

California State University, Northridge

The Effects of Asymmetrical Lifting Versus Symmetrical Lifting on Muscle Activation

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By

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Abstract

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Back pain is the most common and costly musculoskeletal problem in the workplace around the world. No previous study has compared the effects of asymmetrical lifting (lifting with a twist) on both upper body and lower body skeletal muscles with multiple lifting loads. It was hypothesized that the asymmetrical lifts of 20, 35, and 50 pounds could require a significantly higher muscle activation on the nine measured muscles when compared to symmetrical lifts of the same load. The dependent variables were the mean EMG activation of twelve selected muscles during the concentric upward lifting phase. The independent variables were the lifting method with two levels: symmetrical versus asymmetrical, and the lifting load with three levels of 20, 35, and 50 pounds. The results were analyzed with twelve two by three ANOVAs. The results from the twenty-two participants showed no statistical significant differences among the different conditions on mean EMG muscle activation between symmetrical and asymmetrical lifts. These results suggest that untrained individuals that lift heavy objects during their profession may exert the same muscular effort among multiple lifting loads and twisting while lifting may not alter the activation of certain muscles.

Introduction

Back pain is a problem worldwide, with over 80% of people suffering from back pain at some time in their life. Back pain is the most common and costly musculoskeletal problem in the workplace around the world (Murphy & Volinn, 1999). Murphy & Volinn (1999) stated that back pain alone required 8.8 billion dollars of spending in 1995. It is the most common excuse for lack of physical activity and it greatly effects the world's working population (Hoy et al., 2010). Back pain is the most prevalent and costly musculoskeletal disorder as result of poor working conditions (Dai, Jin, Ning & Mirka, 2010). Some workers experience chronic back pain that lasts for two months or longer. Chronic back pain can render employees unable to work. Many workers suffering from chronic back pain may rely on workers' compensation programs for income. Overdependence of worker's compensation leaves a large financial burden on local and global economic stability (Walker, Muller, & Grant, 2003). Lifting with a spinal twisting motion and other characteristics that aggravate back pain are common in the workplace and increase the chances of injury (Murphy & Volinn, 1999). Previous studies have examined the effects of lifting on skeletal muscular structures and back pain. No previous study has compared the effects of asymmetrical lifting (lifting with a twist) on both upper body and lower body skeletal muscles with multiple lifting loads. The present study will mimic occupational conditions including: lifting heavy loads and twisting during a lift. Lifting conditions will be evaluated for their risk back pain using the National Institute of Occupational Safety and Health (NIOSH) lifting equation guidelines. The goal of this study was to: add to the existing occupational lifting guidelines and raise awareness of back pain as a world-wide problem.

Back pain affects all socioeconomic classes and it is the main cause of injury among workers. Chronic back pain can lead to disability as well as dependency on workers' compensation. Because of this, workplace healthcare plan costs increase. As a result, it is difficult for companies to supply their workers with affordable health coverage (Hoy et al., 2010). Despite its prevalence and the damage it causes, respected medical journals do not recognize back pain as an epidemiological problem. Back pain is ignored by major developed countries that are socially and economically affected by the condition (Hoy et al., 2010).

Back pain has been overlooked as an epidemic for three reasons. Firstly, back pain is overshadowed by infectious disease, coronary disease, cancer, and other conditions that are more likely to lead to death. Secondly, studies have ignored the increasing occurrence of back pain. Thirdly, back pain lacks a unified definition. Previous studies have categorized back pain with most other musculoskeletal conditions (Hoy et al., 2010).

Medical practitioners have difficulty diagnosing back pain without a standardization of pain location and duration. The medical world in general does not acknowledge the severity of back pain. Hoy et al. (2010), Costa et al. (2009), & Karahan, Kav, Abbasoglu, & Dogan (2009) agree that a more accurate definition of back pain will help bring attention to the issue and help clinicians better recognize signs and symptoms of back pain. Back pain studies raise awareness and help define the issue in more detail.

Literature Review

The National Institute for Occupational Safety and Health created a lifting equation in 1981 to analyze the risk of back injury that result from common lifting tasks in the workplace (Waters, Putz-Anderson, Garg, & Fine, 1993). This equation was used to quantify forces on the lifter's back and the risk of back pain from lifting. In 1991, the NIOSH lifting equation was revised to apply to a larger demographic of workers. NIOSH's revised equation is generally recognized by many large businesses and it is used to set lifting guidelines and decrease back pain occurrence (Waters, Putz-Anderson, Garg, & Fine, 1993). Unfortunately, Auguston (1995), Dempsey & Fatalhallah (1999), and Hidlago et al. (1995), and others propose that the revised 1991 version of the equation can be improved upon. They state that the equation should be altered to more accurately evaluate the risk of lower back pain as a result of lifting tasks. The NIOSH lifting equation may have slight flaws but it is the one of the few existing tools to quantify the risk of lower back pain due to lifting conditions. The current study aims to help expand the existing knowledge of lower back pain risk.

Elfeituri & Taboun (2002) explain how the NIOSH lifting equation quantifies back pain caused by lifting. The study also mentions, however, that some qualities of the NIOSH lifting equation may need to be altered to better analyze the risk of real world manual lifting scenarios. Elfeituri & Taboun (2002) evaluated the validity of the NIOSH equation by comparing data results from lifting. This study analyzed the following criteria:

1. Validity of Recommended weight limit (RWL)

The RWL are lifting conditions that the majority of healthy workers can achieve for a maximum of 8 hours without a high risk of back pain. It is calculated by multiplying the

reference mass (Mref) by 6 other variables. These variables are: The load constant (LC). This is the maximum acceptable load for lifts and is a constant value of 23kg, or 50 pounds. The horizontal distance (H) of the lifted object is measured in centimeters (CM) from the midpoint of the lifters' ankles, where the heels meet, to the midpoint of the object where the lifter grasps to lift the object. The Vertical height of the lift (V) is measured in CM from the floor to the location the lifter grasps on the object lifted. The vertical displacement (D) is the distance the object travels in CM from the resting point to the final point's height of the lifted object. The Asymmetry multiplier (AM) measures the angle the object faces from the midpoint of the ankles in degrees. Gripping quality is scored on a scale of 1-3. Good quality grips (1) are when the lifted objects has handles cut out which allow the item to be lifted with neutral wrist posture achieved. Fair quality lifts (2) are when the lifted objects' handles do not allow neutral wrist posture during the lift, and the object can be held with a 90 degree flex in the wrist of the lifter. Poor quality grips (3) are when the object lifted does not allow the lifter to maintain good or fair quality gripping posture. The lifting frequency (F) is the average number of lifts per minute and time spent lifting in hours. The reference of mass (Mref) is the recommended weight limit of the mass lifted for an individual population group based on gender, age, and percentage of the population protected.

$$RWL = LC \times H \times V \times D \times AM \times \text{gripping quality} \times F$$

2. Validity of Lifting Index (LI)

The LI is the estimation of physical stress as a result from the lifting action of the object and is calculated as the weight of the load divided by RWL.

LI = weight of load/RWL

A higher LI value implies a greater risk for injury during the lifting situation. A RWL score less than or equal to 1 implies that the lift is safe for 99% of men and 75% of women. A RWL score greater than 3 implies that the lift is safe for 25% of men and only 1% of women.

3. Validity of the asymmetric multiplier (AM)

The asymmetry multiplier (AM) measures the amount of twisting occurs from the lift from the midpoint where the ankles meet on the lifter, its range is from 0-135 degrees.

4. Validity of NIOSH Compression Force Guidelines.

Lifting posture and the weight of the load lifted both impact the total load placed on the lumbar spine during a lift. The NIOSH equation guidelines state that compression on the lumbar portion of the spine from lifting should not exceed 3400N to avoid the risk of back injury.

Elfeituri & Taboun (2002) and others argue that some components of the 1991 revised NIOSH guidelines do not accurately represent the risks of real life occupational lifts on musculoskeletal structures. Elfeituri & Taboun (2002) compared the results among multiple lifting studies to inspect the validity of the NIOSH guidelines. The studies included lifting tasks within the criteria of the NIOSH equation guidelines. Individual components of the NIOSH guideline were evaluated as follows.

Evaluation of Recommended Weight Limit

(RWL): $RWL = H \times V \times D \times A \times \text{gripping quality} \times F$

The NIOSH lifting equation assigns the value of 25 cm to the Horizontal distance of the load (H) (Elfeituri & Taboun, 2002). Wang et al. (1998) found that most real world lifting tasks

have an H value greater than 63cm. According to Elfeituri & Taboun, (2002), this proves NIOSH equation's (H) value at 25cm is impractical for analyzing occupational lifts.

Evaluation of Lifting Frequency (F)

Elfeituri & Taboun, (2002) state that NIOSH equation's F value is the most flawed variable for calculating actual lifts. Wang et al. (1998) reported that occupational tasks like brick making and fertilizer creating typically have an F value of zero in because loads are lifted less frequently than one load per minute. These jobs consist of multiple heavy lifting loads over the course of 8 hours. They yield an RWL value of zero when plugging the F value in the equation. According to Elfeituri & Taboun (2002), this zero value proves that RWL value is unrealistic for measuring infrequent occupational lifts with big loads.

Evaluation of Asymmetry Multiplier (AM)

Depmsey & Fathallah (1999) Contend that the NIOSH AM addresses biomechanical and psycho-social factors of lifting. The NIOSH lifting guideline's AM variable criteria neglect epidemiological and psychological factors influencing lifts. Waters, Putz-Anderson, Garg, & Fine (1993) State that NIOSH is impractical because of this.

The NIOSH guidelines also suggest a linear increase in back pain risk in asymmetrical lifts from 30 60 and 90 degrees. Chaffin & page, (1994) questioned this linear pattern of lifting. They stated that there is a greater increase in risk of musculoskeletal injury from 60 to 90 degrees than any other linear succession of AM variable scores.

Elfeituri & Taboun, (2002) suggest the NIOSH guidelines are limited in certain aspects of real world occupational lifting scenarios. This study most greatly challenges the NIOSH

equations' AM and F variables in their ability to accurately assess the risk of certain specific real life lifting scenarios. Genaidy et al., (1998) stated that the F and H variables especially need to be adjusted to more accurately evaluate the risks of real world occupational lifts.

