DIFFERENCES IN MUSCLE ACTIVATION IN THE LOWER EXTREMITIES WHILE PERFORMING TRADITIONAL SQUATS AND NON-TRADITIONAL SQUATS

by

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ABSTRACT

Differences in Muscle Activation in the Lower Extremities While Performing Traditional Squats and Non-Traditional Squats

Christopher M Scotten

Purpose: To determine if muscle activation in the lower back and lower extremities differ when performing traditional squats compared to non-traditional (forward center of pressure on foot) squats. The erector spinae, hamstrings, quadriceps, adductor longus, gastrocnemius, and gluteus maximus muscles were monitored for differences in this study. There are several variations of the back squat and each variation may possibly target muscles differently. Determining if non-traditional squats leads to larger erector spinae muscle activation, which in turn may lead to more lower back fatigue and possible lower back injury is a major aim of this study. **Participants:** Thirteen healthy males (age = 25.15 ± 2.38 yrs, height = 70.35 ± 3.2 in, weight = 174.45 ± 18.35 lbs and body fat = 10.31% ± 2.97%), which have participated in a steady exercise program for at least a year and included a version of the squat exercise in their routine at least once a week, were the participants in this study. Participants could not have sustained a serious knee, back, or ankle injury in order to qualify for this study. Participants were recruited from Boise State University via flyers and word of mouth. **Methods:** This study consisted of individuals performing traditional squats for one set of ten reps and non-traditional squats for one set of ten reps. Prior to testing, each subject performed maximum voluntary isometric contraction tests for each muscle being monitored (vastus medialis, vastus lateralis, gluteus maximus, bicep femoris, semitendinosus, adductor longus, gastrocnemius, and erector spinae) in order to normalize data collected during the two squatting variations. All testing took place at the biomechanics lab in the Micron Engineering Center at BSU. **Statistical Analysis:** Data was analyzed using the SPSS statistical software package. An ANOVA with a post hoc test consisting of paired t-tests were used to compare differences in activity between the two squatting techniques. **Hypothesis:** The gluteus maximus, biceps femoris, and semitendinosus muscle activation will be significantly larger during the traditional squats. The erector spinae and gastrocnemius muscle activation will be significantly larger during the non-traditional squats. The vastus medialis, vastus lateralis, and adductor longus muscle activation will not be significantly different between the two squat variations. **Results:** The semitendinosus and gastrocnemius muscle activation was significantly larger during the non-traditional squat. The vastus medialis and vastus lateralis muscle activation was significantly larger during the traditional squats. **Conclusions:** When performing back squats, keeping one's center of pressure on the heels of their feet will activate the quadriceps to a larger degree than if performing squats while the center of pressure is on one's toes. Participants claimed their lower back felt more activated during the non-traditional squats; however, the quantitative data did not support this claim.

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CHAPTER ONE: INTRODUCTION

Determining the activation of specific muscles during resistance training is important in designing a workout that effectively utilizes targeted muscles so that time and effort are not wasted when performing exercises that may not provide the desired benefits. Knowing what muscles are activated during specific exercises can also lower the risk of injury during a workout. In addition, many untrained and trained individuals are not aware of what muscles they are activating during certain exercises due to either lack of proper instruction or lack of available material that explains how to properly perform a specific exercise. A lack of knowledge about certain exercise techniques in the general population demands studies that clarify why certain exercise techniques are more effective than others.

The squat exercise is a frequently used exercise because it activates several lower extremity muscles as well as core stabilizer muscles (2, 6, 19). The squat is a resistance training exercise with many variations and each may provide a different benefit by altering the joint angles and range of motion. In addition, it is a closed-chain kinetic exercise and can be a heavy load-bearing exercise that can be used to increase strength and power, while also being used to rehabilitate individuals with various knee injuries (6, 12). Differing the placement of the squat bar, varying squat depth, changing stance width and foot rotation, or performing the squat on a stable or labile surface are all examples of technique variations. Researchers have utilized electromyography (EMG) and video analysis to compare different versions of the squat exercise and how they effect joint forces and muscle activation throughout the lower extremities (5, 9, 10, 12, 17, 18, 19, 20, 21, 22, 23, 29, 30).

The traditional back squat consists of placing a weighted squat bar across the upper trapezius muscles of the back with feet shoulder width apart and in a natural foot placement (whatever is comfortable for the lifter, usually feet slightly abducted). The lifter begins in a standing erect position and then descends bending the knees and lowering the hips, keeping the heels planted, head up and preventing the upper body from leaning forward. The lifter should focus on keeping the center of pressure (COP) over the center or heel of their foot the entire repetition. When the lifter has reached the desired point of knee flexion (usually 70-100°), the ascending motion is started and continued until returning to the beginning position (6).

When monitoring the activation of the muscles in the lower body during resistance exercises, the quadriceps and hamstrings receive much of the attention, but an increasing number of studies have recently focused on the activation of the gluteus maximus (7, 9, 17, 18, 19, 20), calves (7, 20, 21), and erector spinae (2, 17, 18). This is valuable as determining how all of the lower body and core muscles are activated during the back squat and its variations will help trainers, coaches, and athletes apply the proper technique safely into their exercise regimen. For example, Caterisano et al. studied the effects of back squat depth (knee angles of 135°, 90°, and 45°) and determined that as squat depth increased, the activation of the gluteus maximus significantly increased, whereas the activation of the quadriceps and hamstrings did not (5).

There have been studies that compare lower body muscle activation in utilizing different squatting stances (narrow, shoulder width, and wide), foot positions (straight ahead and 30° abducted), bar positions (upper trapezius and mid-trapezius), and loads (9, 10, 19). Escamilla et al. found that there were no significant differences in knee forces or muscle activation when different foot angles were implemented in a narrow or wide stance position, although the gastrocnemius was significantly more active during the narrow stance squat (10). Gullett determined that back squats had higher compressive knee forces compared to front squats but relative muscle activity was the same for the quadriceps, hamstrings, and erector spinae. The higher compressive knee force was determined to be due to the heavier load being used during the more common back squat and not to differences in technique (15).

Of the reviewed studies, few have monitored more than four muscle groups that may have different activation during the squat exercise. This may be due to the lack of equipment (only being able to monitor 2 or 3 muscle groups) or an assumption that the muscles monitored were the only muscles that may have differed significantly during the comparison of the techniques being studied. Experience confirms that when comparing squat techniques, monitoring as many muscle groups in the lower body as possible will help explain muscle activity more thoroughly when using different techniques.

Although several studies have evaluated muscle activation while performing squats, it has not been documented how performing squats with significantly different COP's hinder an individual's goals and thus activate their muscles differently. The COP is the location of the resultant force vector of the load acting through the CG and at a single point, in this case on the foot (34). Determining if a COP over the toe instead of the heel or arch of the foot alters the muscle activity in limbs of the lower body, as well as in the erector spinae muscles, can help trainers, coaches, and therapists teach proper squatting technique to their clients and players. No studies investigating the difference in muscle activation of the lower body between squats with varying COP's on the foot have been located in the literature review, although one study did monitor the participants' COP change while performing a body weight squat of a single technique (7). Given the lack of studies involving COP as a measured variable, this study will examine the muscle activation of the major muscle groups (gluteus maximus, vastus lateralis, vastus medialis, biceps femoris, semitendinosus, gastrocnemius, adductor longus, and erector spinae) in the lower body while performing squats traditionally (COP over heel) and non-traditionally (COP over toe).

Hypotheses

Eight hypotheses will be investigated during this study:

1. Compared to the traditional squat, knee flexion should be less and hip flexion should be more during the non-traditional squat; therefore, gluteus maximus muscle activation will be significantly higher during the traditional squat compared to the non-traditional squat.
2. Because squat stance width does not deviate between techniques, the adductor longus muscle activation will not be significantly different during the traditional squat compared to the non-tradtional squat.
3. Due to the longer moment arm caused at the erector spinae by the anterior motion of the upper body during the non-traditional squat, the erector spinae

muscle activation will be significantly higher during the non-traditional squat compared to the traditional squat.

4. Due to the forward lean in the non-traditional squat and the COP being on the toes, the gastrocnemius muscle activation will be significantly higher during the non-traditional squat compared to the traditional squat.
5. Since the vastus medialis is a large contributor during both techniques, the muscle activation will not be significantly different during the traditional squat compared to the non-traditional squat.
6. Since the vastus lateralis is a large contributor during both techniques, the muscle activation will not be significantly different during the traditional squat compared to the non-traditional squat.
7. Since knee flexion should be less and hip flexion should be more during the non-traditional squat, the bicep femoris muscle activation will be significantly higher during the traditional squat compared to the non-traditional squat.
8. Since knee flexion should be less and hip flexion should be more during the non-traditional squat, the semitendinosus muscle activation will be significantly higher during the traditional squat compared to the non-traditional squat.

Limitations

Due to ease of recruitment and interest in this population, this study will consist of young male adults who are trained in the squatting technique. Untrained individuals may have different muscle recruitment and fatigue that causes the results to be skewed;

therefore, results are limited to individuals with at least one year of trained lifting experience.

Delimitations

Studying men and women separately may help determine exercise programs specifically designed for each gender, since biomechanically and physiologically men and women are different. Compared to males, females typically have a significantly lower hamstring/quadriceps strength ratio (0.62 and 2.25, respectively) (29); therefore, the participants of this study consisted of the same gender to avoid any discrepancies that may occur. This study consisted of men since they were more readily available as squat-knowledgeable participants.

Definitions

Electromyography (EMG) - An instrument used in the diagnosis of neuromuscular disorders that produces an audio or visual record of the electrical activity of a skeletal muscle by means of an electrode inserted into the muscle or placed on the skin (1).

Center of pressure (COP) – The moment in the y-coordinate divided by the vertical force. COP is reported as a % of the longitudinal foot length of the participants from the farthest back part of the heel to the tip of the toe (7). COP is the projection on the ground plane of the centroid of the vertical force distribution. The COP is the location where the resultant force vector would act if it could be considered to have a single point of application (34).

Center of gravity (CG) – The point at which the total body mass can be assumed to be concentrated without altering the body's translational inertia properties. Forces applied through the CG of an unrestrained body generate zero moment and result in translation but no rotation of the body (34).

Closed-chain kinetic exercises (CCK) – Closed linkages in which a movement in one joint simultaneously produces movements in other joints of the extremity (24). During CCK, the end of the limb is in contact with a surface (foot on the floor during the squat) and the adjacent joints (ankle, knee, hip) accompany the movement (35).

Stoop technique – When the knee joints fully extended and the hip joints and vertebral column are flexed to reach the load on the ground (3).

CHAPTER TWO: REVIEW OF LITERATURE

The squat is an exercise implemented in almost every athlete's and serious lifter's regimen because it can effectively strengthen and increase power in the lower body (6). The squat movement has both biomechanical and neuromuscular similarities to several athletic motions, which makes it a useful and popular exercise in the sporting world (6). However, performing the squat is not always easy for everyone and proper form can be an issue in causing injury or decreasing the efficiency and effectiveness of the exercise.

Squatting exercises are closed-chain kinetic exercises, which recruit several joints and muscles in order to perform the lift properly. Many variables need to be considered when performing a proper squat. Neglecting any one of them may cause harm or result in different muscle activation than desired. Studying muscle activity and joint forces during different variations of the squat can help determine the proper technique for each squat and clarify which benefits are gained by performing different variations of the squat.

Analysis of Joint and Ligament Forces

Toutoungi et al. performed a study analyzing the forces placed on the anterior and posterior cruciate ligaments while performing typical rehabilitation exercises, including two types of squats (26). This study used 16 subjects separated into two groups (n = 8), with each group performing isometric exercise, isokinetic exercise, or two types of squats. The subjects performing squats were instructed to keep a shoulder-width stance and bend at the knees to a point that was no further than comfortable. One set of squats was performed while keeping the heels in contact with the ground, while a second set of squats was performed while raising the heels off the ground. For the subjects who could perform one-legged squats, data were also collected during this action and compared to the two-legged squats. The difference in the peak posterior cruciate ligament (PCL) force between the three squats was significant ($p<0.05$) during the descending phase but not during the ascending phase. The heels on the ground squat had the largest peak PCL force of the three types of squats (26). Since the PCL prevents the femur from moving too far forward over the tibia and works in conjunction with the quadriceps muscle, it can be concluded that the quadriceps may also have a large peak activity during squats where the heels are on the ground. They also determined that the forces placed on the PCL are significantly larger than the forces placed on the anterior cruciate ligament (ACL), which is in agreement with a study by Frohm et al. (12). Although ACL forces were not significantly different between squats, the heel off the ground squats did tend to have a larger peak ACL force (although not significantly larger) compared to the heel on the ground squats (26). This finding supports the theory that heels coming off the ground, which is characteristic in the non-traditional squat, will have an effect on muscle activation in the lower body, since hamstrings work in conjunction with the ACL to prevent the forward movement of the tibia from underneath the femur.

