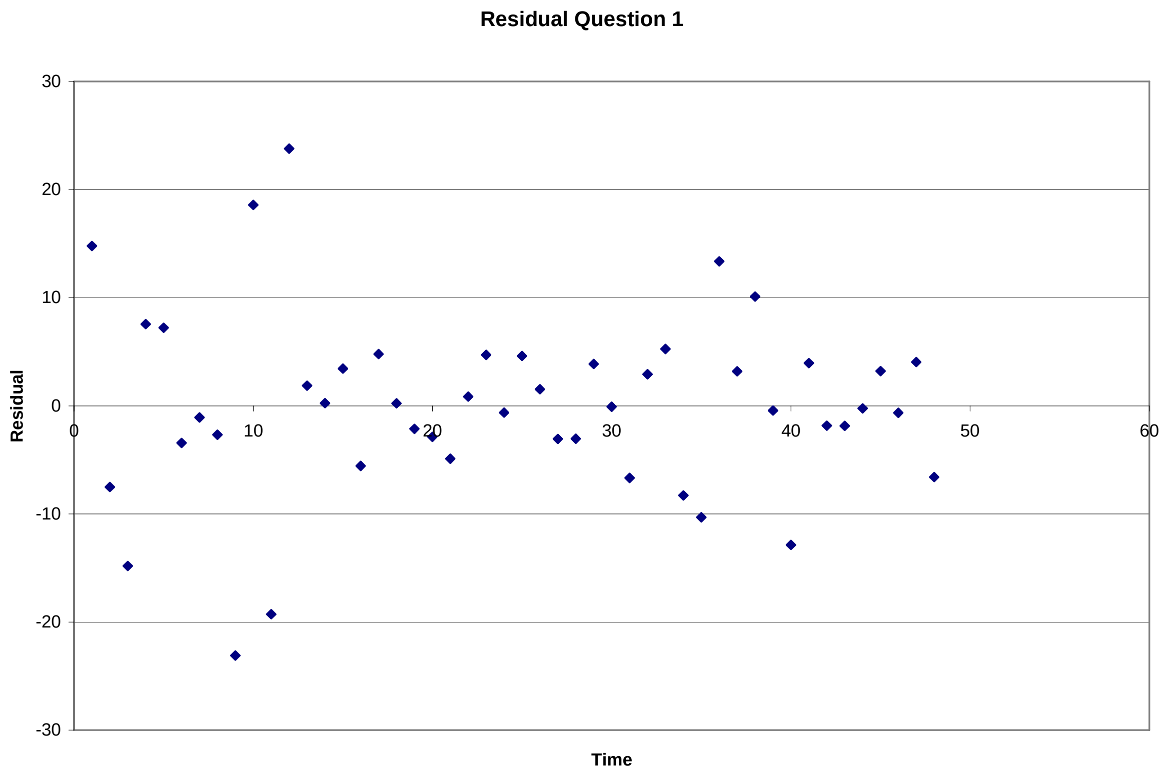
6.4 Assumptions of ANOVA (typical results) for Survey Data

Normality of Residual

Question 1 Results



Independence



Homogenity