Occupational Back Pain in Practical Settings

Kucera et al. (2009) followed commercial fisherman with the objective to find which lifting tasks lead to work limiting back pain. This was recorded with a self reported back pain questionnaire and measurement back pain duration. This is similar to Torner et al., (1988) which followed Swedish fishermen, half of whom had back pain at least one year prior to the study. No study before Kucera et al., (2009) observed the effects that lifting frequency, and lifting duration have on the commercial fisherman population.

Crab pot fishermen and gill net fishermen's back pain increased when exposed to asymmetrical lifts, particularly with a load greater than 20lbs. Further risk of back pain increased with spinal compression forces greater than 3,400N and an LI greater than 3. Kucera et al., (2009), Torner et al., (1988) Lipscomb, Loomis, Anne McDonald, Kucera, Marshall, & Li, (2004), & McDonald, Loomis, Kucera, & Lipscomb, (2004) all agree that lifting with awkward postures as seen with fishermen during shoveling and lifting tasks lead to an increased risk of back pain. Engkvist, Hagberg, Hjelm, Menckel, & Ekenvall, (1998) found similarly that increased load, awkward postures and twisting while lifting lead to an increase of back pain among nursing staff. Twisting while lifting in awkward positions can be quantified in degrees by the NIOSH AM variable.

Another factor affecting occupational back pain is lifting technique. Karahan, Kav, Abbasoglu, & Dogan, (2009) indicated that proper lifting technique can help decrease back strain

and pain in the workplace. Kucera et al., (2009) found that fisherman had a decrease in back pain with increased years of experience as a commercial fisherman. The years of work experience may have possibly attributed to increased lifting technique among the fishermen, resulting in a decrease of back pain. This, directly opposes the findings of Karahan, Kav, Abbasoglu, & Dogan, (2009). They found that injury-causing lifting accidents occurred more frequently with nurses that have a greater number of years lifting patients. Karahan, Kav, Abbasoglu, & Dogan, (2009) & Engkvist, Hagberg, Hjelm, Menckel, & Ekenvall, (1998) suggested that back injuries accumulate from a build up of damage over the years as a result from repetitive lifts.

Kucera et al., (2009) found that repetitive asymmetrical lifting movements led to an increase in back pain risk. They found unassisted lifts of large loads led to severe back pain among commercial fishermen as a result of high volume of compressive forces on the lumbar spine. They also found that fishermen with less years of work experience had a higher level of back pain. Kucera et al., (2009) contradict the NIOSH lifting equation and suggest that task lifting frequency does not predict the occurrence of back pain among the commercial fishermen population.

Complex lifting, also known as asymmetrical lifting occurs when the lifter is required to side bend or twist the spine during a lift. Asymmetrical lifts occur when workers have limited space to lift loads, much like nurses in the article previously stated (Karahan, Kav, Abbasoglu, & Dogan, 2009). Past studies have proven that asymmetrical spinal movements paired with spinal loading lead to an increase in back disability risk.

Little is known about the muscular activation that occurs during asymmetrical lifting tasks. Shirazi-Adl (2006) found that combining side bending and spinal rotation in one single movement led to a great increase of sprains on lumbar vertebrae. Fathallah, Marras, & Parnianpour, (1998) hypothesized that lifting a load with simultaneous twisting and side bending will lead to a combination of shearing and compressive loading between back vertebral discs. This implies that there may be an increase of forces placed on the back during asymmetrical lifts.

Past studies like Granata & Marras, (1993) could only measure spinal loading as result of spinal lateral flexion (side-bending) when participants' pelvis was static and restrained. Fathallah, Marras, & Parnianpour, (1998) created a study model that did not require participants' pelvis to be restrained by analyzing loading of the spine during whole-body complex asymmetrical lifts. Fathallah, Marras, & Parnianpour, (1998) used silver-chloride muscle activity scanners called electromyograms (EMG). An EMG reads the electrical activity of muscles. The EMG sensors were strategically placed on the participants to achieve a three dimensional trunk movement analysis. The external oblique muscles, the latissimus dorsi muscle, and the rectus abdominis muscle were all observed at a frequency of 20 m/second moving on average.

Fathallah, Marras, & Parnianpour, (1998) had 11 participants stand on a force plate with electromyography (EMG) measurements. A force plate measures the pressure distribution of the object as well as which direction the force is displaced. They attached the EMG to the L5 to S1 portions of the lumbar spine to read the activity of lifting muscles as the participants lifted three different loads asymmetrically. Other studies like Gallagher, Pollard, & Porter, (2011) measured lower body muscles that cross the knee and activate during lifting postures including the vastus lateralis, vastus medialis, bicep femoris and semitendinosus.

For the Symmetrical lifts Fathallah, Marras, & Parnianpour, (1998) had participants lift a box that was placed at above knee height in front of the participant. The participant was instructed to hold the box as closely as possible to the body while maintaining straight arms. These instructions led the participant to finish the lift holding the box about 20 cm below the iliac crest. Asymmetrical lifts (lifting with a twist) began with the box placed in front of the lifter identical to the symmetrical lifts. Asymmetrical lifters were instructed to place the lifted box to their side on another platform that was placed at iliac crest level and arms distance horizontally from the participant.

Lifting speed was controlled by a metronome, signifying the beginning and end of the lift. Participants were instructed to lift with their arms and legs as straight as possible in a “stoop lift”. This lift style was used by Dempsey & Fathallah, (1999) to unify lifters’ form and decrease the variable of lifting technique. Similar to Dempsey & Fathallah, (1999), both asymmetrical and symmetrical lifts will be performed with three different loads lifted. Three loads were lifted to observe the different forces placed on the spine during lift weights. This study used loads with a greater weight than to Dempsey & Fathallah, (1999). Loads of 15, 35 and 50 pounds will be lifted to further the forces placed on the spine. These loads all fit within the load parameters of the NIOSH lifting guidelines to ensure safety (Elfeituri & Taboun, 2002). Participants will be given 60 seconds of rest between lift efforts, and were told to rest as much time as necessary to lift the next load. This will be to avoid fatigue that may affect lifting performance results.

Fathallah, Marras, & Parnianpour, (1998) found that lateral shearing forces increased significantly, by 40% during asymmetrical lifts when compared to symmetrical lifts. Compressive forces also increased significantly the same load amount from symmetrical to

asymmetrical lifts. This explains why previous research results suggest a correlation between asymmetric lifting and back pain in occupational settings. Increased shearing and compression on the spine as a result of asymmetrical lifting may produce forces greater than the spinal tissues can tolerate and lead to back injury (Fathallah, Marras, & Parnianpour, 1998). Duncan & Ahmed, (1991) suggested spinal rotation alone is not unsafe for the spine, but lifting a load paired with spinal rotation may damage the spine. Gunzburg, Hutton, & Fraser, (1991), Shirazi adl, (2006) and Duncan & Agmed, (1991) all agree that simultaneous spinal rotation and lifting lead to back pain. Gunzburg, Hutton, & Fraser, (1991) explained that spinal rotation range of motion decreases during spinal flexion (which occurs during lifting). This decrease in range of motion leads to spinal bracing and an increased load carried on spinal facets. Shirazi-Adl, (2006) found that lateral flexion of the spine while twisting led to a great strain on spinal disk fibers. This may degenerate the facets on the spinal vertebrae and lead to spinal injury.

Fathallah, Marras, & Parnianpour, (1998) used a model that was based off of EMG readings. EMG signals may be altered by outside influences found in the laboratory environment, affecting results. EMG readings cannot account for passive tissue actions that occur during lifts. Fathallah, Marras, & Parnianpour, (1998) knew of this limitation and made sure that participants did not perform spinal flexion further than 45 degrees to reduce the use of passive tissues during lifts. Some muscles that contribute to lifting, twisting and spinal lateral flexion were not accounted for with EMG readings. The multifidus muscle, for example is a spinal extensor deep to the spine. Although the multifidus contributes to lifting efforts, muscle activity readings from deep muscular structures like this are inconvenient to evaluate. Measuring electrical signals from the multifidus muscle requires electrodes to enter below the skin with

needles. Fathallah, Marras, & Parnianpour, (1998) focused on muscular activation recordings from the most prominent force producing muscles during lifting to make up for this shortcoming.

Back pain is a problem for workers around the world (Chanplakorn et al., 2012). Back injury is the most common musculoskeletal injury as a result of occupational activities like lifting (Dai, Jin, Ning & Mirka, 2010). Back pain can become chronic and progress into disability (Hoy et al., 2010). Disability from back pain leaves some workers unable to attend work, and turn to unemployment for income. This cycle leaves an economic strain that increases the cost of Medicare coverage (Hoy et al., 2010). Despite the damage back pain causes, the medical world does not recognize it as an epidemic (Costa et al., 2009).

The NIOSH lifting equation was created in 1981 to assess occupational lifting loads' influence on back injury (Waters, Putz-Anderson, Garg, & Fine, 1993). This was revised in 1991 to apply to a larger population of workers (Waters, Putz-Anderson, Garg, & Fine, 1993). Elfeituri & Taboun, (2002) and other studies have tested components of the NIOSH equation to see if they are valid in real world situations. Their findings suggested that expansions can be made to help improve the already comprehensive NIOSH equation. Shirazi-Adl, (2006) and Fathallah, Marras, & Parnianpour, (1999) found that asymmetrical occupational lifts create greater forces on the spine when compared to symmetrical lifts. Asymmetrical lifting is a common lifting strategy for workers with a restricted vertical workspace (Gallagher, Pollard, & Porter, 2011).

This prospective study will evaluate asymmetrical lifts compared to symmetrical lifts. Unlike former studies with one force plate, two force plates will be used to evaluate both the pressure of the load forces and direction of the forces acting on both legs separately during lifts.

Participants in the study will lift loads with an upper limit of 50 pounds, which is a greater load than previous studies. This study will evaluate both upper body and lower body muscle activities during asymmetrical lifts as opposed to previous studies that only measured either upper body or lower body muscles. The purpose of this study will be to evaluate the risk of upper and lower body asymmetrical lifting vs. symmetrical lifting among three different lifting loads. The results can possibly help further progress knowledge to create new lifting guidelines. These lifting guideline improvements will lead to a decreased occurrence of injury from occupational lifting.

It was hypothesized that the asymmetrical lifts of 20, 35 and 50 pounds will place a significantly higher amount of forces on the spine when compared to symmetrical lifts of the same loads.