In the study performed by Frohm et al., loading of the patellar tendon was measured while subjects performed four different types of eccentric squats: submaximal and maximal efforts (using a device designed for eccentric overloading) on a decline board and a horizontal surface. Fourteen healthy habitually active males volunteered with ten subjects completing both parts of the study. In the submaximal free weight condition, the patellar tendon forces were 25-30% higher during the eccentric squat on a decline board compared to the horizontal surface condition (12). The biomechanics of the squat performed on the decline board could be comparable to a squat performed with a forward COP, since the heels of the participant are elevated compared to the toes in both techniques. Although both techniques share this similarity, a factor that may be more significant in determining COP is the forward lean of the upper body. Forward lean in the upper body is characteristic of a non-traditional squat, but not necessarily in a squat performed on a decline board. A patellar tendon force that is larger than optimal (optimal load was not determined by the reviewed study) may lead to an increased risk for injury, especially if the lifter is performing squats when recovering from tendinopathy (12).

When writing an exercise program, correcting muscle imbalances is important to a well rounded exercise routine. Bilateral difference between legs during the squat is an issue that may cause muscle imbalances. An investigation comparing bilateral differences in net joint torques during the squat exercise found that it should not be assumed that net joint torques are equal between legs during a squat (11). This study measured average net joint moment, maximum flexion angle, average vertical ground reaction force, and average distance from the ankle joint center to the COP for 18 subjects (men, n = 9; women, n = 9) while they performed squats under four loading conditions (25, 50, 75, and 100% of their three repetition maximum). The investigators discovered that the average net joint moment for the hip, knee, and ankle were significantly different between legs for the group but few subjects exhibited the pattern identified by the group average. Also, no subject exhibited insignificant bilateral differences for all three joints (11). In order to verify equal dispersion of work between the left and right leg during the squat, force plates were used during the current study.

EMG Muscle Activation

Isear et al. determined the lower extremity muscle recruitment patterns during an unloaded squat, as well as the amount of hamstring-quadriceps co-contraction (16). After 41 healthy subjects performed three series of four complete squats for data collection, the results revealed minimal hamstring activity. The conclusion was that the minimal hamstring activity was due to the low demand placed on the hamstring muscles to counter the anterior shear forces acting at the proximal tibia (16). It was suggested that further research needed to be performed in order to support or refute the co-contraction hypothesis of the hamstrings and quadriceps during a squat. Including external weights (beside own body weight) during squatting exercises to induce a significant reaction from the hamstring muscles is a study that would increase support of the authors' theory, therefore the current study used 75% of the participants' 10 repetition maximum of the squat as an external load.

In a study by McCaw and Melrose, the effect of stance width and bar load on the leg muscle activity during the parallel squat was investigated (19). EMG data was collected for 9 male lifters who performed five non-consecutive reps of the squat using a shoulder width stance, narrow stance (75% shoulder width), wide stance (140% shoulder width), and two loads (60% and 75% of 1 RM, respectively). It was determined that the rectus femoris, vastus medialis, and vastus lateralis all had an increase in muscle activity with the higher load, while the bicep femoris demonstrated no increase in muscle activity. The adductor longus exhibited higher activity in the narrow stance during the descent phase, the gluteus maximus exhibited higher activity in the wide stance (compared to the narrow stance) during the ascent phase, and the biceps femoris had higher activity during the ascent phase during all three stances (19). The findings of this study suggest that quadriceps muscles do not increase or decrease activity significantly with varying stance width. The authors also concluded that the gluteus maximus and biceps femoris are more active during the ascent phase of the squat to contribute to the large hip torque needed to return to the upright position, as well as stabilizing the knee joint (19). A traditional squat should have more hip flexion compared to a non-traditional squat, which should lead to larger gluteus maximus and biceps femoris muscle activity as determined by the previous study.

Escamilla et al. investigated the effects of the back squat of different foot positions and foot angles on lower extremity muscle activity (10). Ten experienced male lifters performed squats while employing a wide stance, narrow stance, and two foot angle positions (0° or 30° abducted). The investigators discovered that there were no differences in muscle activity between the two foot angle positions (straight ahead and 30° abductied). However, it was determined that significant differences in muscle activity were evident between the narrow stance squat and wide stance squat. The narrow stance squat showed higher gastrocnemius activity than the wide stance squat (10). The biomechanics of the narrow stance squat cause the CG of the lifter to shift to anterior region of the frontal plane, which is similar to the non-traditional squat using a shoulder width stance. When the CG shifts forward, the COP concurrently shifts forward (toward the toes) because the vertical force that runs through the CG of the participant and remains perpendicular to the floor intersects the floor at the COP. From this observation, both narrow stance squats and non-traditional squats should induce a higher gastrocnemius activity than the traditional squat.

Another investigation analyzing squat depth, conducted by Caterisano et al. (5), revealed significant differences in muscle activation for the gluteus maximus. For this study, EMG surface electrodes were placed on the vastus medialis, vastus lateralis, biceps femoris, and gluteus maximus. Ten experienced lifters performed squats at three different depths and it was discovered that as depth increased, so did the activity of the gluteus maximus during the ascent phase of the lift. The biceps femoris, vastus medialis, and vastus lateralis, however, did not show a significant difference in activity between the three squat depths (5). The findings of this study suggest lifters increase squat depth if the goal of the lifter is to induce muscle activity in the gluteus maximus. Since squat depth is not a variable of this study, any differences in the gluteus maximus muscle activity will be attributed to a factor other than squat depth.

A study by Manabe et al. (17) had ten male athletes squatting at three different speeds (slow, normal, and quick), all stances shoulder width apart and all loads at 30% of the participants one rep maximum for the normal squat speed. Eight muscles of the lower extremities were monitored using EMG surface electrodes. The result was that seven muscles (erector spinae, gluteus maximus, gluteus medius, rectus femoris, biceps femoris, adductor longus, and vastus lateralis) had significantly higher activity during the quick squat compared to both the normal squat and the slow squat. The conclusion was that during the quick squat, a stretch-shortening cycle increased the activity of these muscles, especially the gluteus maximus, but the slow squat posed a lower risk of injury (17). The current study will employ verbal cues for the up and down phases of the squat to maintain uniformity between participants and to decrease variability of muscle activity due to squat speed.

Lower Back Load and Activity

A recent study in 2008 by Sasaki et al. analyzed the effects of fatigue in the quadriceps femoris and load placed on the lower back due to this fatigue (22). An isometric muscle force analyzer (Musculator GT-30; OG Giken, Okayama, Japan) was used to determine quadriceps muscle fatigue of 18 male students. Joint angles, EMG, and ground forces were measured while the participants lifted a heavy load for 3 different levels of muscle fatigue determined by the isometric muscle force analyzer (0%, 25%, and 50%). It was discovered that at 25% fatigue of the quadriceps femoris, the subjects changed their mode of lifting from squat to stoop technique and at 50% fatigue the lumbar muscle activity increased. The load being placed at 3 different distances from the participants toes (5 cm, 15 cm, and 25 cm) was also a variable that was measured in the study. They found that as the object being lifted moved farther from the participants' feet, the anterior load also increased. The investigators concluded that during relatively low levels of quadriceps femoris fatigue, altering the mode of lifting somewhat lessens low back load, but during high quadriceps femoris fatigue, changing lifting technique does not decrease the low back load. The authors also theorized that an increase in low back load can increase the risk of lumbar injury (22). The load during the non-traditional squat is similar to moving a load on the ground farther from the toes, since it creates a shift of the upper body forward. This may increase the force felt on the lower back due to an increase in the moment arm created due to the forward shift of the upper body.

The study by Anderson and Behm measured the muscle activity of the major muscles in the lower extremities including the trunk muscles and limb muscles, while squats were performed on a Smith machine, using free weights and on an unstable disc (2). EMG was used to measure the muscle activity of the soleus, vastus lateralis, biceps femoris, abdominal stabilizers, upper lumbar erector spinae, and lumbo-sacral erector spinae in 14 male participants. The investigators found that all of the trunk muscles had higher activity while squats were being performed on the unstable discs. They also discovered that the vastus lateralis muscle activity was significantly higher when squats were performed on the Smith machine compared to the free weight squat. Free weight squats did show the second highest trunk muscle activity and the highest bicep femoris muscle activity. The soleus had significantly higher activity on the unstable discs than either of the stable squats. This increase in activity may be due to the soleus being an important muscle in controlling the ankle and maintaining posture (2). Traditional and non-traditional squats should illicit erector spinae muscle activity, therefore experienced lifters will be used to avoid the possibility of injury due to the unstable nature of free weight squats compared to Smith machine squats.

A study comprised of 10 male athletes performing three different types of squats (normal squats, knee push squats, and hip drive squats) used EMG to monitor the muscle activity of eight lower extremity muscles (18). Knee push squats emphasize knee joint movement without moving the hip joint position back and forth, which would shift the weight farther over the toes, causing a forward lean compared to normal squats or hip drive squats. Hip drive squats emphasize hip joint movement, while keeping the knee joint position fixed. The investigators found that erector spinae muscle activity was significantly higher during hip drive squats compared to knee push squats and that hip drive squats were effective for training hip extensor muscles, while knee push squats were effective for training rectus femoris muscles (18). Hip drive squats and traditional squats both de-emphasize knee movement anteriorly, therefore the study supports the hypotheses that gluteus maximus and hamstring muscle activity should increase when performing traditional squats.

From this review of literature, it is supported that different squatting techniques can cause significant differences in lower body muscle activity. However, there was no study found that investigated the differences in muscle activity between squats with an anterior COP or a posterior COP. As a certified personal trainer, I believe many individuals perform non-traditional squats when they should be performing traditional squats. Therefore, the purpose of this study was to measure muscle activity of the lower back and the lower extremities during a traditional squat and a non-traditional squat to determine if there was a significant difference in muscle activity between the two variations. This will help identify significant differences in muscle activity due to alterations of the COP, which will induce other researchers to delve further into comparing squats using different COP's as a main variable.

CHAPTER THREE: METHODS

The squat exercise has been utilized extensively due to its success in activating the lower extremities (5, 7, 10, 17, 18, 19, 20) and core muscle groups (2). Athletes and the everyday exercisers alike perform all several different techniques, including back squats, front squats, hack squats, and single leg squats. Therefore, determining which technique targets which muscle groups differently than another technique may be useful in designing an exercise program for specific individuals or purposes. Personal observance of several gym patrons and athletes who believe they are properly performing a traditional back squat, while they are actually performing a back squat that includes excess forward lean (non-traditional squat) leads me to the conclusion that a study needs to be performed to compare the muscular activation between these two variations of the squat. EMG was used to monitor the traditional squat and non-traditional squat techniques to verify which variation activated the hamstrings, quadriceps, gastrocnemius, gluteus maximus, adductor longus, and erector spinae more.

The traditional back squat activates lower body muscles including the vastus medialis (VM), vastus lateralis (VL), gluteus maximus (GM), bicep femoris (BF), semitendinosus (ST), adductor longus (AL), gastrocnemius (GT), and erector spinae (ES) muscles (2, 5, 6, 7). The previously listed muscles were monitored by electromyography (EMG) during this study.

The information gathered during this study will be helpful in determining if a forward COP during the back squat results in differences in muscle activation of the lower extremeties compared to traditional back squats. Thus, the purpose of this study was to clarify if the VM, VL, GM, BF, ST, AL, GT, and ES muscles are activated significantly differently ($p < 0.05$) when performing traditional squats and non-traditional squats.

Subjects

After performing a power analysis using the G-power 3.1.2 statistical software package (33), it was determined that 16 participants were needed to obtain enough power to have a 95% confidence interval with the statistical calculations. The participants for this study consisted of 13 healthy males (age = 25.15 ± 2.38 yrs, height = 1.79 ± 0.08 m, weight = 79.3 ± 8.3 kg, and body fat = 10.31% ± 2.97%) with at least a year of participating in a workout program that utilized a version of the weighted squat exercise once a week (or more). The 10 repetition maximum squat average for the group was 101.4 ± 13.8 kg, therefore the average weight each participant squatted (75% of 10 repetition maximum) was 76.1 ± 10.4 kg. All participants were volunteers from the BSU campus. All subjects signed an informed consent form and filled out a questionnaire to determine if they qualified for the study.