Methods

Twenty two participants between the ages 20-45 years old were recruited for this study (Chanplakorn et al., 2012). Candidates with prior hip or spinal surgery were excluded from the study (Fathallah, Marras, & Parnianpour, 1998). Potential participants suffering from chronic back pain were excluded from the study (Fathallah, Marras, & Parnianpour, 1998).

Participants participated in the study voluntarily signing a written consent form approved by California State University, Northridge Human Subject Review Board prior to any data collection. Participants were informed of all of the risks and benefits of the study. They were also told that they would be monitored as they perform the lifts prior to the study.

The dependent variables were the mean EMG activation of the selected muscles as well as force plate readings from the lifts. There were two independent variables

1. Lifting techniques, with two conditions symmetrical vs. asymmetrical
2. Lifting loads with three condition of 20, 35 and 50 pounds.

Only participants that fit inclusion criteria were admitted into to the study. Participants were randomly selected to make sure they were not picked in any order or pattern that would affect the data result outcomes. Participants were required to sign the bill of rights and adult consent form to state they were fully aware of all of the possible risks of the study confidentiality policies prior to any data collection. Each of the twenty two participants met with the researcher at their designated appointment time at California State University's biomechanics laboratory room located in Redwood hall on campus. The researcher greeted the participant and briefly explained the procedures that occurred during the experiment. The researcher then measured participants' leg length, ankle width, knee width height and mass to enter into the Vicon (Oxford

Scientific) motion capture system software. The researcher then placed the adhesive sensors to the participants' muscles. The researcher next wiped down EMG attachment sites on the participant with rubbing alcohol and shaved that location. This helped remove dead skin, dirt and hair from the EMG attachment sites to ensure an optimal EMG muscular signal. EMG electrodes were attached the participants' left and right bicep femoris muscles, followed by the right and left rectus femoris and vastus medialis. The researcher next attached electrodes to the left and right portion of the rectus abdominis followed by the left and right external obliques. Finally, the researcher attached EMG electrodes to the participants' right and left latissimus dorsi muscles. Each electrode was attached facing the direction of the muscle fibers to ensure optimal signal. After each EMG electrode was attached with adhesive tape the researcher further secured the EMG sensors with pre wrap and athletic tape. This was to help ensure secure attachment of the electrodes and decrease the likelihood electrodes from detaching. The EMG data was collected with Trigno (Delsys Inc) wireless electrode sensors. Sensors were placed identically on both sides of the participant's body, according to past studies utilizing Delsys EMG sensors (Sihin & Kim, 2007).

The sensors on the bicep femoris muscles were placed fifty percent between the ischial tuberosity and the lateral epicondyle of the knee. The sensor was placed in a vertical orientation to run parallel to the muscle fibers (Sihin & Kim, 2007). The rectus femoris sensors were placed fifty percent between the anterior sacroiliac spine and the upper patella. The sensor was placed in a vertical orientation to run parallel to the muscle fibers (Sihin & Kim, 2007). The vastus medialis sensors were placed eighty percent between the anterior sacroiliac spine and the medial epicondyle of the knee. The sensor was medially angled to run parallel with muscle fibers. The

recuts abdominis sensors were placed two centimeters horizontally from the umbilicus (Kulas, Schmitz, Shultz, Henning, & Perrin, 2006).

The sensors were placed in a vertical orientation to run parallel to the muscle fibers. The outer oblique sensors were placed twelve centimeters horizontally from the umbilicus (Kulas, Schmitz, Shultz, Henning, & Perrin, 2006). The sensors were placed roughly forty five degrees laterally to run parallel to the muscle fibers. The latisimmus dorsi sensors were placed four centimeters below the inferior angle of the scapula, and fifty percent horizontally between the participant's spine and the end of their back (Sihin & Kim, 2007).

Three sensors were placed on the box to be lifted facing upward. The trigon delsys EMG sensors also record velocity and accelerations with internal accelerometers. These sensors were used to track the forced of the box's movement during each lifting phase.

EMG sensor signals were visually evaluated through Nexus data collection software. Each of the twelve sensors individually tested through an assigned channel. Signals through channel one and two were viewed as the participant performed knee flexion of his or her left and right leg. Next Channels three through six were observed as the participant performed a knee extension while sitting at the edge of a table. Channels seven and eight were observed as the participant performed a sit-up. The participant was instructed to recline on his or her back on top of a table. The Participants' feet were to remain flat on the surface of the table and the arms crossed over the chest to avoid strain form tugging on the neck. The participant was instructed to perform spinal flexion from this position. From this position the participants performed an oblique sit-up. Next the left outer oblique muscle was observed on channel nine. The participant remained lying on the table in the same basic position with the left hand on his or her head and

the right foot resting on top of the left knee. The participant was instructed to touch the left elbow to the right knee, performing a combination of spinal flexion and rotation. The same position and muscular action was performed on the opposite side to observe the right external oblique signal. This was observed through channel ten. Finally, the latismus dorsi muscle signals were observed through channels eleven and twelve. The participant was instructed to place his or her hands on the surface of a table with elbows extended. The participant then performed shoulder flexion against the tables' surface in a downward motion. If any of the channels had a weak signal, the EMG sensors were re-attached until the signal had a strong visual recording.

Prior to any lifts, each muscle was contracted with maximal effort to measure its maximum voluntary isometric contraction (MVIC). The signal from maximal contractions were recorded and used as a baseline to compare to lifting muscular contractions. Isometric contractions occur when the force a muscle creates is equal to load lifted. As a result, the muscles contract without shortening or lengthening. According to the length-tension relationship, this contraction type activates the highest number of muscle fibers and is commonly used to find the peak electromyographic activity. Studies that require EMG recording use maximal voluntary isometric contraction (Howarth, Polgar, Dickerson & Callaghan, 2010) as their EMG signal baseline.

For hamstring MVIC participants were instructed to lay prone on a table. The researcher used a goniometer to place the knee joint in forty five of flexion (Ekstrom, Donatelli & Carp, 2007). Next the researcher grasped the participant's ankle with two hands and instructed the participant to flex the knee as thoroughly as possible. Participants remained prone for abdominal MVIC recording with the feet flat on the surface of the table, knees flexed and hands crossed

over the chest. The research assistant held the participant's feet stable while the researcher held the participant's shoulders flat on the table with extended arms. The participant was instructed to sit up against the pressure on the shoulders (Ekstrom, Donatelli & Carp, 2007). Rectus abdominis and vastus medialis MVIC was recorded with knee flexion. Participants sat on the edge of a table with the knee flexed at sixty five degrees. (Ekstrom, Donatelli & Carp, 2007). The researcher stabilized the leg with two hands just above the ankle (Ekstrom, Donatelli & Carp, 2007). The participant was instructed to extend the knee against the researcher's hand without grasping the table (Ekstrom, Donatelli & Carp, 2007). Latissimus dorsi MVIC was recorded with shoulder extension. Two cotton belts hung were hung in a doorway suspended. This door-anchored system is similar to a concept used by Krasnow, Ambegaonkar, Stecyk, Wimerding, Wyon & Koutedaksi, (2011). In this study, the researchers used portable suspension tools made of anchors and belts to find MVIC for dancers. The participant was instructed to grasp the belts standing arm's length away from the belts. The participant's shoulder was placed into ninety degrees of flexion. The participant was instructed to grasp the belts with thumbs facing up, and extend the shoulder toward the floor. For the outer oblique MVIC, participants assumed the prone laying on the table once again. They were instructed to place their left hand on their head, left foot flat on the table surface, and right foot resting on the left knee. The researcher stabilized the participant's shoulder and instructed the participant to perform spinal rotation against, in an attempt to bring the left elbow to touch the right knee (Ekstrom, Donatelli & Carp, 2007). The same steps were repeated on the right outer oblique.

Each MVIC recording lasted five seconds long (Ekstrom, Donatelli & Carp, 2007). Participant performed MVIC on each muscle starting with the left muscle followed by the right side. This approach is called bi-lateral MVIC and allows the participant to rest each segment for

one minute or longer between contractions while continuously performing MVIC (Krasnow, Ambegaonkar, Stecyk, Wimerding, Wyon & Koutedaksi, 2011). Participants were instructed to perform MVIC once prior to recording to help reduce MVIC performance error (Meldrum, Cahalane, Conroy, Fitzgerald, & Hardiman, 2007). Two trials were taken for each MVIC trial and the strongest of the two trials were taken to ensure optimal maximal contraction readings (Meldrum, Cahalane, Conroy, Fitzgerald, & Hardiman, 2007).

Small reflective markers were placed throughout landmarks on the participant's body. These markers reflected light picked up by seven Vicon infrared cameras to visually track body segment movements as well as record numerical data on the velocity acceleration and direction of the participant's body segments during the lifts. Markers were placed on the lateral portion on the participants' right and left side.

A basic Vicon "plug-in-gait-model" was used for the lower body. Markers were placed on the participant's heel, second toe and ankle. These markers were placed on the outside of the participant's foot. The heel marker was placed with the same vertical alignment as the toe. A marker was placed on the participant's lateral epicondyle of the knee. Another marker was placed on the anterior sacroiliac spine (ASI). One marker was placed between the ASI and the knee. Another marker was placed on the tibia bone, between the knee and the ankle. A reflective marker was placed on the sacrum.

A separate template model was created for the shoulder to track trunk rotations during twisted lifts, in order to avoid using a full Vicon plug-in gait model. This model consisted of three markers: one marker on each of the two acromion processes of the shoulder and one on the

sternum. The shoulder segment was observed in reference to the participant's pelvis to measure rotation.

A separate model was created for the box. This was to measure the three phases of the lift trajectory. The box model consisted of three markers: the right bottom corner, left bottom corner and a middle marker on the upper end of the box. These three points created a triangular shape to obtain a strong visual reference on rotational movements.

Each body segment recoded with the Vicon motion capture system consisted of at least three markers. Three markers per segment ensured a marker could still be recreated if momentarily hidden by referencing a similarly moving marker. Three markers per segment also gave a stronger visual reference on rotational movements which were utilized much in this study. All Vicon motion capture trials were recorded using Nexus 1.8.5 software.

Participants were instructed to stand with each foot on a separate force plate below them during all lifts. Each participant lifted all three loads using both asymmetrical (lifting with a twist) and symmetrical lifting procedures. After all measurements were complete, the researcher debriefed the participants and thanked them for their participation and time.

The time duration of all lifts were not controlled among each lift. Participants were instructed to lift with their arms and legs as straight as possible in a "stoop lift". This lift style was used in Dempsey & Fatalhallah (1999) to unify lifters' form and decrease the variable of lifting technique. Similar to Dempsey & Fatalhallah (1999), both asymmetrical and symmetrical lifts were performed at with three different loads lifted to observe the different forces placed on the spine during lifts. This study used loads with a greater weight than Dempsey & Fatalhallah (1999). Loads of 20, 35 and 50 pounds were lifted to further the forces placed on the spine

during lifts. These loads all fit within the load parameters of the NIOSH lifting guidelines to ensure safety. Fifty pounds is the largest recommended load lifted within the NIOSH guidelines (Waters, Putz-Anderson, Garg, & Fine, 1993). Participants were given 60 seconds of rest between each lift effort, and then told to rest as much time as necessary to lift the next load. The resting time helped avoid fatigue that may affect lifting performance results. When transitioning from symmetrical to asymmetrical lifts, participants rested in the time required for the research team to set up equipment to measure the next lift. This transition took approximately 7 minutes. Participants were given additional time preferred to rest before performing the next lift type. This helped decrease the incidence of fatigue among participants.

Symmetrical lifts

A box with gripping handles was placed in front of the participant. The participant was instructed to step forward with each foot on a force plate and lift the box while holding the box as closely as possible to the body with straight arms to maintain a stoop lift posture (Dempsey & Fatalhallah, 1999). The participant was then instructed to place the load down lowering by bending the knees while looking forward to maintain erect spinal posture. Participants first lifted the box without a load to practice form (Dempsey & Fatalhallah, 1999). The participant lifted the box loaded with thirty five pounds, followed by fifty pounds and finally twenty pounds.

Asymmetrical Lifts

During asymmetrical lifts the box was placed in front of the lifter identical to the symmetrical lifts. Participants were instructed to place the lifted box to their right side. They were also instructed to line up a marker placed in the middle of the box with a blue line of tape that was placed sixty degrees from the original lifting placement. This was to assure no lifts

were performed with twisting greater than sixty degrees, which may lead to an exponential increase in forces on the spine. (Chaffin & page, 1994)

Data Collection Protocol

Participants were required to set an appointment date. During the data collection, participants were required to wear non-restrictive clothing to ensure full flexibility and range of motion during the lifts. This allowed access for adhesive EMG sensors on the participants' body. There was one data collection appointment per participant. Each appointment evaluated patient's exercise performance. Each appointment lasted roughly 90 minutes.

The movement analysis tools used were a seven camera Vicon motion analysis system, synchronized with two 9287 Kistler force plates and a Trigno Delsys EMG muscle system. The cameras system captured the lifters' form for further analysis

Data reduction

The mean EMG signals were taken from each lift to estimate forces placed on the spine. The lifts were separated into four phases:

1. Bending and grabbing of the load.
2. Lifting the load to the required height during the concentric phase of the lift.
3. Twisting during asymmetrical lifts only or just holding the weight for symmetrical lifts
4. Placing the load down on the surface of the force plate during the eccentric phase.

Figure 1 is a visual representative of these phases. The pink line represents the trajectory of the participant's sacrum during the course of the lift. The blue line represents the height of the box during the lift. Phase one occurs from X values two to four. The participant is lowering to grasp the box. Phase two occurs from X values four to roughly five and a half. Both the participant and the box's height increase during this upward lifting phase. Phase three occurs roughly from X values five and a half to six. This is when the box height and participant height have reached the maximum and plateau while the participant either twists or simply holds the box, depending on the style of lift used. Phase four is represented from X values seven to eight. This is when the box and participant lower until the box reaches the floor.

The results focused on Phase 4 of straight versus twisted lifting trials. This was because Phase 4 had the greatest degree of difference between the variables. Phase 4 had the greatest angle of participant twisting from straight to twisting trials.

EMG signals from the left and right portions of the abdominal muscle and the outer oblique muscles were also of the most interest in the results. Mean activation of these muscles are the strongest indicators of lower back strain. Fathallah, Marras, & Parnianpour, (1998) used EMG activation of these muscles in particular to examine spinal loading. This is because activation of these muscles indicates lateral flexion and spinal twisting which lead to shearing and compression of the spinal vertebral discs and strain on the lifter's lower back.

The remaining lifting phases and EMG muscle signals were observed as residual data. They were stored to be examined for patterns that may lead to future studies as well.

Two-by-three ANOVA analysis was used to compare straight versus twisting lifts with loads of twenty, thirty five and fifty pounds. Twenty four ANOVAS were analyzed, for twelve muscles in two different phases using the mean EMG signals of twisted versus straight lifts that were compared among Phase 2 (concentric phase) and Phase 4 (eccentric phase) of the lifts were of main interest. Post processing compared (i) thirty-six different paired-t-tests for the 12 muscles in three different conditions between symmetric and asymmetric lifts during the concentric phase or Phase 2, and (ii) thirty-six different paired-t-tests for the 12 muscles in three different conditions between symmetric and asymmetric lifts during the eccentric phase or Phase 4. There were 12 one way repeated measures ANOVA for the concentric phase 2 and 12 one way repeated measures ANOVA for the eccentric phase 4 among the three weight conditions of 20, 35, and 50 lbs.

Results

This study consisted of ten male participants and twelve female participants. The average participant height was 1.71 m tall, roughly five feet and six inches tall. The average weight of the participants was 74.25 kilograms (163.68 lbs). Most participants were in the early twenties age group (see Table 1).

Most two-by-three ANOVAs of the different muscles showed no statistical significance among the three different loads lifted or between straight and twisted lifts. Only two comparisons were significant. Firstly the right biceps femoris had significant interactions (muscle 2) during the concentric phase 2 which warrants further investigation (see Table 2, Figure 2). Secondly there were significant difference between symmetrical and asymmetrical lifts in the right rectus femoris (muscle 5) during the eccentric phase 4 (see Table 3, Figure 3).

Interactions among the right biceps femoris demonstrated significant correlations between trials but did not have and significant differences among the t-tests (Table 4 and Table 5) for muscle #2 biceps femoris. Table 6 shows some significant differences between eccentric and concentric phase for muscle 2 biceps femoris during symmetric lifts at 20 lbs. There were no differences found in Table 7 among asymmetric lifts. Table 8 displayed some differences between symmetric and asymmetric lifts under 20 lbs. and 35 lbs. during the concentric phase but not during eccentric phase (Table 9). Table 10 shows some significant differences among the three different loads lifted during symmetric concentric phase but not during the eccentric phase (Table 11). Similarly, asymmetric concentric lifts had some differences among the three loads (Table 12). These differences were not observed during the eccentric phase (Table 13). According to the results, the biceps femoris had some differences between symmetric and

asymmetric lifts, and among the three loads during the concentric phase. The eccentric phase did not show such patterns.

The right rectus femoris differences (muscle #5) had some differences between symmetric and asymmetrical lifts under 50 lbs. during the concentric phase, (Table 16), but not in the eccentric phase (Table 17). The right rectus femoris had load differences in EMG activation during the concentric phase, but not during the eccentric phase (Table 18 and 19). The rectus femoris also had EMG differences among the asymmetric concentric phase but not in the eccentric phases (Tables 20, 21).

The pairwise comparisons of Table 22 and 23 show that there were some differences between concentric and eccentric phases for 35lbs. loads lifted, and between symmetric and asymmetric lifts. As mentioned, there were some differences among the lifting phases and the loads lifted between symmetric and asymmetric lifts. Although most of the data patterns were insignificant, they can be investigated in future lifting studies.

Discussion

The studies by Elfeituri & Taboun (2002) and Dempsey & Fatalhallah (1999), found differences in EMG activation among the three different loads lifted. The present study intended to find EMG activation differences among the loads between the concentric phase (phase two) and eccentric phase (phase four) in straight versus twisted lifts. This pattern was not observed but in very few comparisons, which falls within possible statistical error. However two muscles on the right side (biceps femoris and rectus femoris) showed that as the load changed there were statistically significant differences in the muscle activation as well. During eccentric phase that was not evident as the participants probably did not control the weight adequately and they were just dropping it. Participants' EMG activity decreased during the eccentric phase (phase four) as the load increased (see Figure 4). This was not expected and may be due to the lack of control as the participants lowered the weight down.

Differences in muscular activation between straight and twisted lifts, like those found in Shirazi-Adl (2006) and Fathallah, Marras, & Parnianpour (1998), were expected. Very few comparisons reflected this pattern. The left portion of the rectus abdominis muscle with a 35 pound load had some relationship patterns from straight to twisted lifts (see Table 22, 23). One explanation for this lack of difference is the inconsistency of the participants' execution of the twist. Participants were not given specific directions on how to perform the twist and were given no warm-up to practice prior to lifting. Kinematic analysis showed that most participants just lifted upward symmetrically so there were probably no differences in muscular recruitment and synergies. On the other hand during the eccentric phase four the Vicon motion capture analysis visual trials showed that many participants were lowering weight with a twisted spinal posture, however they had lack of erect spinal posture and possibly less control over the heavier load.

Only the left portion of the rectus abdominis with a thirty five pound load during phase two had significant EMG signal differences between symmetric and asymmetric loads among the three loads lifted (see Table 22, 23). Typically an increase in mean EMG values as the load increases during straight lifts signifies less risk of lower back strain (Elfeituri & Taboun, 2002). In some cases, increased EMG activity may suggest more control.

The Delsys EMG produced small data values which were difficult to interpret after normalization. The EMG linear envelope with a four order Butterworth filter of 12 Hz was set high compared to similar studies that typically use 10 Hz to preserve the low amplitude data but still this may have over smoothed the data and eliminated patterns. Participants were not instructed or trained on proper lifting mechanics. This may have produced varied lifting strategies and led to a random range of EMG data recordings. Uniform instructions for pre-lifts, warm ups and practice lifts may help participants adjust muscular response to each load. The rectus abdominis and outer oblique muscles produced extremely weak EMG readings. This may be due to participants' varying fat to lean tissue ratios. The Vicon markers would disappear at times during participant movement, especially during twisting movements. This made joint angle measurements difficult to recreate. In the future, more motion capture cameras with higher resolution may help keep the motion capture markers visible.