Procedures

The first meeting session consisted of filling out the consent form (Appendix B) and questionnaire (Appendix C), conducting a Jackson & Pollock skinfold body composition test, and determining the participants 10 repetition maximum for the back squat. The second meeting session took place 3-14 days after the initial session. All testing for the second session took place in the biomechanics laboratory in the Micron Engineering Center at Boise State University. At the beginning of the second session, the participant was familiarized with each of the squatting techniques being used by visually watching the techniques being performed and then the participant simulated the techniques using just their body weight. After practicing the techniques using just their body weight they performed weighted squats with an Olympic barbell. The weight used during each technique was 75% of the subject's 10 repetition maximum, which was determined in the first session. In the Anderson and Behm study, the subjects lifted 60% of their body weight while standing on unstable discs and no injuries occurred, so it was correctly anticipated that lifting 75% of one's 10 repetition maximum on a steady surface would not lead to injuries (2). There were no problems due to excessive weight being used while performing either variation of the back squat during this study.

The second session include the main data collection and isometric tests that were performed on each muscle group being monitored in order to determine the maximum voluntary isometric contraction (MVIC). The MVIC data were used for comparison of the muscle activity during the two different squatting techniques. The isometric tests were performed on the same day as the data collection of the two squat variations because the participant's hydration level could affect EMG output readings, so performing EMG tests on different days could skew results due to different hydration levels. Also, with multiple sessions, placement of EMG electrodes may be slightly different (e.g., on different areas of the participant's muscle), which may result in different muscle output readings.

Isometric Tests

All but one of the isometric tests (Appendix E) were performed on the Biodex machine (Shirley, NY). The EMG device was a Telemyo 900 unit (Noraxon, Scottsdale, AZ) with a capture rate of 1000 Hz and silver-silver chloride surface electrodes. The participant had eight electrodes connected to the belly of each muscle on the surface per the Noraxon EMG & Sensor Systems diagram (Appendix F) (31).

The following were performed to measure the MVIC for each muscle group (32):

- BF and ST – isometric knee flexion on Biodex with knee at a 90° angle for three seconds. Three trials were performed.
- VM and VL – isometric knee extension on Biodex with knee at a 90° angle for three seconds. Three trials were performed.
- GT – isometric plantar flexion on Biodex foot pad for three seconds. Three trials were performed.
- AL – isometric hip adductor motion (lying on side) on Biodex for three seconds. Three trials were performed.
- GM – isometric hip extension (supine) on the Biodex for three seconds. Three trials were performed.
- ES – superman isometric exercise on the trainer table in the prone position, while lower body was resisted behind the knees and upper body was resisted mid-back by tester, for three seconds. Three trials were performed.

Techniques

Both techniques were used by each lifter. Half of the participants performed the traditional technique first while the other half performed the non-traditional technique first. A randomizer found on the Google website (www.random.org/lists/) was used to determine which subjects were to perform which squats first. Before the traditional or non-traditional squat was performed, each subject performed five reps of squats in the manner in which they usually perform this exercise in order to warm up and also make sure the EMG and motion capture was functioning properly.

Figure 3.1 Example of lowest point during traditional squat

<u>Traditional Technique</u>

The traditional technique has the feet slightly wider than shoulder width apart at a comfortable foot angle. The lifter descends until the upper thigh is parallel to the floor while the heels remain in contact with floor the entire time. The shanks need to be as close to vertical as possible (less than 30° from vertical) and the knees crossing the vertical plane of the toes as little as possible, if at all. The upper body remains as still as possible with chest out and the eyes looking forward or slightly up. The hips are lowered as if sitting in a chair and at the lowest point the COP is over the heel or arch of the foot (ideally, 45-60% of length of the foot). The lifter then begins to ascend, extending the knees, hips, and ankle until they are again standing erect in the starting position. The weight bar needs to be maintained over the fulcrum point in the ankle.

Figure 3.2 Example of lowest point during the non-traditional squat.

<u>Non-Traditional Technique</u>

The non-traditional technique has the feet slightly wider than shoulder width apart at a comfortable foot angle. The lifter descends until the upper thigh is parallel to the floor. The knees cross the vertical plane of the toes due to forward lean. The upper body leans forward and slightly lowers during descent, while the hips are lowered, but not as dramatically as in the traditional squat. At the lowest point of the squat, the COP is over the toes or balls of the feet (greater than 60% of the length of the foot). The lifter then begins to ascend extending their knees and hips, and returning their torso to the beginning position. The weight bar is ahead of the fulcrum point in the ankle.

Data Collection

Along with EMG monitoring, retro-reflective markers were placed on sites of the hip, thigh, knee, shank, ankle, foot, and torso (Appendix G) to analyze squatting kinematics and kinetics using the Vicon motion system (Nexus, Los Angeles, CA) with a capture rate of 250 Hz. Prior to executing the squatting techniques, each participant performed a series of motions that allowed the Vicon motion system to identify the participants' hips and knees.

Kistler Force plates (Model 9281CA, Switzerland), with a capture rate of 1000 Hz, were used to collect the force displacement throughout the participant's foot. The force plate data also allowed for the calculation of the power output at the knee, hip, and ankle. Each participant performed 10 reps for each squatting technique and the measurements for the middle 6 reps of each technique were averaged and used for the statistical analysis. The middle 6 reps were used for analysis because the first 2 reps are considered learning reps and the last 2 reps may be affected by fatigue. The participants were allowed a five minute rest between the two squat techniques.

Data Analysis

The data collected via the Vicon Nexus motion capture were displayed as a 3D model through which kinematic and kinetic data were calculated. The EMG and kinematic data, which were statistically analyzed, were first post processed (normalization, area under the curve, peak amplitudes, joint moment, joint power, and joint range of motion) via a custom Matlab program (Math Works Inc., version 6.0, Natick, MA).

- Kinematics/Kinetics
    - Trajectories filtered
        - 6 Hz zero-lag low pass Butterworth (4^{th} order)
    - Time normalized to 100% of squat rep based on vertical movement of the Center of Mass
    - Subjects average calculated from reps 3-8

        - First two reps discarded because participant may be adjusting to verbal cues given to properly perform the technique.
        - Last two reps discarded due to possibility of fatigue becoming a factor.

- EMG
    - Band pass filtered 20-450 Hz using Butterworth (4th order)
    - Full wave rectified
    - MVIC
        - Six second capture
        - Trimmed to a three second contraction
        - Peak amplitude of each of the three trials was recorded
        - Averaged MVIC peak amplitude from the three trials
    - Squat Trial
        - Normalized to peak average MVIC
        - Time normalized to 100% of squat rep
        - Area under the curve
        - Percent contribution based on both %MVIC and area

Statistics

The peak and mean electrical activity were determined for each muscle group monitored and compared to the peak amplitude of the MVIC data collected. An average peak and mean of the middle 6 reps was taken to minimize potential variations during each rep. Using the percentage of MVIC data, a post hoc paired t-test for each muscle group comparing the two techniques was performed if the repeated measures ANOVA determined any significant ($p < 0.05$) differences in muscle activity. Kinematic and kinetic data were also analyzed using repeated measures ANOVA to determine significant ($p < 0.05$) differences in joint range of motion (hip, knee, and ankle) and squat variation COPs. All data were analyzed using the PAWS statistical package (Winwrap Basic, 1993-2007 Polar Engineering and Consulting) and data were stored on a computer in the biomechanics laboratory and a flash drive, which was kept in the biomechanics laboratory. Paired t-tests were used for post hoc analyses to determine significant differences ($p < 0.05$) between each of the eight muscles monitored and to determine significant differences ($p < 0.05$) in the kinematic data collected.

CHAPTER FOUR: RESULTS

The purpose of this study was to analyze the muscle activity, kinetic and kinematic differences between a traditional and non-traditional squat. The main factor that determined the difference between the two squat variations was the COP on the participant's foot during the execution of the exercise. Sixteen healthy males participated in this study but only 13 participants' data were usable for statistical analysis due to EMG and video equipment issues during three of the participants' trials. The results of this study will be presented in tables and graphs that illustrate the averages of all the participants' data collected during repetitions 3-8 of the set of both the traditional and non-traditional squat techniques. The average peak normalized EMG amplitude data are presented as a ratio of the average peak amplitude (mV) during each repetition and the average of the MVIC (mV) data for each muscle. The average total EMG area (mV·s) data are presented as the average of the total volume of muscle activity occurring during each repetition of the squatting exercise for each muscle.

No significant difference existed in the normalized peak EMG activities between the traditional (Trad) and non-traditional (Non) squat.

Table 4.1 Averages and standard deviations for peak EMG data.

Average Peak Normalized EMG Amplitude (Peak Amplitude[mV]/ MVIC[mV])								
Muscle	Gluteus Maximus		Adductor		Gastrocnemius		Vastus Medialis	
Squat	Trad	Non	Trad	Non	Trad	Non	Trad	Non
Average ± SD	4.76 ± 4.48	4.47 ± 4.47	1.63 ± 1.38	1.68 ± 1.59	0.43 ± 0.26	0.67 ± 0.23	2.71 ± 2.92	1.86 ± 1.25
Muscle	Vastus Lateralis		Biceps Femoris		Semitendinosus		Erector Spinae	
Squat	Trad	Non	Trad	Non	Trad	Non	Trad	Non
Average ± SD	1.98 ± 1.06	1.73 ± 0.93	1.37 ± 0.83	1.67 ± 1.22	0.47 ± 0.33	0.64 ± 0.37	1.46 ± 0.72	1.49 ± 0.68

Overall average total area in the EMG output between traditional and non-traditional squats returned an $F_{(1,7)} = 4.359$, $p < 0.05$, and the GS, VM, VL, and ST muscles post hoc results gave a $p < 0.05$. Figure 3 displays the averages and standard deviations for the eight muscles monitored. Muscles for which activation was significantly different between the two squats are marked with an asterisk. Significantly higher muscle activity readings were measured for the gastrocnemius and semitendinousus during the non-traditional squat. The vastus lateralis and vastus medialis muscles had a significantly higher muscle activity reading during the traditional squat compared to the non-traditional squat.

Table 4.2 Averages and standard deviations for total EMG area data.
*- Significant difference between Trad and Non technique ($p < 0.05$)

Average Total EMG Area (mV·s)								
Muscle	Gluteus Maximus		Adductor		Gastrocnemius*		Vastus Medialis*	
Squat	Trad	Non	Trad	Non	Trad	Non	Trad	Non
Average ± SD	1048 ± 910.48	893.38 ± 762.0	310.11 ± 236.7	284.80 ± 270.0	66.76 ± 43.7	103.16 ± 33.9	506.26 ± 338.6	371.76 ± 261.5
Muscle	Vastus Lateralis*		Biceps Femoris		Semitendinosus*		Erector Spinae	
Squat	Trad	Non	Trad	Non	Trad	Non	Trad	Non
Average ± SD	463.67 ± 265.4	353.82 ± 219.2	330.68 ± 206.6	344.37 ± 235.3	80.78 ± 55.5	111.90 ± 68.1	349.75 ± 184.8	336.88 ± 182.9

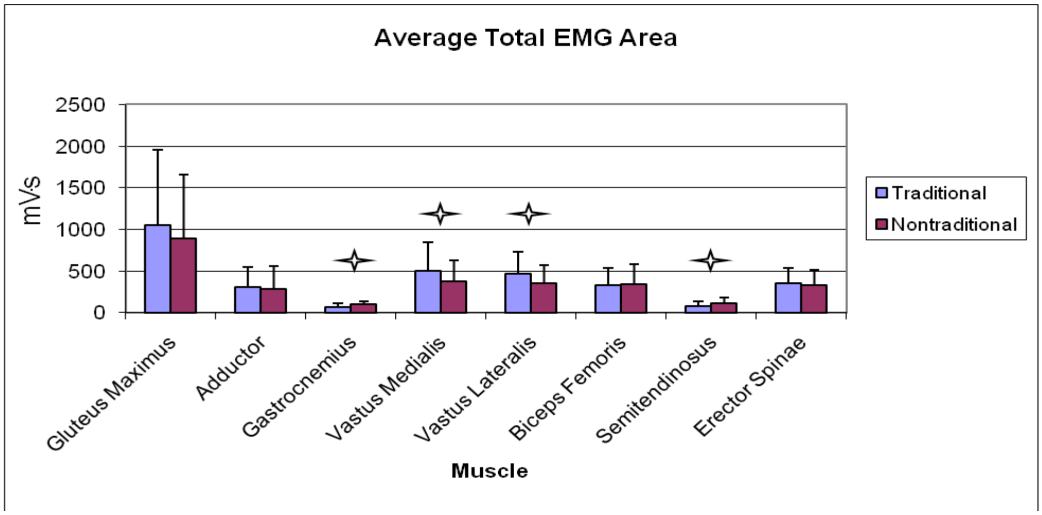

Figure 4.1 Averages and standard deviations for total EMG area data. Significant differences based on paired t-tests. (= p < 0.05)

Overall percent contribution for the average total area in the EMG output between traditional and non-traditional squats returned an $F_{(1,7)}$ =4.192, $p < 0.05$, and the GS, VM, VL, and ST muscles post hoc results gave a $p < 0.05$. Figure 4 displays the averages and standard deviations for the eight muscles monitored as well as identifying the muscles that were significantly different between the two squats. The gastrocnemius and semitendinousus reported significantly higher muscle activity readings during the non-traditional squat. The vastus lateralis and vastus medialis muscles had significantly higher muscle activity during the traditional squat compared to the non-traditional squat.