Untrained participants may adapt a co-contraction of agonist and antagonist muscles. Unlike learned movement skills, individuals that are given new tasks may contract unnecessary muscles to perform the movement. The participants may have indiscriminately executed similar muscular force synergies to lift all three loads due to the lack of skilled practice. This would explain the lack of significant differences in EMG activation among the three loads lifted. This lack of pattern was observed in the present study.

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Appendix A: Tables

Table 1. Participant Parameters.

Participant	Bodymass(KG)	Hght(MM)
1	70	1727
2	68	1676
3	70.5	1727
4	67	1700
5	93.2	1753
6	68	1727
7	91	1752
8	77	1676
9	79	1778
10	68	1676
11	91.17	1854
12	70	1676
13	68.04	1674
14	71	1524
15	64	1676
16	67.5	1676
17	85	1803
18	89	1803
19	70.5	1727
20	69	1829
21	68.5	1588
22	68	1676

Table 2. EMG2 during Phase 2 showing interaction. There were significant interactions on the right biceps femoris (muscle 2) during the concentric phase 2 which warrants further investigation.

Multivariate Tests^a

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power ^c
w_load	Pillai's Trace	.014	.131 ^b	2.000	19.000	.878	.014	.262	.067
	Wilks' Lambda	.986	.131 ^b	2.000	19.000	.878	.014	.262	.067
	Hotelling's Trace	.014	.131 ^b	2.000	19.000	.878	.014	.262	.067
	Roy's Largest Root	.014	.131 ^b	2.000	19.000	.878	.014	.262	.067
twist	Pillai's Trace	.007	.148 ^b	1.000	20.000	.705	.007	.148	.066
	Wilks' Lambda	.993	.148 ^b	1.000	20.000	.705	.007	.148	.066
	Hotelling's Trace	.007	.148 ^b	1.000	20.000	.705	.007	.148	.066
	Roy's Largest Root	.007	.148 ^b	1.000	20.000	.705	.007	.148	.066
w_load * twist	Pillai's Trace	.309	4.252 ^b	2.000	19.000	.030	.309	8.504	.671
	Wilks' Lambda	.691	4.252 ^b	2.000	19.000	.030	.309	8.504	.671
	Hotelling's Trace	.448	4.252 ^b	2.000	19.000	.030	.309	8.504	.671
	Roy's Largest Root	.448	4.252 ^b	2.000	19.000	.030	.309	8.504	.671

a. Design: Intercept
Within Subjects Design: w_load + twist + w_load * twist

b. Exact statistic

c. Computed using alpha = .05

Table 3. EMG5 during Phase 4 showing differences between symmetrical and asymmetrical lifts. There were significant difference between symmetrical and asymmetrical lifts on right rectus femoris (muscle 5) during the eccentric phase.

Multivariate Tests^a

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power ^c
w_load	Pillai's Trace	.040	.392 ^b	2.000	19.000	.681	.040	.784	.104
	Wilks' Lambda	.960	.392 ^b	2.000	19.000	.681	.040	.784	.104
	Hotelling's Trace	.041	.392 ^b	2.000	19.000	.681	.040	.784	.104
	Roy's Largest Root	.041	.392 ^b	2.000	19.000	.681	.040	.784	.104
twist	Pillai's Trace	.265	7.225 ^b	1.000	20.000	.014	.265	7.225	.725
	Wilks' Lambda	.735	7.225 ^b	1.000	20.000	.014	.265	7.225	.725
	Hotelling's Trace	.361	7.225 ^b	1.000	20.000	.014	.265	7.225	.725
	Roy's Largest Root	.361	7.225 ^b	1.000	20.000	.014	.265	7.225	.725
w_load * twist	Pillai's Trace	.022	.211 ^b	2.000	19.000	.812	.022	.421	.078
	Wilks' Lambda	.978	.211 ^b	2.000	19.000	.812	.022	.421	.078
	Hotelling's Trace	.022	.211 ^b	2.000	19.000	.812	.022	.421	.078
	Roy's Largest Root	.022	.211 ^b	2.000	19.000	.812	.022	.421	.078

a. Design: Intercept
Within Subjects Design: w_load + twist + w_load * twist

b. Exact statistic

c. Computed using alpha = .05

Table 4. Concentric phase 2 and eccentric phase 4 for a symmetric lift showing the expected significant correlation but no significant t-test differences.

	N	Correlation	Sig.
Pair 1 w20_str_phs2_emg_01 & w20_str_phs4_emg_01	22	.874	.000
Pair 2 w35_str_phs2_emg_01 & w35_str_phs4_emg_01	22	.827	.000
Pair 3 w50_str_phs2_emg_01 & w50_str_phs4_emg_01	22	.637	.001

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair 1 w20_str_phs2_emg_01 - w20_str_phs4_emg_01	-.129704927	2.968325744	.6328491750	-1.44578683	1.186376979	-.205	21	.840
Pair 2 w35_str_phs2_emg_01 - w35_str_phs4_emg_01	-.207825469	4.116347151	.8776081614	-2.03291155	1.617260613	-.237	21	.815
Pair 3 w50_str_phs2_emg_01 - w50_str_phs4_emg_01	1.001355405	2.645416278	.5640046456	-.171556465	2.174267274	1.775	21	.090

Table 5. Concentric phase 2 and eccentric phase 4 for an asymmetric lift showing the expected significant correlation but no significant t-test differences.

	N	Correlation	Sig.
Pair 1 w20_tws_phs2_emg_01 & w20_tws_phs4_emg_01	21	.864	.000
Pair 2 w35_tws_phs2_emg_01 & w35_tws_phs4_emg_01	21	.824	.000
Pair 3 w50_tws_phs2_emg_01 & w50_tws_phs4_emg_01	22	.598	.003

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair 1 w20_tws_phs2_emg_01 - w20_tws_phs4_emg_01	.7425482943	2.194915911	.4789699194	-.256565450	1.741662038	1.550	20	.137
Pair 2 w35_tws_phs2_emg_01 - w35_tws_phs4_emg_01	.6920596735	3.719954154	.8117605473	-1.00124316	2.385362503	.853	20	.404
Pair 3 w50_tws_phs2_emg_01 - w50_tws_phs4_emg_01	-.111407524	4.905492503	1.045854516	-2.28638105	2.063566006	-.107	21	.916

Table 6. Concentric phase 2 and eccentric phase 4 for a symmetric lift showing the expected significant correlation but no significant t-test differences for muscle #2 right biceps femoris.

	N	Correlation	Sig.
Pair 1 w20_str_phs2_emg_02 & w20_str_phs4_emg_02	22	.456	.033
Pair 2 w35_str_phs2_emg_02 & w35_str_phs4_emg_02	22	.687	.000
Pair 3 w50_str_phs2_emg_02 & w50_str_phs4_emg_02	22	.718	.000

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair 1 w20_str_phs2_emg_02 - w20_str_phs4_emg_02	2.937352981	6.333262574	1.350256118	.1293416650	5.745364298	2.175	21	.041
Pair 2 w35_str_phs2_emg_02 - w35_str_phs4_emg_02	-.826538699	2.236489450	.4768211529	-1.81814257	.1650651721	-1.733	21	.098
Pair 3 w50_str_phs2_emg_02 - w50_str_phs4_emg_02	.6720765596	3.123173313	.6658627876	-.712660912	2.056814031	1.009	21	.324

Table 7. Concentric phase 2 and eccentric phase 4 for an asymmetric lift showing the expected significant correlation only under 20 lbs and 50 lbs but no significant t-test differences for muscle #2 right biceps femoris. .

Paired Samples Correlations

	N	Correlation	Sig.
Pair 1 w20_tws_phs2_emg_02 & w20_tws_phs4_emg_02	21	.751	.000
Pair 2 w35_tws_phs2_emg_02 & w35_tws_phs4_emg_02	21	.161	.487
Pair 3 w50_tws_phs2_emg_02 & w50_tws_phs4_emg_02	22	.696	.000

Paired Samples Test

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair 1 w20_tws_phs2_emg_02 - w20_tws_phs4_emg_02	-.479095151	2.371523635	.5175088843	-1.55859977	.6004094658	-.926	20	.366
Pair 2 w35_tws_phs2_emg_02 - w35_tws_phs4_emg_02	1.353613071	5.896789744	1.286785017	-1.33057344	4.037799581	1.052	20	.305
Pair 3 w50_tws_phs2_emg_02 - w50_tws_phs4_emg_02	-.585869893	3.465724510	.7388949481	-2.12248606	.9507462710	-.793	21	.437

Table 8. Concentric phase 2 between a symmetric lift and an asymmetric lift showing the expected significant correlation under 20 lbs., and with significant t-test differences for muscle #2 right biceps femoris

	N	Correlation	Sig.
Pair 1 w20_str_phs2_emg_02 & w20_tws_phs2_emg_02	21	.461	.035
Pair 2 w35_str_phs2_emg_02 & w35_tws_phs2_emg_02	21	.267	.241
Pair 3 w50_str_phs2_emg_02 & w50_tws_phs2_emg_02	22	.160	.476

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair 1 w20_str_phs2_emg_02 - w20_tws_phs2_emg_02	3.523294546	6.376753599	1.391521717	.6206311088	6.425957984	2.532	20	.020
Pair 2 w35_str_phs2_emg_02 - w35_tws_phs2_emg_02	-2.65912247	5.050353981	1.102077591	-4.95801604	-.360228900	-2.413	20	.026
Pair 3 w50_str_phs2_emg_02 - w50_tws_phs2_emg_02	-.187882763	5.256338426	1.120655118	-2.51841266	2.142647135	-.168	21	.868

Table 9. Eccentric phase 4 between an asymmetric lift and an asymmetric lift not showing the expected significant correlation at any condition, and with no significant t-test differences for muscle #2 right biceps femoris

	N	Correlation	Sig.
Pair 1 w20_str_phs4_emg_02 & w20_tws_phs4_emg_02	21	.142	.539
Pair 2 w35_str_phs4_emg_02 & w35_tws_phs4_emg_02	21	-.183	.428
Pair 3 w50_str_phs4_emg_02 & w50_tws_phs4_emg_02	22	.237	.289