Table 4.3 Averages and standard deviations for % contribution total EMG area
*- Significant difference between Trad and Non technique (p < 0.05)

Average Percent Contribution of Each Muscle Based on Total EMG Area								
Muscle	Gluteus Maximus		Adductor		Gastrocnemius*		Vastus Medialis*	
Squat	Trad	Non	Trad	Non	Trad	Non	Trad	Non
Average ± SD	29.43% ± 17%	28.74% ± 17%	9.57% ± 5.7%	9.26% ± 6.2%	2.58% ± 1.8%	4.39% ± 2.4%	16.53% ± 6.9%	13.63% ± 6.8%
Muscle	Vastus Lateralis*		Biceps Femoris		Semitendinosus*		Erector Spinae	
Squat	Trad	Non	Trad	Non	Trad	Non	Trad	Non
Average ± SD	14.86% ± 4.3%	12.63% ± 4.5%	11.14% ± 5.6%	12.64% ± 6.3%	2.67% ± 1.7%	4.07% ± 2.4%	13.23% ± 8.1%	14.65% ±9.99%

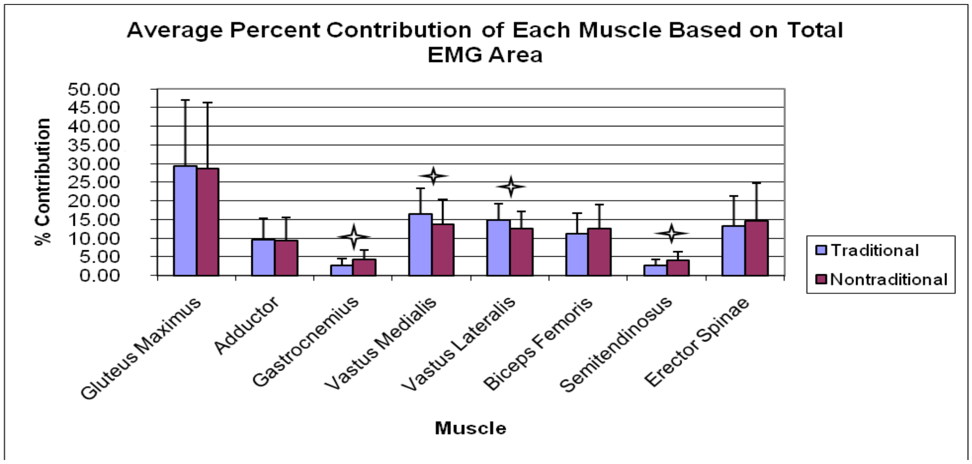

Figure 3.2 Average % Contribution of Muscle Based on Total EMG
Significant differences based on paired t-tests. (= p < 0.05)

Overall percent contribution for the average peak normalized EMG values between traditional and non-traditional squats returned an $F_{(1,7)} = 2.785$, $p < 0.05$, and the GS and ST muscles post hoc results gave a $p < 0.05$. Figure 5 displays the averages and standard deviations for the eight muscles monitored as well as identifying the muscles that were significantly different between the two squats. The gastrocnemius and semitendinousus reported significantly higher muscle activity readings during the non-traditional squat.

Table 4.4 Averages and standard deviations for % contribution of peak EMG.
*- Significant difference between Trad and Non technique (p < 0.05)

Average Percent Contribution of Each Muscle Based on Peak Normalized EMG Amplitude								
Muscle	Gluteus Maximus		Adductor		Gastrocnemius*		Vastus Medialis	
Squat	Trad	Non	Trad	Non	Trad	Non	Trad	Non
Average ± SD	29.15% ±18.6%	27.58% ± 17%	10.32% ± 5.8%	10.91% ± 7.7%	3.67% ± 2.6%	5.51% ± 2.6%	17.46% ± 10%	13.97% ± 7.5%
Muscle	Vastus Lateralis		Biceps Femoris		Semitendinosus*		Erector Spinae	
Squat	Trad	Non	Trad	Non	Trad	Non	Trad	Non
Average ± SD	13.98% ± 4.64%	12.41% ± 4.1%	10.05% ± 5.3%	11.98% ± 6.5%	3.35% ± 2.2%	4.70% ± 2.8%	12.03% ± 7.7%	12.92% ± 8.3%

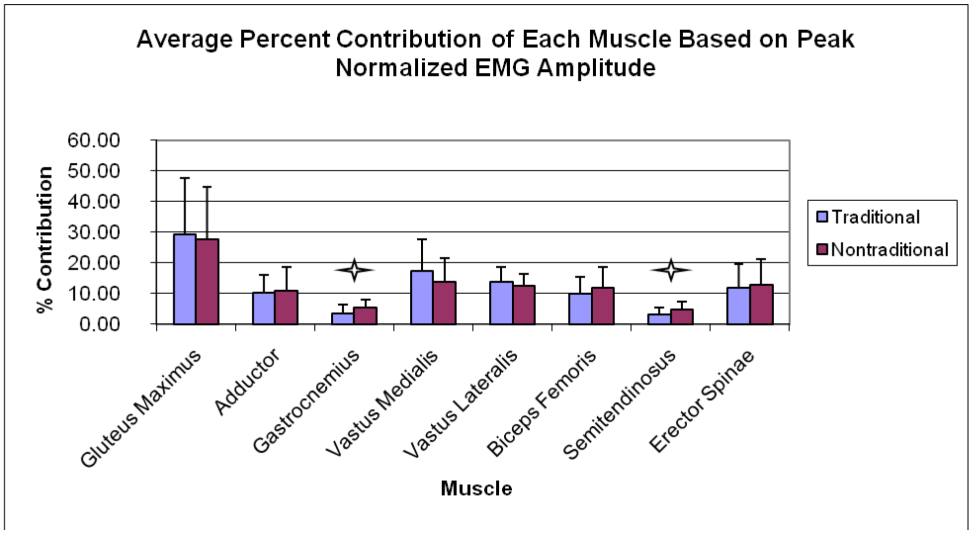

Figure 4.3 Average % contribution of muscle based on peak normalized EMG amplitude. Significant differences based on paired T-tests. (= p < 0.05)

ANOVA results for the overall kinematic and kinetic data analysis between traditional and non-traditional squats returned an $F_{(1,5)} = 4.138$, $p < 0.05$, and post hoc results for the COP and range of motion for the ankle and knee gave a $p < 0.05$. In Table 5, the average COP and ROM for the knee, hip, and ankle are displayed. COP is measured as a percentage of the longitudinal length of the participant's foot with the heel = 0 and the toe = 100. The ranges of motion are measured from the beginning of the squat to the lowest decent point. Post-hoc t-tests revealed that the COP was significantly closer to the heels during the traditional squat compared to the non-traditional squat. T-tests also revealed that the ROM knee and ROM ankle were significantly larger in the traditional squats compared to the non-traditional squats. The ROM hip was not significantly different but the data revealed a trend that the traditional squat elicits a larger range of motion compared to the non-traditional squat.

Table 4.5 Averages and standard deviations for kinetic and kinematic data. **: *-**
Significant difference between Trad and Non technique ($p < 0.05$)

Kinematic and Kinetic Average Data								
	Average COPy*		ROM Knee (degrees)*		ROM Hip (degrees)		ROM Ankle (degrees)*	
Squat	Trad	Non	Trad	Non	Trad	Non	Trad	Non
Average ± SD	52 ± 9.0	70 ± 4.0	101.56 ± 6.68	93.30 ± 14.52	110.96 ± 25.76	101.50 ± 19.24	26.50 ± 4.23	20.62 ± 6.09

The % Squat in Figures 6, 7, 8, 9, 10, and 11 refer to the time it took the center of mass of the participant to cycle through one repetition. One repetition begins when the center of mass begins to descend and ends when the center of mass returns to the beginning position. The average COP for the traditional squat was significantly closer to the heel during the entire downward and upward phase of the motion as seen in Figure 6 and determined by the paired t-test for COP between the two squats giving a $p < 0.05$.

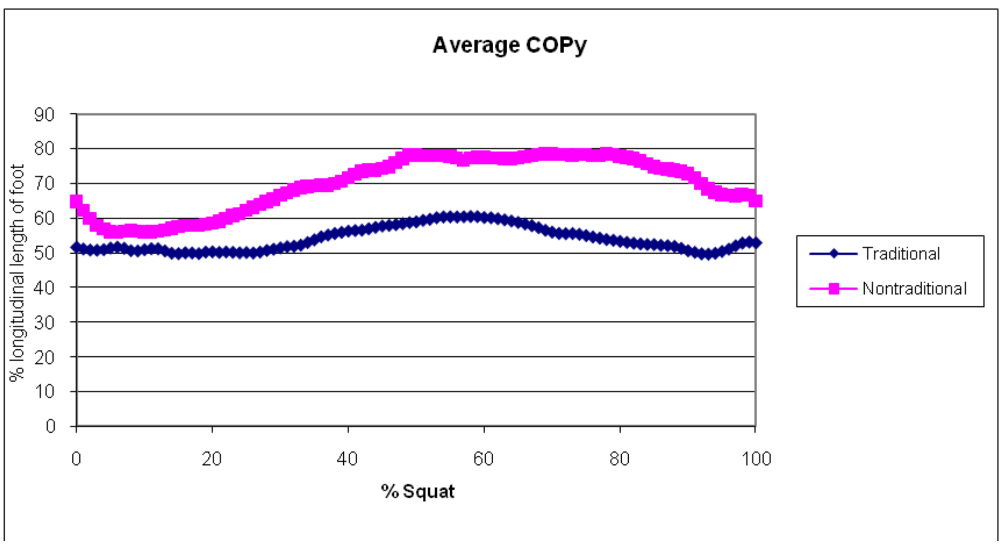

Figure 4.4 Average center of pressure.
(0 = heel, 100 = toe).

The range of motion for the ankle was significantly less ($p < 0.05$) in the non-traditional squat; however, both squat types follow a similar range of motion through the entire squatting technique as shown in Figure 7.

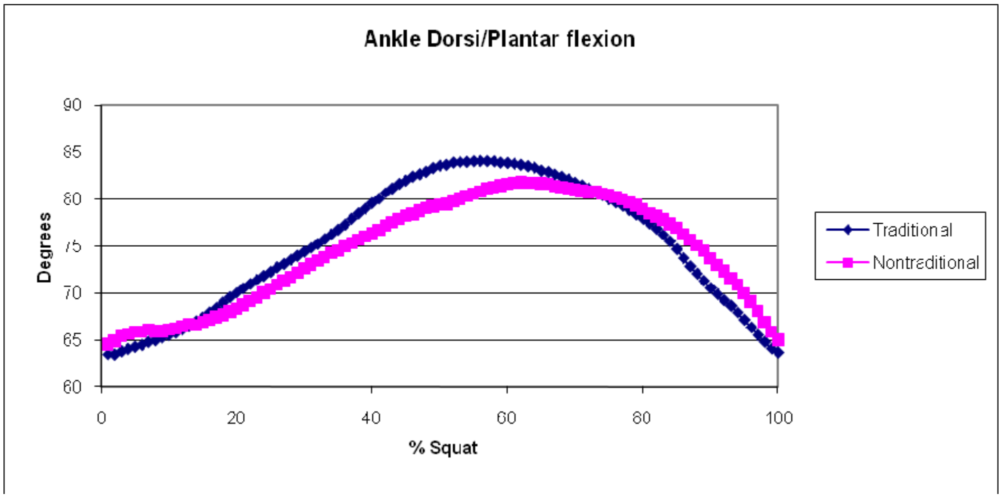

Figure 4.5 Average ankle flexion.
T-test gave $p < 0.05$.

In Figure 8, the average ankle power is displayed during each squat and it can be seen that the lowest and highest points recorded were during the non-traditional squat. The EMG average total area, percent contribution to the total area, and percent contribution to the peak EMG data for the GT was significantly higher in non-traditional variation of the squat, and Figure 8 complements these results by showing that the ankle power output is larger during the non-traditional squat.

Figure 4.6 Average ankle power.

The paired t-test for knee range of motion gave a $p < 0.05$, with the traditional squat having a significantly larger range of motion compared to the non-traditional squat. Figure 9 does show that both squatting techniques averaged over 90 º of knee flexion, and although the peak for both variations are close, almost every participants' knee range of motion was larger during the traditional squat.

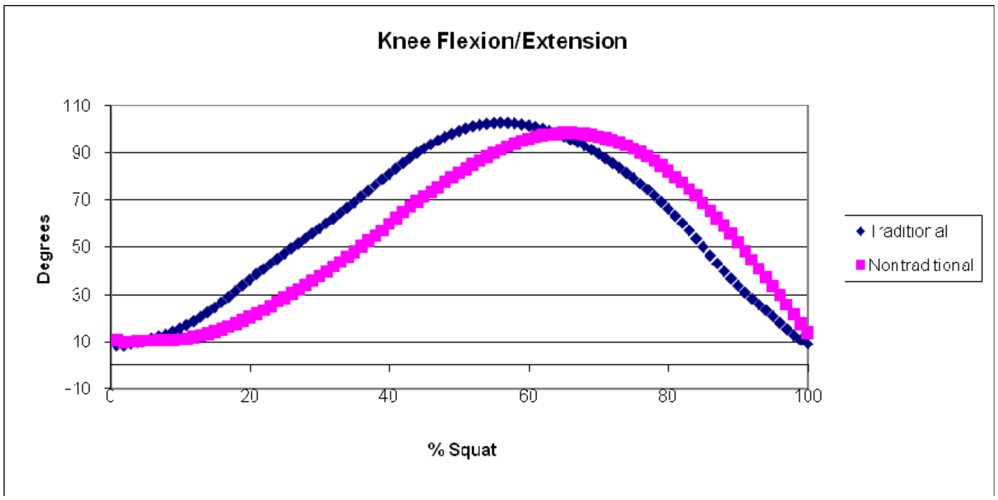

Figure 4.7 Average knee range of motion during the squatting variations.

In Figure 10, it can be seen that the traditional squat has a lower minimum and higher maximum power output. From the EMG data, the VL and VM were significantly more active during the traditional squat. Figure 9 complements the results from the EMG data by showing that knee power output is larger during the traditional squat.

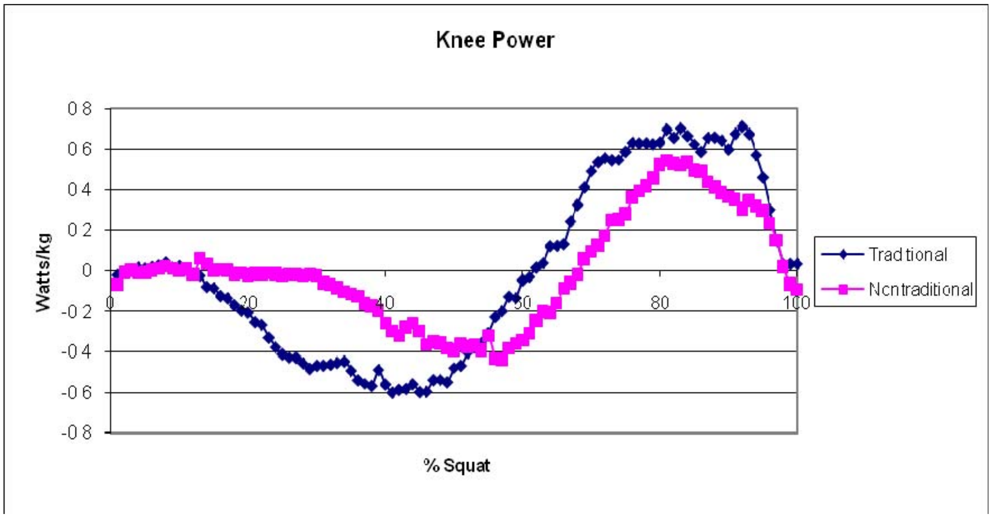

Figure 4.8 Average knee power.

In Figure 4.9, the average hip power is illustrated during the percent squat. The data used in creating this chart were not always consistent due to an interruption of the monitoring of the hip reflectors in several of the participants. This interruption was due in part to the front hip reflectors being covered inadvertently by either clothing during the lowest part of the squat or by the cameras losing tracking due to the height of the squat rack safety bar being around hip level at the bottom of the squat. The majority of tracking was lost between 40-80% of the squat as can be seen by the erratic data points in that range in Figure 11. Due to processing of the video taking place after half of the participants completed the study, this interruption was not noticed until midway through the study. Although this is an artifact of the study, some results can be drawn from the data. The data points that were identified as legitimate were not significantly different between the two techniques, which correspond to the gluteus maximus muscle activity not being significantly different between the two squats.

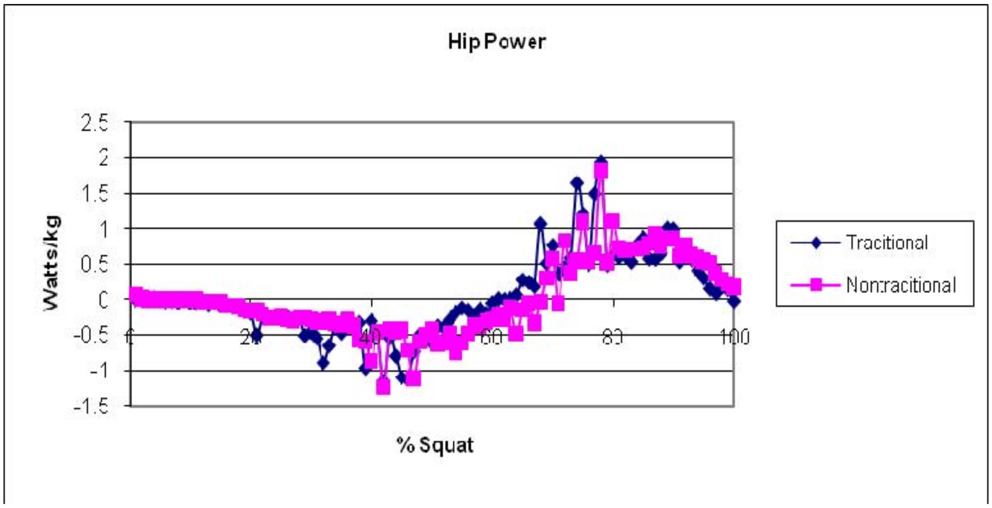

Figure 4.9 Average hip power.

The hypotheses of this study were based on observation and experiences encountered while performing the squatting exercise. The results of this study supported the hypotheses that the adductor longus would not experience a significant difference in muscle activity between the two squat techniques and that the gastrocnemius would have larger muscle activation during the non-traditional squat compared to the traditional squat. The rest of the hypotheses were not supported by the results of this study. The gluteus maximus, biceps femoris, and erector spinae did not experience a significant difference in muscle activity between the two techniques as was expected. The vastus medialis and vastus lateralis exhibited significantly larger muscle activity during the traditional squat compared to the non-traditional squat. The semitendinosus muscle activity was significantly larger during the non-traditional squat compared to the traditional squat, which was the opposite expectation going into the study.

CHAPTER FIVE: DISCUSSION

Performing exercises with proper form increases efficiency, effectiveness, and safety. The squat exercise is a strength exercise that is implemented in workout routines in order to activate the quadriceps, hamstrings, calves, gluteus, and core musculature. Several variations of the squat exercise have been compared in laboratory settings in order to determine specific muscle activation differences between the various techniques and discover the most effective technique to train a specific muscle group (2, 5, 9, 10, 12, 19, 21).

The aim of this study was to determine significant differences between activation of the lower body musculature while performing two variations of the squatting exercise. The two squatting techniques were labeled traditional and non-traditional, and were described in detail in previous chapters. Statistical analysis of the eight muscles monitored during the squatting variations indicated significant differences between the two techniques.

The gluteus maximus showed no difference in muscle activity between the two techniques. The GM is typically more active when squat depth is increased (5) and when stance width is increased from 75% of shoulder width to 140% of shoulder width (19). However, this study did not use differing squat depth or stance width as variables, so the hypothesis that the GM activity would be significantly different between the two squats was based on the COP being either more toward the heel (traditional squat) or more toward the toe (non-traditional squat) of the foot, which was not supported in this study.

Thus, the position of the COP does not appear to be a factor that would cause a significant difference in muscle activity of the GM.

The adductor longus has been shown to increase in muscle activity as stance width increases by a previous study (19), however stance width was maintained at shoulder width during both squat variations in this study and the results were as expected. There were no previous studies using COP or squat depth as a variable measuring adductor longus muscle activity, therefore comparison of results is limited. The adductor longus does not appear to be affected by COP positioning but is affected by stance width.

A surprising finding of this study was that the erector spinae musculature did not show a significant difference in activation between the two squat variations. Sparto et al. determined that repetitive lifting caused forward tilt angle of the upper body, which in turn increased the demand on the trunk extensors (36). Therefore, it was hypothesized that the erector spinae would increase in activity during the non-traditional squat because of the anterior shift of the upper body, causing a larger moment arm for the erector spinae muscle; however, the results of this study do not support this. Interestingly, several of the participants communicated that their lower back felt more strain during the non-traditional squats compared to the traditional squats. This “feeling” may be attributed to stressors or forces being applied to tissues (e.g., tendons, ligaments, bone, or muscles) that were not monitored during this study. Further research should be conducted in order verify this speculation.

Another possibility that needs to be researched further is the increase in fatigue during repetitive lifting being the main contributor to the increase in erector spinae muscle activation. Since fatigue was not a measured variable in this study, future work may include fatigue as a factor and compare it to previous studies in which lower back musculature was prone to increased activity as muscle fatigue increased (22, 36).

The total area of EMG activity, percent contribution of total area of EMG activity, and percent contribution of peak EMG activity of the gastrocnemius showed a significant increase in muscle activity during the non-traditional squat. Figure 7 displays the ankle power during both traditional and non-traditional squats and it can be seen that ankle power is stronger during the non-traditional squat. This complements the results of more muscle activity in the gastrocnemius during the non-traditional squat, since the insertion point of this muscle is at the ankle. A study by Roelants et al. discovered that the gastrocnemius was significantly more active when squats were performed while experiencing whole body vibration compared to no vibration stimulus (21). Both non-traditional squats and squats performed during whole body vibration can be considered unstable conditions. These studies reported that unstable squatting conditions will produce more muscle activation from the gastrocnemius, and that the gastrocnemius appears to be more active when an individual is off balance. The gastrocnemius is a muscle that contributes largely to the balancing of an individual when performing lifting maneuvers. Another speculation is that if the heel comes off the ground during the non-traditional squat, the gastrocnemius and other calf muscles may be responsible for this action eliciting further muscle activity, although the heel coming off the ground may be due to lack of flexibility in the gluteus, hamstring, and calf musculature. In the study by Dionisio et al., the ankle torque, COP, and gastrocnemius muscle activity was monitored during the descent and ascent of a body weight squat. As the COP shifted toward the toe, the ankle torque and the gastronemius muscle activity increased, which is in agreement with the current study (7). If the goal of an athlete is to increase gastrocnemius strength, then performing squats in which the COP is directly over the toes will help accomplish that goal more completely than performing traditional squats.

Total EMG area activation and percent contribution of total EMG area activation for the quadriceps were significantly ($p < 0.05$) larger for the traditional squat. The participants again stated that after performing the non-traditional squats that they felt their quadriceps were "worked" more compared to the traditional squats. However, after evaluating power output of the knee from Figure 9 and realizing the moment arm at the knee joint would be shortened due to the forward shifting of the COP in the non-traditional squat, it can be expected that the quadriceps muscle activity would be larger during the traditional squat. This complements the study by Toutoungi et al., which found PCL peak forces to be larger during squats where the participants' heels remained in contact with the ground compared to squats where the participants' heels came off the ground (26). The PCL and quadriceps work together to stabilize the femur from sliding forward over the tibia or prevent the tibia from moving posterior, so when measuring just the PCL or just the quadriceps, it may be assumed that when a large force is placed on one, a large force will also be placed on the other. This may also be a reason why certain individuals perform squats where they lean forward and their COP shifts over their toes. If the PCL is injured or weak, shifting the COP over the toes would place less force on the PCL. Conversely, a decrease of force on the PCL would mean an increase of force placed on the ACL and hamstrings.

After observing the results of the study, rationalizing the data, and further reviewing previous studies, the statement made about the hamstring musculature was determined to be an incorrect hypothesis. From the results, it was determined that the biceps femoris did not show any significant difference in muscle activation between the two squats. The results did show that the semitendinosus exhibited significantly more muscle activity during the non-traditional squat compared to the traditional squat, although this was not the difference that was hypothesized. The total area of EMG activity, percent contribution of total area of EMG activity, and percent contribution of peak EMG activity of the semitendinosus showed a significant increase in muscle activity during the non-traditional squat compared to the traditional squat. One explanation for the increased muscle activity during the non-traditional squat is that the forward lean experienced during this technique needs to be countered in order to return the participant back to the original position. The semitendinosus is a major muscle being recruited in order to accomplish this counter balancing force.