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair 1 w20_str_phs4_emg_02 - w20_tws_phs4_emg_02	-.022538526	4.461780423	.9736403106	-2.05351663	2.008439572	-.023	20	.982
Pair 2 w35_str_phs4_emg_02 - w35_tws_phs4_emg_02	-.417748373	5.369457179	1.171711617	-2.86189598	2.026399231	-.357	20	.725
Pair 3 w50_str_phs4_emg_02 - w50_tws_phs4_emg_02	-1.44582922	5.543581781	1.181895607	-3.90371568	1.012057252	-1.223	21	.235

Table 10. Concentric phase 2 some differences among three different loads as were expected, mainly between 20 lbs and 35 lbs, under symmetric conditions for muscle #2 right biceps femoris

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power ^a
w_load	Sphericity Assumed	110.819	2	55.410	3.344	.045	.137	6.688	.601
	Greenhouse-Geisser	110.819	1.624	68.259	3.344	.056	.137	5.429	.538
	Huynh-Feldt	110.819	1.740	63.685	3.344	.053	.137	5.819	.558
	Lower-bound	110.819	1.000	110.819	3.344	.082	.137	3.344	.415
Error(w_load)	Sphericity Assumed	695.916	42	16.569					
	Greenhouse-Geisser	695.916	34.094	20.412					
	Huynh-Feldt	695.916	36.543	19.044					
	Lower-bound	695.916	21.000	33.139					

a. Computed using alpha = .05

Table 11. Eccentric phase 4 no differences among the three different weights under symmetric conditions for muscle #2 right biceps femoris

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power ^a
w_load	Sphericity Assumed	5.953	2	2.977	.293	.748	.014	.585	.093
	Greenhouse-Geisser	5.953	1.657	3.592	.293	.707	.014	.485	.090
	Huynh-Feldt	5.953	1.782	3.341	.293	.723	.014	.521	.091
	Lower-bound	5.953	1.000	5.953	.293	.594	.014	.293	.081
Error(w_load)	Sphericity Assumed	427.323	42	10.174					
	Greenhouse-Geisser	427.323	34.806	12.277					
	Huynh-Feldt	427.323	37.416	11.421					
	Lower-bound	427.323	21.000	20.349					

a. Computed using alpha = .05

Table 12. Concentric phase 2 some differences among three different loads as were expected, under asymmetric conditions for muscle #2 right biceps femoris.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power ^a
w_load	Sphericity Assumed	86.561	2	43.280	3.362	.045	.144	6.724	.602
	Greenhouse-Geisser	86.561	1.612	53.704	3.362	.057	.144	5.419	.536
	Huynh-Feldt	86.561	1.732	49.978	3.362	.053	.144	5.823	.558
	Lower-bound	86.561	1.000	86.561	3.362	.082	.144	3.362	.415
Error(w_load)	Sphericity Assumed	514.913	40	12.873					
	Greenhouse-Geisser	514.913	32.236	15.973					
	Huynh-Feldt	514.913	34.640	14.865					
	Lower-bound	514.913	20.000	25.746					

a. Computed using alpha = .05

Table 13. Eccentric phase 4 no differences among the three different weights under asymmetric conditions for muscle #2 right biceps femoris.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power ^a
w_load	Sphericity Assumed	39.505	2	19.752	1.754	.186	.081	3.509	.346
	Greenhouse-Geisser	39.505	1.681	23.497	1.754	.192	.081	2.949	.315
	Huynh-Feldt	39.505	1.818	21.727	1.754	.190	.081	3.190	.328
	Lower-bound	39.505	1.000	39.505	1.754	.200	.081	1.754	.243
Error(w_load)	Sphericity Assumed	450.379	40	11.259					
	Greenhouse-Geisser	450.379	33.626	13.394					
	Huynh-Feldt	450.379	36.364	12.385					
	Lower-bound	450.379	20.000	22.519					

a. Computed using alpha = .05

Table 14. Concentric phase 2 and eccentric phase 4 for a symmetric lift showing the expected significant correlation but no significant t-test differences for muscle #5 right rectus femoris, though there is a trend under 20lbs.

Paired Samples Correlations

	N	Correlation	Sig.
Pair 1 w20_str_phs2_emg_05 & w20_str_phs4_emg_05	22	.726	.000
Pair 2 w35_str_phs2_emg_05 & w35_str_phs4_emg_05	22	.857	.000
Pair 3 w50_str_phs2_emg_05 & w50_str_phs4_emg_05	22	.539	.010

Paired Samples Test

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair 1 w20_str_phs2_emg_05 - w20_str_phs4_emg_05	-.105670567	2.408959216	.5135918306	-2.12477835	.0113670084	-2.057	21	.052
Pair 2 w35_str_phs2_emg_05 - w35_str_phs4_emg_05	.4965842651	1.894129004	.4038296605	-.343225488	1.336394018	1.230	21	.232
Pair 3 w50_str_phs2_emg_05 - w50_str_phs4_emg_05	-.447249345	4.670767328	.9958109403	-2.51815156	1.623652873	-.449	21	.658

Table 15. Concentric phase 2 and eccentric phase 4 for an asymmetric lift showing the expected significant correlation only under 20 lbs and 35 lbs but no significant t-test differences for muscle #2 right rectus femoris, though there is a trend under 20lbs. .

Paired Samples Correlations

	N	Correlation	Sig.
Pair 1 w20_tws_phs2_emg_05 & w20_tws_phs4_emg_05	21	.802	.000
Pair 2 w35_tws_phs2_emg_05 & w35_tws_phs4_emg_05	21	.946	.000
Pair 3 w50_tws_phs2_emg_05 & w50_tws_phs4_emg_05	22	.237	.289

Paired Samples Test

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair 1 w20_tws_phs2_emg_05 - w20_tws_phs4_emg_05	.2053506347	3.873282473	.8452195295	-1.55774641	1.968447678	.243	20	.811
Pair 2 w35_tws_phs2_emg_05 - w35_tws_phs4_emg_05	-.409458078	2.030755468	.4431471738	-1.33384688	.5149307283	-.924	20	.367
Pair 3 w50_tws_phs2_emg_05 - w50_tws_phs4_emg_05	-1.93039532	4.588872402	.9783508834	-3.96498736	.1041967250	-1.973	21	.062

Table 16. Concentric phase 2 between a symmetric lift and an asymmetric lift not showing the expected significant correlation, and with a significant t-test differences for muscle #5 right rectus femoris, under 50 lbs

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	w20_str_phs2_emg_05 & w20_tws_phs2_emg_05	21	.203	.377
Pair 2	w35_str_phs2_emg_05 & w35_tws_phs2_emg_05	21	.333	.140
Pair 3	w50_str_phs2_emg_05 & w50_tws_phs2_emg_05	22	.443	.039

Paired Samples Test

		Paired Differences				t	df	Sig. (2-tailed)	
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower				Upper
Pair 1	w20_str_phs2_emg_05 - w20_tws_phs2_emg_05	-2.80179386	6.334829099	1.382373041	-5.68537349	.0817857777	-2.027	20	.056
Pair 2	w35_str_phs2_emg_05 - w35_tws_phs2_emg_05	-1.00857995	4.848986155	1.058135529	-3.21581199	1.198652084	-.953	20	.352
Pair 3	w50_str_phs2_emg_05 - w50_tws_phs2_emg_05	1.247275271	2.167764573	.4621689598	.2861423036	2.208408238	2.699	21	.013

Table 17. Eccentric phase 4 between an asymmetric lift and an asymmetric lift showing the expected significant correlation at 20 lbs and 35 lbs conditions, and with no significant t-test differences for muscle #5 right rectus femoris, though there is a trend under 35 lbs.

		N	Correlation	Sig.
Pair 1	w20_str_phs4_emg_05 & w20_tws_phs4_emg_05	21	.647	.002
Pair 2	w35_str_phs4_emg_05 & w35_tws_phs4_emg_05	21	.597	.004
Pair 3	w50_str_phs4_emg_05 & w50_tws_phs4_emg_05	22	-.051	.823

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	w20_str_phs4_emg_05 - w20_tws_phs4_emg_05	-1.49134070	4.191443458	.9146479485	-3.39926288	.4165814923	-1.631	20	.119
Pair 2	w35_str_phs4_emg_05 - w35_tws_phs4_emg_05	-1.98813004	4.644764098	1.013570622	-4.10240131	.1261412272	-1.962	20	.064
Pair 3	w50_str_phs4_emg_05 - w50_tws_phs4_emg_05	-.235870701	7.406467166	1.579064105	-3.51971428	3.047972874	-.149	21	.883

Table 18. Concentric phase 2 some differences among three different loads as were expected, under symmetric conditions for muscle #5 right rectus femoris

Multivariate Tests^a

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power ^c
w_load	Pillai's Trace	.297	4.219 ^b	2.000	20.000	.030	.297	8.438	.671
	Wilks' Lambda	.703	4.219 ^b	2.000	20.000	.030	.297	8.438	.671
	Hotelling's Trace	.422	4.219 ^b	2.000	20.000	.030	.297	8.438	.671
	Roy's Largest Root	.422	4.219 ^b	2.000	20.000	.030	.297	8.438	.671

a. Design: Intercept
Within Subjects Design: w_load

b. Exact statistic

c. Computed using alpha = .05

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power ^a
w_load	Sphericity Assumed	16.254	2	8.127	2.534	.091	.108	5.067	.479
	Greenhouse-Geisser	16.254	1.683	9.655	2.534	.102	.108	4.265	.436
	Huynh-Feldt	16.254	1.814	8.961	2.534	.097	.108	4.595	.454
	Lower-bound	16.254	1.000	16.254	2.534	.126	.108	2.534	.330
Error(w_load)	Sphericity Assumed	134.718	42	3.208					
	Greenhouse-Geisser	134.718	35.352	3.811					
	Huynh-Feldt	134.718	38.088	3.537					
	Lower-bound	134.718	21.000	6.415					

a. Computed using alpha = .05

Table 19. Eccentric phase 4 no differences among the three different weights under symmetric conditions for muscle #5 right rectus femoris.