The biceps femoris muscle is also part of the hamstring musculature that is responsible for returning the lifter to the original position while performing the non-traditional squat. However, the findings of this study did not indicate a significant difference in muscle activity between the two techniques, although all the EMG data for the BF were larger in the non-traditional squat compared to the traditional squat. De Looze et al. noted that the biceps femoris activated to a greater degree during the ascent phase of the squat in order to contribute to the large hip extensor torque required to return the lifter to the upright position and also stablilize the knee joint, which agrees with the higher muscle activation of the hamstrings in the non-traditional squat compared to the traditional squat (37). This trend may also suggest that a larger participant pool might lead to finding significantly higher muscle activity in the biceps femoris during the non-traditional squat compared to the traditional squat in later studies.

Wright et al. determined that compared to back squats, stiff-leg deadlifts elicited nearly double the EMG muscle activity from both the biceps femoris and semitendinosus (28). The non-traditional squat is a version of the back squat but has some attributes of the stiff-leg deadlift, mainly a forward COP. The anterior motion of the upper body during descent is also a feature seen in both exercises, which shifts the COP forward and also causes the hamstrings to activate in order to return the upper body to the beginning position. Similar findings of increased hamstring activity as trunk flexion increased were observed during a study by Ohkoshi et al. and discussed in the study by Wright et al.(28, 38). Lack of knee flexion in the stiff-leg deadlifts and less knee flexion in the non-traditional squat increased the lengthening of the hamstrings compared to the traditional squat, therefore more contraction of the hamstrings takes place during the ascent phase of the stiff-leg deadlift and non-traditional squat compared to the traditional squat.

In the study by Toutoungi et al., the ACL peak forces were larger during the heel off the ground squats compared to the heel on the ground squats (26). Since the ACL and hamstrings work together to stabilize the tibia from sliding too far forward under the femur, an increase of force on the ACL would lead one to believe that hamstrings muscle activity would increase in male athletes as well. These findings concur with the results that semitendinosus muscle activity increases when the COP is focused over the toes compared to the heels during the squat.

McLaughlin et al. found that inexperienced lifters tended to lean forward with the trunk more than skilled lifters and that this forward lean increased trunk torque, which stretches the hamstrings and increases their muscle activation during the ascent of the squatting motion (39). The observation of McLaughlin et al. concurs with the findings of this study that forward trunk motion, as seen in the non-traditional squat, increases hamstring activation. Since the more skilled lifters in McLaughlin et al.'s study had lower trunk torque due to less forward trunk lean, which is similar to the traditional squat; this leads one to determine that traditional squats may be considered a more proper form of the squat technique compared to the non-traditional squat.

The major findings of this study were that there is a difference in muscle activity, kinetics, and kinematics when the COP is shifted from the heel/arch of the foot to the toe. These findings will help trainers and coaches explain why they prefer their clients or athletes to stay back on their heels when squatting or why they might want them to lean forward on their toes. Although this study was able to determine muscle activation differences in the squat variations, it was not determined if COP over the toes during the weighted back squat is unsafe compared to a squat that focuses on keeping the COP over the heels. Participant feedback did reveal that during the non-traditional squat, they felt more tension in the lower back; however, the measured variable (ES EMG) did not reveal a significant difference between the traditional and non-traditional squat. Participant feedback points to the need for further studies designed to determine the risk of possible injury during a non-traditional squat; however, with a light load or body weight, performing squats where the COP is over the toes will safely help strengthen the gastrocnemius and semitendinosus muscles more compared to squats where the COP is over the heels.

Conclusion

Of the several hypotheses made prior to this study, only two were accepted while six were rejected. Major findings of this study were that COP on the heel of the foot would elicit different muscle activation for variations of the same lift compared to COP on the toes or ball of the foot. In comparing the traditional squat and non-traditional squat, it can be determined that traditional squats (COP on the heel) will elicit more muscle activation in the quadriceps and non-traditional squats (COP on the toes) will activate the hamstrings and gastrocnemius more effectively. Another observation in this study was that participants had a "feeling" of muscle activation in the lower back and quadriceps after performing non-traditional squats, but the EMG readings were not significantly different for the erector spinae and actually lower in the non-traditional squats compared to the traditional squats for the quadriceps.

Overall power between the squats displayed larger output in the knees for the traditional squat, larger output in the ankles for the non-traditional squat, and no difference in hip power. It appears that when the COP is over the toes, the calf muscles compensate for the loss of power in the quadriceps in order to move the same load. However, non-traditional squats may also cause unwanted stressors in the lower back, which was communicated by the participants after performing non-traditional squats. Further studies, which are more focused on the lower back, spine, and core musculature, comparing these two variations of the squat, could help determine if there is a spinal safety discrepancy between the traditional and non-traditional squat. Studies that use fatigue of different muscle groups as a factor will also help determine safety procedures that should be followed when performing squats, since fatigue was not a measured factor in this study but previous work found fatigue to be a factor that changed muscle activity and biomechanical motion significantly (22, 36). The study was successful in showing that COP shifting from the heels to the toes will elicit different muscle activation, although it was not successful in determining if the traditional technique was safer due to lower back stressors compared to the non-traditional squat. In conclusion, each technique is valuable in strengthening the lower extremities and simply shifting the COP will elicit significant differences in quadriceps, hamstrings, and gastrocnemius muscle activity.

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APPENDIX A

IRB Approval

Office of Research Compliance
Institutional Review Board
HumanSubjects@boisestate.edu | 208.426.5401

DATE: December 9, 2009
TO: Christopher Scotten (PI)
Shawn Simonson (co-PI)
FROM: Institutional Review Board (IRB)
C/o Office of Research Compliance
SUBJECT: IRB Notification of Approval
Project Title: *Differences in Muscle Activation in the Lower Extremities During Traditional Squats and Squats with Excess Forward Lean*

The Boise State University IRB has approved your protocol application. Your protocol is in compliance with this institution's Federal Wide Assurance (#0000097) and the DHHS Regulations for the Protection of Human Subjects (45 CFR 46).
Review Type: Expedited
Approval Number: 103-MED10-013
Annual Expiration Date: December 8, 2010
Your approved protocol is effective for 12 months. If your research is not finished within the allotted year, the protocol must be renewed by the annual expiration date indicated above. Under BSU regulations, each protocol has a three-year life cycle and is allowed two annual renewals. If your research is not complete by **December 8, 2012**, a new protocol application must be submitted.
About 30 days prior to the annual expiration date of the approved protocol, the Office of Research Compliance will send a renewal reminder notice. The principal investigator has the primary responsibility to ensure the ANNUAL RENEWAL FORM is submitted in a timely manner. If a request for renewal has not been received 30 days after the annual expiration date, the protocol will be considered closed. To continue the research after it has closed, a new protocol application must be submitted for IRB review and approval.
All additions or changes to your approved protocol must also be brought to the attention of the IRB for review and approval before they occur. Complete and submit a MODIFICATION/AMENDMENT FORM indicating any changes to your project.
When your research is complete or discontinued, please submit a FINAL REPORT FORM. An executive summary or other documents with the results of the research may be included.
All relevant forms are available online. If you have any questions or concerns, please contact the Office of Research Compliance, 426-5401 or HumanSubjects@boisestate.edu.
Thank you and good luck with your research.

Ron Pfeiffer

Dr. Ronald Pfeiffer
Chairperson
Boise State University Institutional Review Board

APPENDIX B

Informed Consent Form

Boise State University - Department of Kinesiology
Research Project
Differences in Muscle Activation in the Lower Extremities During Traditional Squats and Squats with Excess Forward Lean
Consent to be a research participant

A. Purpose and Background

Chris Scotten and Shawn Simonson, Ed.D., in the Department of Kinesiology at the Boise State University are conducting research to determine the differences in lower extremity and trunk muscle activation while performing squats using two different techniques. The study is aimed to verify the differences in muscle activity between these techniques. If the claims of this study are supported by the findings then the traditional technique will be found to activate the leg muscles more, while the excess forward lean squat will be found to activate the lower back muscles more. This will show that performing traditional squats will improve activation in targeted muscles, while decreasing lower back fatigue compared to the excess forward lean squats. From this study, hopefully developing training will be safer and more efficient.

B. Procedures

If I agree to volunteer and participate in the study, the following will take place:

1. I will complete the study contraindications questionnaire to ascertain my ability to participate in this study. If I do not meet safe study participation guidelines, I will not be selected to participate in this study.
2. If I am selected for the study and I agree to participate, I will have my 10 repetition maximum in the squat exercise determined, participate in isometric testing to determine my maximum voluntary contraction activity of muscles monitored in the study, and perform traditional squats and excess forward lean squats to determine the muscle activity elicited in the monitored muscles by the two different techniques.
3. My 10 repetition maximum will be determined at least three days, but no more than two weeks, prior to data collection. I will be visually monitored by the primary investigator in order to validate my 10 repetition maximum weight.

4. I will come to the biomechanics lab 3-14 days after determining my 10 repetition maximum for the squat exercise session.
5. I will be fitted with the silver-silver chloride EMG electrode pads, which will monitor muscle activity during isometric testing and while performing the two squatting techniques.
6. I will then have my maximum voluntary contraction values for each monitored muscle group determined using a series of isometric exercises described by the lab technician.
7. I will then be asked to perform two different squatting techniques using 75% of my 10 repetition maximum for a series of two sets of ten repetitions, with five minutes rest between sets.

C. Risks/Discomforts

1. Performing several repetitions of squats with added weight may be uncomfortable for some individuals. Discomfort may be caused by a heavy load being squatted, in which I can use a padded that can be wrapped around the squat bar. If I feel uncomfortable, the test will be stopped if I so choose.
2. Soreness the next day may take place due to lifting weights with a full body exercise. I will be informed by the investigators on how to lessen this soreness.
3. Spotters will be present during all squats and if I need help while performing squats I will verbally notify the spotter that I need assistance. I may discontinue testing if I feel uncomfortable after needing help from the spotter.
4. Participation in research may involve loss of privacy; however, my records will be handled as confidentially as possible. Only Chris Scotten, Shawn Simonson and the lab technicians will have access to my records. No individual's identities will be used in any report or publication that my result from this study.

D. Consent to be a Research Participant

My permission to participate in this study is voluntary. I am free to deny consent or stop the test at any point, if I so desire. I have read the above and I understand the test procedures that I will perform. For additional questions, I can contact Chris Scotten at 406-570-1369 or Professor Simonson at 208-426-3973.

If I have any comments or concerns about participation in this study, I should first talk with the investigators. If for some reason I do not wish to do this, I may contact the Institutional Review Board, which is concerned with the protection of volunteers in research projects. I may reach the board office between 8:00 AM and 5:00 PM, Monday through Friday, by calling 208-426-1574 or by writing:

Institutional Review Board

Office of Research Administration

Boise State University

1910 University Drive

Boise, ID 83725-1135

I understand that the data gathered from the results of this study will be treated as privileged and confidential and will not be released to any person without my consent. The data, however, will be used as anonymous data for publication of scientific research with my right to privacy retained.

I give my consent to participate in this study:

______________________________ __________

Signature of participant Date

______________________________ __________

Signature of test supervisor Date

The Boise State University Institutional Review Board has reviewed this project for the protection of human participants in research.

APPENDIX C

Questionnaire

Boise State University - Department of Kinesiology
Research Project
Differences in Muscle Activation in the Lower Extremities during Traditional Squats and Squats with Excess Forward Lean
Study Contraindications Screening Questionnaire

Par-Q

Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?

___YES ___NO

Do you feel pain in your chest when you do physical activity?

___YES ___NO

In the past month, have you had chest pain when you were not doing physical activity?

___YES ___NO

Do you lose your balance because of dizziness or do you ever lose consciousness?

___YES ___NO

Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?

___YES ___NO

Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?

___YES ___NO

Do you know of any other reason why you should not do physical activity?
___YES ___NO

Have you ever had any of the following:

1. Major knee injury or surgery ___Yes ____No
2. Major hip injury or surgery ___Yes ____No
3. Major ankle injury or surgery ___Yes ____No
4. Major back injury or surgery ___Yes ____No
5. Doctor say you have high blood pressure ___Yes ____No

How long have you been participating in an exercise program?

How long have you been training with weights?

How many days a week do you lift weights for exercise?

How long have you been weight training with this frequency?

How many days a week do you use a version of the free weight squat exercise in your exercise routine?