Multivariate Tests^a

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power ^c
w_load	Pillai's Trace	.073	.785 ^b	2.000	20.000	.470	.073	1.571	.165
	Wilks' Lambda	.927	.785 ^b	2.000	20.000	.470	.073	1.571	.165
	Hotelling's Trace	.079	.785 ^b	2.000	20.000	.470	.073	1.571	.165
	Roy's Largest Root	.079	.785 ^b	2.000	20.000	.470	.073	1.571	.165

a. Design: Intercept
Within Subjects Design: w_load

b. Exact statistic

c. Computed using alpha = .05

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power ^a
w_load	Sphericity Assumed	16.335	2	8.167	.852	.434	.039	1.703	.186
	Greenhouse-Geisser	16.335	1.184	13.795	.852	.384	.039	1.008	.151
	Huynh-Feldt	16.335	1.214	13.458	.852	.386	.039	1.034	.153
	Lower-bound	16.335	1.000	16.335	.852	.367	.039	.852	.143
Error(w_load)	Sphericity Assumed	402.776	42	9.590					
	Greenhouse-Geisser	402.776	24.867	16.197					
	Huynh-Feldt	402.776	25.488	15.803					
	Lower-bound	402.776	21.000	19.180					

a. Computed using alpha = .05

Table 20. Concentric phase 2 some differences among three different loads as were expected, under asymmetric conditions for muscle #5 right rectus femoris.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power ^a
w_load	Sphericity Assumed	92.811	2	46.405	3.257	.049	.140	6.514	.587
	Greenhouse-Geisser	92.811	1.703	54.494	3.257	.058	.140	5.547	.539
	Huynh-Feldt	92.811	1.845	50.292	3.257	.053	.140	6.011	.563
	Lower-bound	92.811	1.000	92.811	3.257	.086	.140	3.257	.405
Error(w_load)	Sphericity Assumed	569.917	40	14.248					
	Greenhouse-Geisser	569.917	34.063	16.731					
	Huynh-Feldt	569.917	36.909	15.441					
	Lower-bound	569.917	20.000	28.496					

a. Computed using alpha = .05

Table 21. Eccentric phase 4 no differences among the three different weights under asymmetric conditions for muscle #5 right rectus femoris.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power ^a
w_load	Sphericity Assumed	4.789	2	2.394	.137	.873	.007	.273	.070
	Greenhouse-Geisser	4.789	1.681	2.849	.137	.838	.007	.230	.068
	Huynh-Feldt	4.789	1.817	2.635	.137	.854	.007	.248	.069
	Lower-bound	4.789	1.000	4.789	.137	.716	.007	.137	.064
Error(w_load)	Sphericity Assumed	701.052	40	17.526					
	Greenhouse-Geisser	701.052	33.613	20.857					
	Huynh-Feldt	701.052	36.348	19.287					
	Lower-bound	701.052	20.000	35.053					

a. Computed using alpha = .05

Table 22. Muscle #7 Left Abdominis muscle has some significant differences between concentric phase 2 and eccentric phase 4 under 35 lbs. in the asymmetric trials.

Paired Samples Correlations

	N	Correlation	Sig.
Pair 1 w20_tws_phs2_emg_07 & w20_tws_phs4_emg_07	21	.937	.000
Pair 2 w35_tws_phs2_emg_07 & w35_tws_phs4_emg_07	21	.838	.000
Pair 3 w50_tws_phs2_emg_07 & w50_tws_phs4_emg_07	22	.719	.000

Paired Samples Test

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair 1 w20_tws_phs2_emg_07 - w20_tws_phs4_emg_07	.4000825553	1.219719937	.2661647114	-.155127304	.9552924142	1.503	20	.148
Pair 2 w35_tws_phs2_emg_07 - w35_tws_phs4_emg_07	-.410218019	.6672722407	.1456107406	-.713956701	-.106479336	-2.817	20	.011
Pair 3 w50_tws_phs2_emg_07 - w50_tws_phs4_emg_07	.0729147184	1.367882798	.2916335925	-.533570538	.6793999749	.250	21	.805

Table 23. Muscle #7 Left Abdominis muscle has some significant differences between the symmetric and asymmetric trials under concentric phase 2 under 35 lbs.

Paired Samples Correlations

	N	Correlation	Sig.
Pair 1 w20_str_phs2_emg_07 & w20_tws_phs2_emg_07	21	.097	.675
Pair 2 w35_str_phs2_emg_07 & w35_tws_phs2_emg_07	21	.721	.000
Pair 3 w50_str_phs2_emg_07 & w50_tws_phs2_emg_07	22	.798	.000

Paired Samples Test

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair 1 w20_str_phs2_emg_07 - w20_tws_phs2_emg_07	-1.07042641	3.464014789	.7559099990	-2.64722704	.5063742183	-1.416	20	.172
Pair 2 w35_str_phs2_emg_07 - w35_tws_phs2_emg_07	.4303404098	.8875316308	.1936752800	.0263408551	.8343399645	2.222	20	.038
Pair 3 w50_str_phs2_emg_07 - w50_tws_phs2_emg_07	-.416157752	1.306364967	.2785179467	-.995367530	.1630520264	-1.494	21	.150

Table 24. Right oblique muscle #10 showing differences between concentric phase 2 and eccentric phase 4 during asymmetric lift at 50 lbs.

	N	Correlation	Sig.
Pair 1 w20_tws_phs2_emg_10 & w20_tws_phs4_emg_10	21	.817	.000
Pair 2 w35_tws_phs2_emg_10 & w35_tws_phs4_emg_10	21	.939	.000
Pair 3 w50_tws_phs2_emg_10 & w50_tws_phs4_emg_10	22	.924	.000

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair 1 w20_tws_phs2_emg_10 - w20_tws_phs4_emg_10	-.316083929	1.772970091	.3868937926	-1.12313024	.4909623805	-.817	20	.424
Pair 2 w35_tws_phs2_emg_10 - w35_tws_phs4_emg_10	-.729842736	1.772998685	.3869000325	-1.53690206	.0772165892	-1.886	20	.074
Pair 3 w50_tws_phs2_emg_10 - w50_tws_phs4_emg_10	-.900865863	1.681532286	.3585038879	-1.64641551	-.155316214	-2.513	21	.020

Table 25. Left Latisimuss dorsi muscle #11 showing differences between concentric phase 2 and eccentric phase 4 during asymmetric lift at 50 lbs.

	N	Correlation	Sig.
Pair 1 w20_tws_phs2_emg_11 & w20_tws_phs4_emg_11	21	.870	.000
Pair 2 w35_tws_phs2_emg_11 & w35_tws_phs4_emg_11	21	.523	.015
Pair 3 w50_tws_phs2_emg_11 & w50_tws_phs4_emg_11	22	.894	.000

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair 1 w20_tws_phs2_emg_11 - w20_tws_phs4_emg_11	.8406426971	2.155024204	.4702648353	-.140312560	1.821597954	1.788	20	.089
Pair 2 w35_tws_phs2_emg_11 - w35_tws_phs4_emg_11	-.859400867	2.159011470	.4711349279	-1.84217110	.1233693718	-1.824	20	.083
Pair 3 w50_tws_phs2_emg_11 - w50_tws_phs4_emg_11	-1.57633008	3.516281916	.7496738234	-3.13536215	-.017298022	-2.103	21	.048

Appendix B: Figures

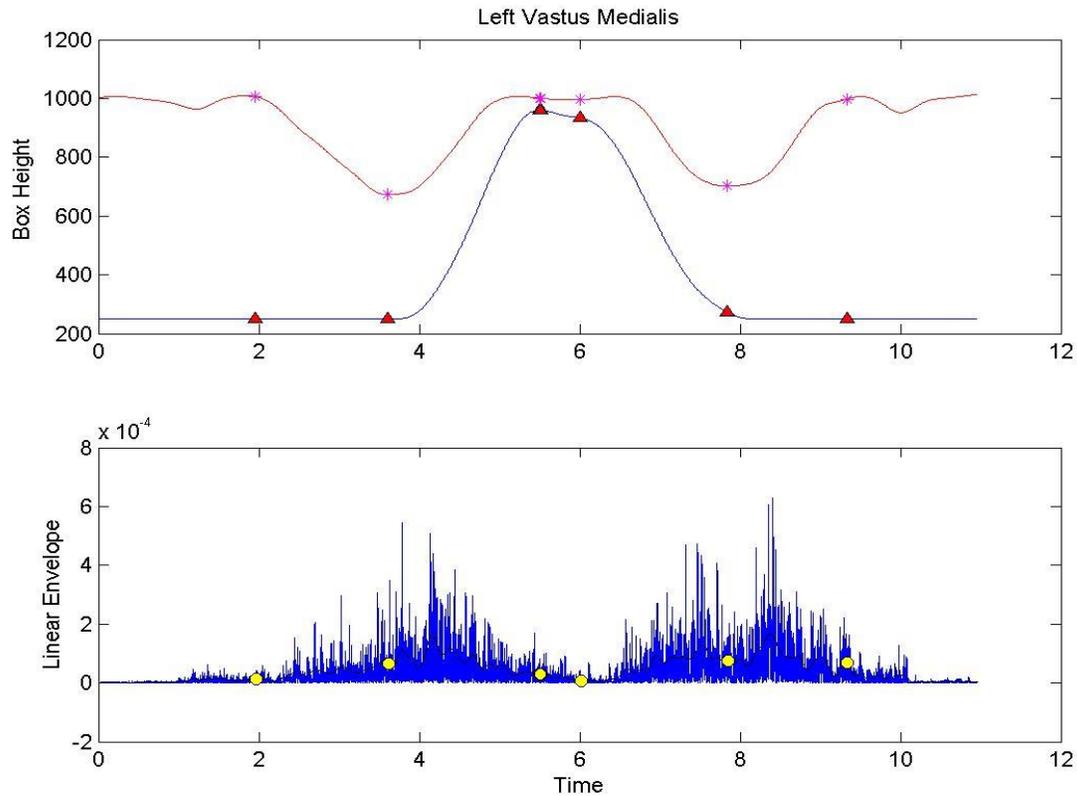


Figure 1. Showing phase two concentric phase from the time markers on the box showed an onset of upward movement till the maximum vertical position of the box. Top figure showing Box Height monitoring lower line that illustrates box center of mass. The pink line represents the trajectory of the participant's sacrum during the course of the lift. The blue line represents the height of the box during the lift. Phase one occurs from X values two to four. The participant is lowering to grasp the box. Phase two occurs from X values four to roughly five and a half. Both the participant and the box's height increase during this upward lifting phase. Phase three occurs roughly from X values five and a half to six. This is when the box height and participant height have reached the maximum and plateau while the participant either twists or simply holds the box, depending on the style of lift used. Phase four is represented from X values seven to eight. This is when the box and participant lower until the box reaches the floor.

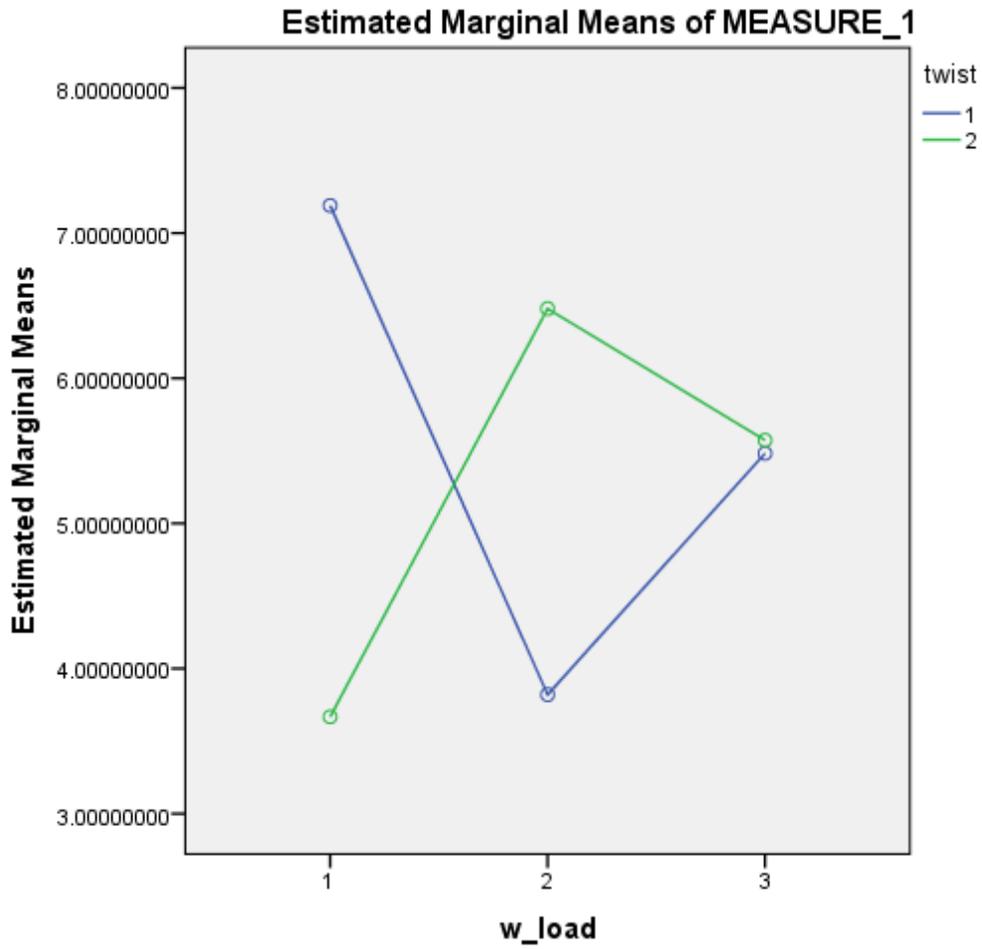


Figure 2. There were significant interactions on the right biceps femoris (muscle 2) during the concentric phase 2 which warrants further investigation, indicating a different muscular effort at 35 lbs. condition

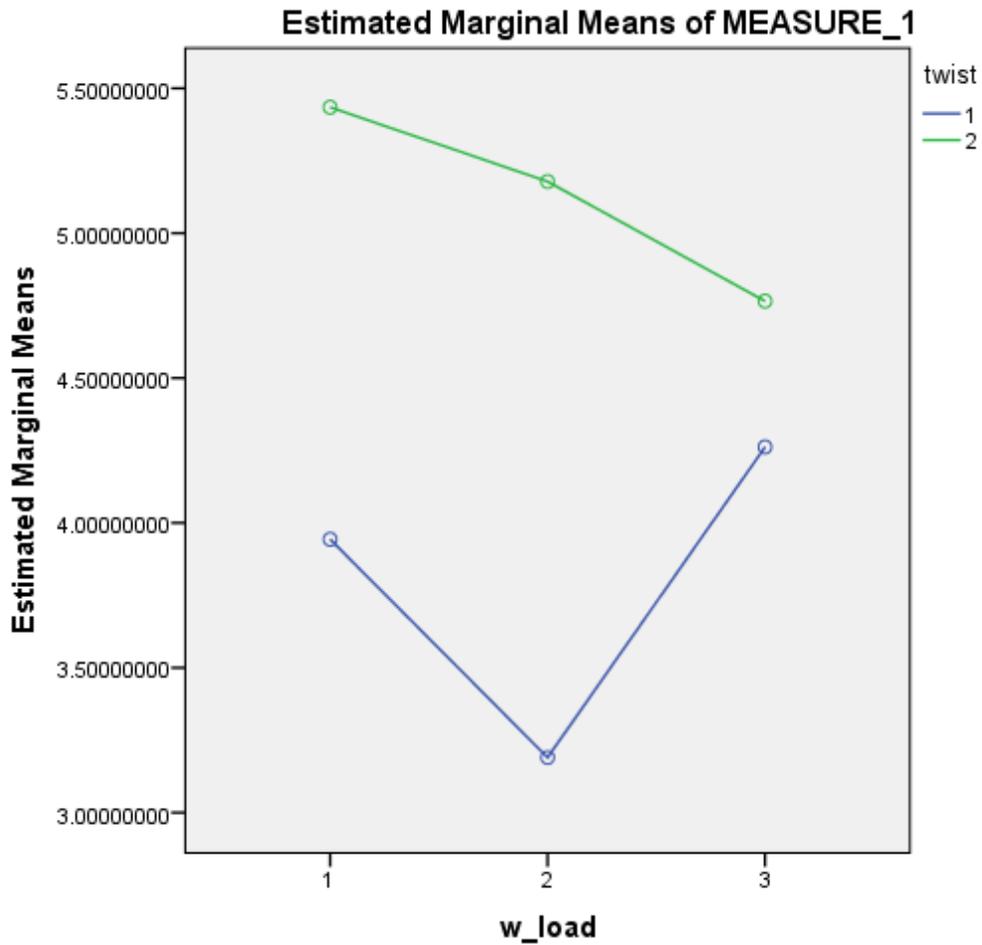


Figure 3. There were significant difference between symmetrical and asymmetrical lifts on right rectus femoris (muscle 5) during the eccentric phase 4, mainly because of differences at the 35 lbs. load.

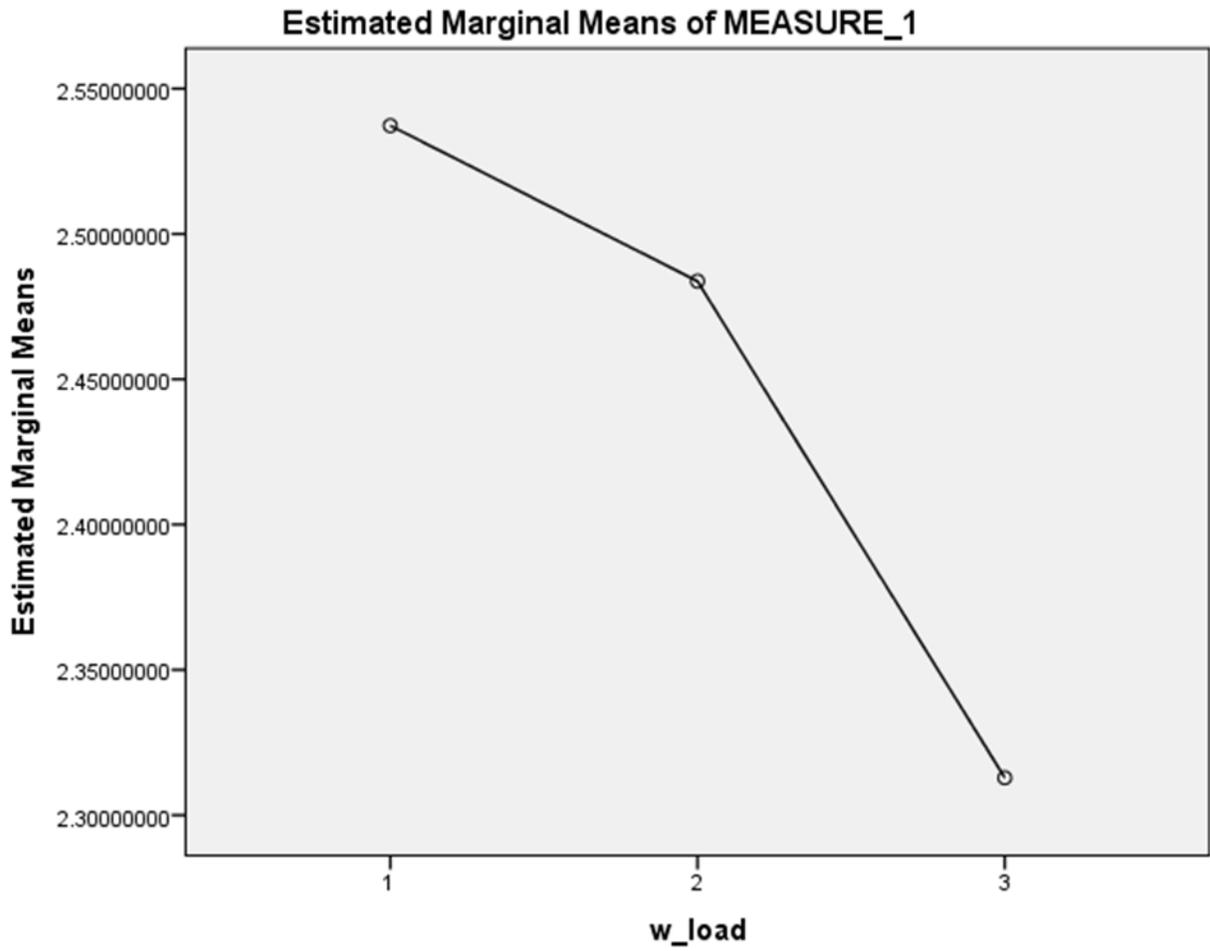


Figure 4. Example whereas EMG activity dropped during eccentric phase 4, as load increased.