Height ______ Weight________ Age___

Name:________________________________ Signature:_________________________
Test Supervisor:_______________________ Signature:_________________________
Date:________

APPENDIX D

Recruitment Flyer

BOISE STATE UNIVERSITY - DEPARTMENT OF KINESIOLOGY
RESEARCH PROJECT PARTICIPANTS NEEDED

Differences in Muscle Activation in the Lower Extremities During Traditional Squats and Squats with Excess Forward Lean

The Department of Kinesiology at Boise State University will be conducting a research project to compare muscle activation in the lower extremities according to two different techniques. Men between the ages of 18-30 years are needed for this project. If you are interested in participating please contact Chris Scotten, a graduate student in exercise science at BSU, at the following phone number 406-570-1369. You may also contact Chris via email at scotten31@hotmail.com.

Research Description

Electromyography (using surface electrodes to monitor electrical activity in the muscle) will be used to measure muscle activation in several muscles in the lower body while performing two different squatting techniques. Illustrations of the two squatting techniques finishing positions are provided below.

Traditional technique

Excess forward lean technique

The traditional technique is performed by keeping the heels in contact the entire motion and keeping the knees from passing the toes by a lot.

The excess forward lean technique has the subject raise the heels off the ground and have their knees pass their toes by a lot.

The testing procedure will not cost anything and will take place in the biomechanics lab at BSU. Feeling sore the next day and some discomfort while performing the squats may occur. Learning more about proper technique and contributing to the discovery of different muscle activation during different squat techniques are just a few benefits from participating. Interested participants need to have no prior back, knee, or ankle injuries that required surgery. Participants must also be involved in an exercise program that includes squatting.

Thank you for your help. The Boise State University Institutional Review Board has reviewed this project for the protection of human participants in research

APPENDIX E

Isometric Motions for MVIC Data Collection
(Visual Aides)

Hip: Extension/Flexion (Supine) (Single Chair)

Measured MVIC for Gluteus Maximus

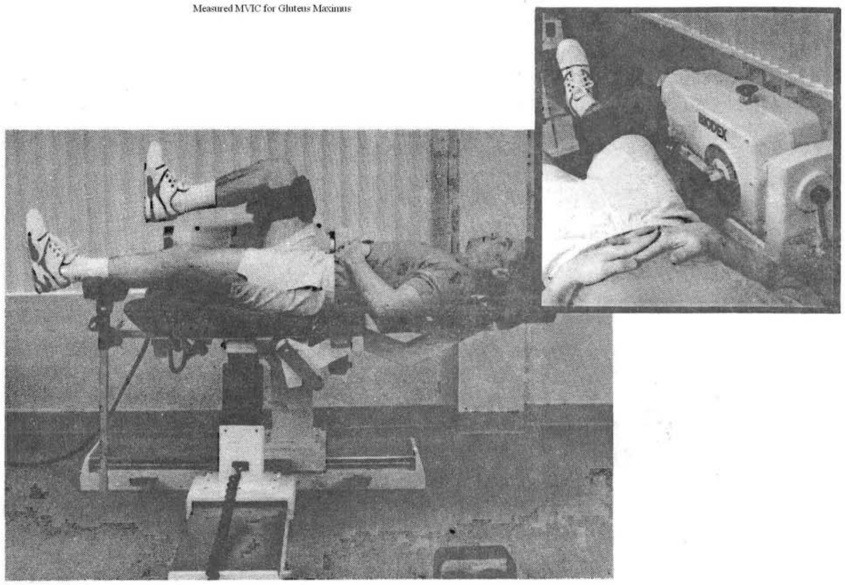


Figure 4.40

Quick Reference

Powerhead Orientation:	90°
Powerhead Tilt:	0°
Seat Orientation:	90°
Seatback Tilt:	Fully Reclined
Sensitivity:	C
Ankle Flexion:	0°
Knee Flexion:	0°
Axis of Rotation:	Superior and anterior to greater trochanter when limb is in neutral position.
Ready Position:	Neutral Extension

Parts Needed

Powerhead:	Knee Attachment (or Wrist upper with Knee lower)
Positioning Chair:	T-Bar Adapters (short and medium), Multi-Support Pad

Figure E.1 MVIC gluteus maximus.

Hip: Hip Abduction/Adduction (Lying on Side) (Single Chair)

Measured MVIC for Adductor Longus

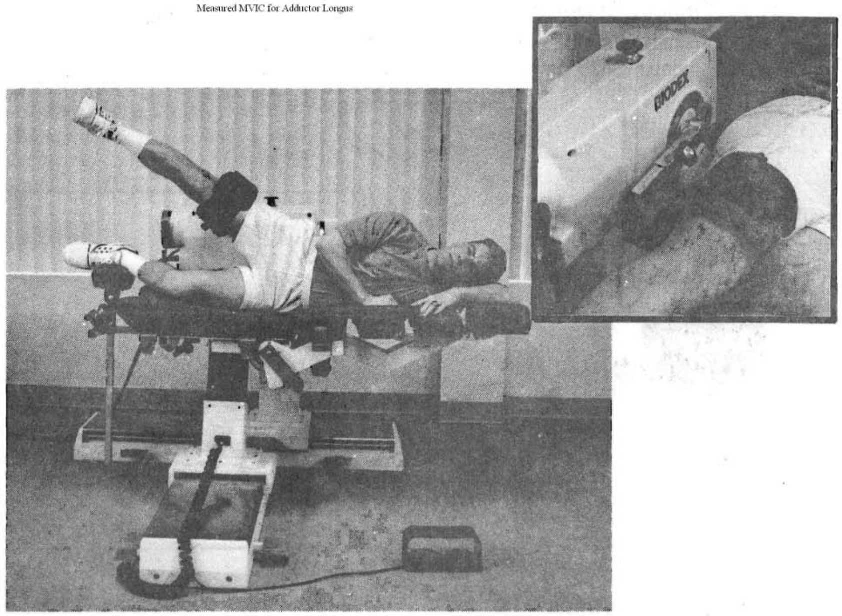


Figure 4.34

Quick Reference

Powerhead Orientation:	90°
Powerhead Tilt:	0°
Seat Orientation:	90°
Seatback Tilt:	Fully Reclined
Sensitivity:	C
Ankle Flexion:	0°
Knee Flexion:	0°
Hip Flexion:	0°
Axis of Rotation:	Superior and medial to greater trochanter.
Ready Position:	Full Adduction

Parts Needed

Powerhead:	Knee Attachment (or Wrist upper with Knee lower)
Accessory Chair:	Short T-Bar Adapter, Multi-Support Pad

Figure E.2 MVIC adductor longus position.

Measured MVIC for Vastus Medialis, Vastus Lateralis, Biceps Femoris and Semitendinosus

Knee: Extension/Flexion (Single Chair)

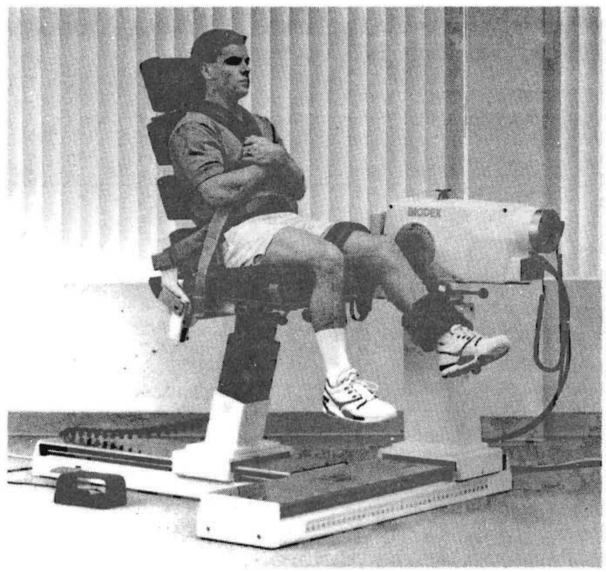


Figure 4.2

Quick Reference

Powerhead Orientation:	0°
Powerhead Tilt:	0°
Seat Orientation:	0°
Seatback Tilt:	15°
Sensitivity:	C
Hip Flexion:	85°
Axis of Rotation:	Compromise axis is a line drawn through the femoral condyles on a sagittal plane.
Ready Position:	Full Flexion

Parts Needed

Powerhead:	Knee Attachment (left or right)
Positioning Chair:	No additional parts required.

Figure E.3 MVIC for vastus medialis, vastus lateralis, biceps femoris and semitendinosus.

Ankle: Plantar/Dorsiflexion (Seated) (Single Chair)

Measured MVIC for Gastrocnemius

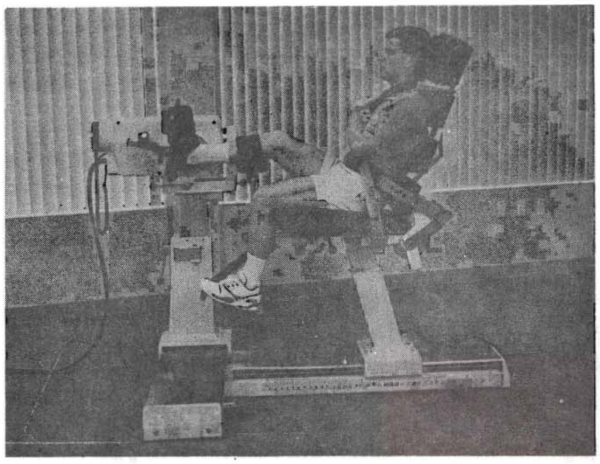


Figure 4.16

Quick Reference

Powerhead Orientation:	0°
Powerhead Tilt:	0°
Seat Orientation:	0°
Seatback Tilt:	15°
Footplate Tilt:	0°
Footplate Color Code:	White dot to red dot
Sensitivity:	E
Ankle Flexion:	0°
Knee Flexion:	30°
Hip Flexion:	60°
Axis of Rotation:	In neutral position, axis passes through the body of talus, fibular malleous, and through or just below the tibial malleous.
Ready Position:	Full Plantarflexion

Parts Needed

Powerhead:	Footplate Attachment
Positioning Chair:	T-Bar Adapters (short and medium), Multi-Support Pad, Footrest (optional)

Figure E.4 MVIC gastrocnemius position.

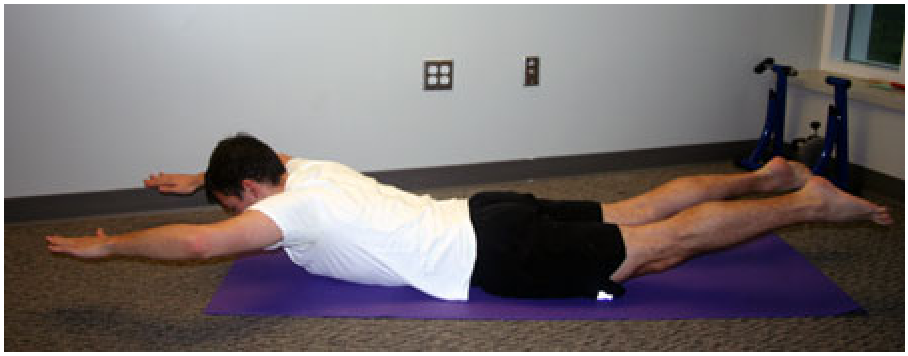


Figure E.5   MVIC erector spinae position.

APPENDIX F

Noraxon EMG Electrode Placements

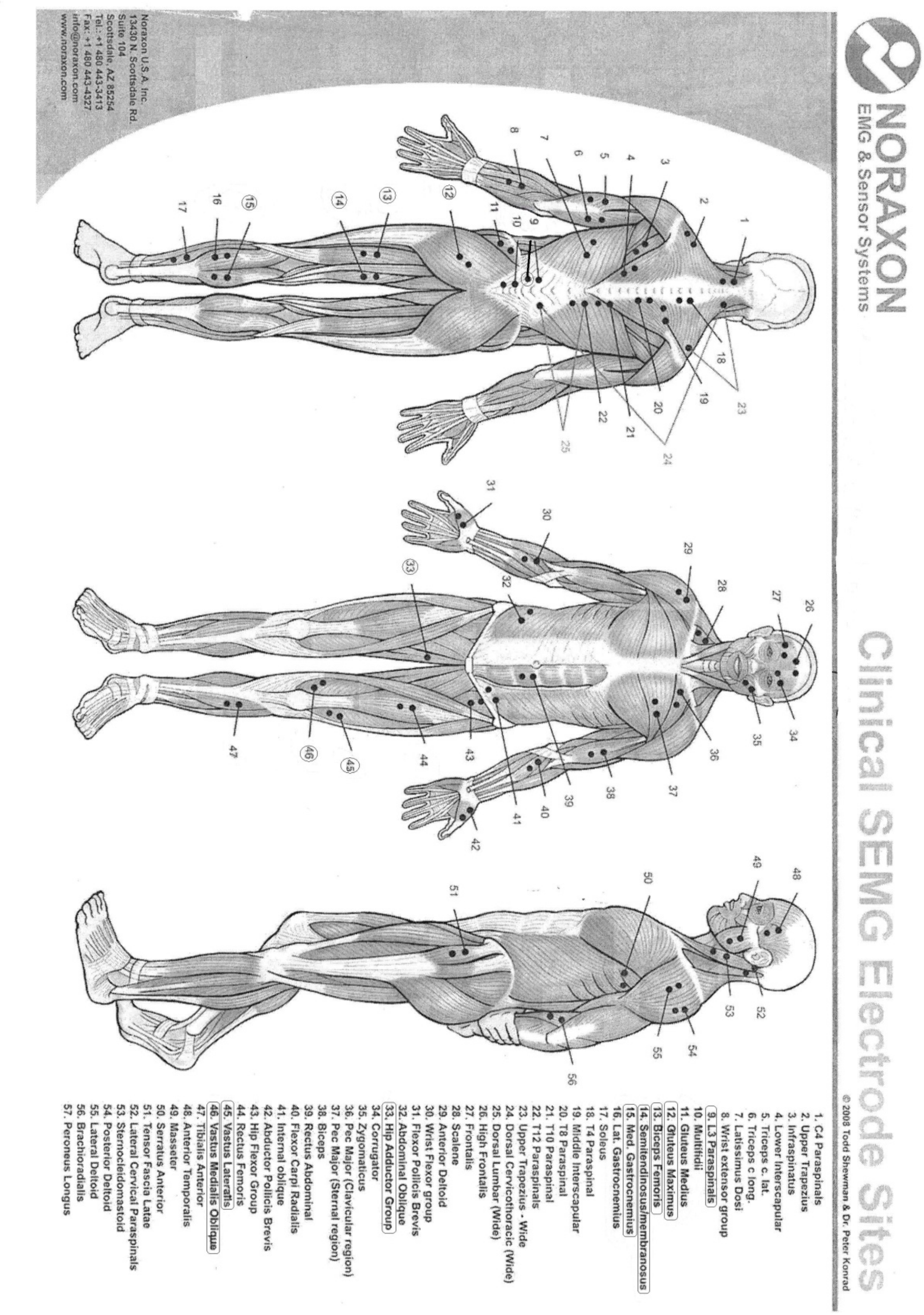


Figure F.1 EMG electrode placement.
(Electrodes placed at sites 9, 12, 13, 14, 15, 33, 45 and 46)

APPENDIX G

Retro Reflective Spherical Marker Placements

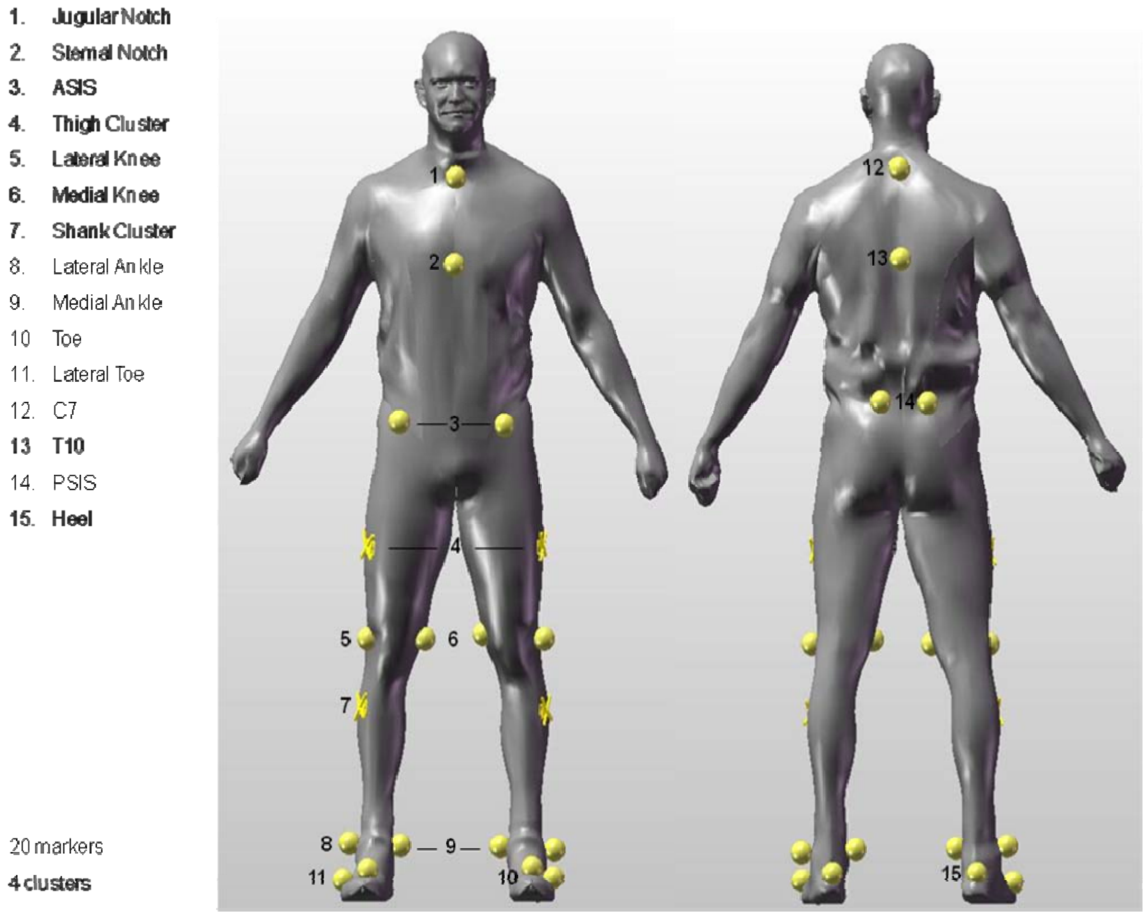


Figure G.1 Retro reflective spherical marker placement.

APPENDIX H

Raw Data

Table H.1 Raw data for normalized peak EMG activity.

	Average Peak Normalized EMG Amplitude															
	Gluteus Maximus		Adductor		Gastrocnemius		Vastus Medialis		Vastus Lateralis		Biceps Femoris		Semitendinosus		Erector Spinae	
Subjects	Trad	Non	Trad	Non	Trad	Non	Trad	Non	Trad	Non	Trad	Non	Trad	Non	Trad	Non
SO2	4.860	4.051	0.495	0.449	0.399	0.905	1.293	0.642	1.108	1.054	0.931	1.303	0.261	0.744	1.294	1.574
SO3	1.360	1.020	1.220	0.360	0.630	0.600	1.790	1.030	1.920	0.840	1.120	0.850	0.090	0.090	1.580	1.860
SO4	15.850	17.040	1.200	1.300	0.260	0.580	1.670	1.460	3.130	2.680	0.620	0.880	0.470	0.760	1.100	1.460
SO5	4.030	3.980	0.570	0.630	0.070	0.180	1.450	1.120	1.090	0.850	0.870	1.610	0.280	0.660	3.650	3.410
SO6	1.390	1.330	5.480	6.170	0.480	0.870	11.840	4.540	3.720	3.470	1.090	1.230	0.470	0.490	1.940	2.000
SO7	0.760	0.670	0.400	0.390	0.500	0.580	1.040	0.920	1.120	0.940	0.900	0.930	0.460	0.690	1.180	1.250
SO9	0.850	0.850	0.270	0.480	0.380	0.440	1.330	1.700	0.980	1.040	0.440	0.340	0.090	0.130	1.210	1.190
S10	2.300	2.350	2.450	2.580	0.370	0.660	2.940	2.340	1.960	1.920	1.380	1.200	0.340	0.410	1.320	1.400
S11	6.420	7.980	2.610	2.050	1.120	1.040	1.510	1.190	1.440	1.030	0.490	0.580	0.620	0.770	1.220	1.260
S13	5.650	5.980	1.450	1.500	0.350	0.840	1.860	1.310	2.810	2.070	2.420	3.700	1.220	1.450	0.850	0.820
S14	11.280	6.570	1.950	2.740	0.230	0.720	1.490	1.280	0.880	1.360	2.700	4.280	0.180	0.290	1.490	0.820
S15	1.490	1.580	1.860	2.000	0.570	0.870	2.070	2.200	1.740	1.920	2.680	2.870	0.700	0.710	1.300	1.470
S16	5.650	4.650	1.250	1.220	0.270	0.480	4.910	4.390	3.880	3.300	2.130	1.880	0.900	1.110	0.890	0.920

Table H.2 Raw data for total EMG area.

	Average Total EMG Area															
	Gluteus Maximus		Adductor		Gastrocnemius		Vastus Medialis		Vastus Lateralis		Biceps Femoris		Semitendinosus		Erector Spinae	
Subjects	Trad	Non	Trad	Non	Trad	Non	Trad	Non	Trad	Non	Trad	Non	Trad	Non	Trad	Non
SO2	1177.78	753.61	129.58	103.03	63.33	100.92	270.84	145.14	281.12	215.41	247.11	232.01	53.31	87.33	300.67	226.51
SO3	260.91	179.71	220.60	69.36	71.68	85.21	357.21	172.31	378.44	150.88	287.99	179.60	22.81	20.64	306.69	390.89
SO4	3092.32	2620.87	190.45	166.56	45.32	96.04	378.43	238.57	742.93	431.91	152.23	151.39	87.21	132.53	274.38	314.54
SO5	946.44	708.38	131.10	109.44	12.19	30.03	416.58	186.43	347.60	163.52	150.02	306.03	53.44	111.31	931.77	870.11
SO6	306.97	286.68	936.40	1056.31	83.84	137.16	1231.86	970.31	857.23	791.69	278.55	294.32	79.01	100.93	417.03	494.86
SO7	175.22	158.50	75.46	69.76	84.00	138.83	220.73	164.62	211.89	170.06	228.42	222.55	67.67	130.40	299.61	306.39
SO9	143.44	134.10	41.55	61.60	38.69	72.28	261.99	288.65	176.13	191.44	99.14	85.51	13.19	15.89	251.39	244.99
S10	603.00	612.69	427.98	414.30	60.00	108.36	543.21	443.81	424.40	352.05	307.04	261.34	68.55	79.81	282.45	290.46
S11	1517.19	1894.58	473.55	330.92	196.78	166.35	368.81	292.49	358.33	293.37	103.59	118.21	93.05	131.61	311.35	308.91
S13	1107.97	1233.15	361.59	382.01	56.07	102.92	365.25	315.57	465.80	394.66	562.65	694.66	219.12	279.43	188.04	220.16
S14	2419.86	1499.64	424.51	392.67	43.11	105.55	410.59	283.26	272.07	199.35	620.61	825.63	29.60	56.65	377.57	128.27
S15	360.27	353.61	378.63	371.09	68.13	116.16	503.65	473.83	445.90	467.01	600.20	585.21	127.76	138.78	361.93	328.97
S16	1512.63	1178.48	240.07	175.38	44.76	81.21	1252.27	857.94	1065.91	778.32	661.36	520.37	135.45	169.36	243.84	254.37

Table H.3 Raw data for percent contribution of normalized peak EMG activity (X 100%).

Average Percent Contribution of Each Muscle Based on Peak Normalized EMG Amplitude																
	Gluteus Maximus		Adductor		Gastrocnemius		Vastus Medialis		Vastus Lateralis		Biceps Femoris		Semitendinosus		Erector Spinae	
Subjects	Trad	Non	Trad	Non	Trad	Non	Trad	Non	Trad	Non	Trad	Non	Trad	Non	Trad	Non
SO2	0.454	0.379	0.047	0.042	0.037	0.084	0.121	0.060	0.104	0.098	0.088	0.122	0.025	0.070	0.123	0.145
SO3	0.141	0.154	0.125	0.054	0.067	0.092	0.181	0.155	0.199	0.125	0.115	0.127	0.009	0.014	0.163	0.280
SO4	0.647	0.649	0.050	0.050	0.011	0.022	0.070	0.057	0.131	0.104	0.025	0.034	0.020	0.029	0.046	0.056
SO5	0.336	0.320	0.048	0.051	0.006	0.015	0.121	0.089	0.090	0.068	0.072	0.129	0.024	0.053	0.304	0.275
SO6	0.053	0.066	0.207	0.306	0.019	0.043	0.446	0.226	0.142	0.173	0.042	0.062	0.018	0.025	0.074	0.100
SO7	0.119	0.107	0.063	0.061	0.078	0.091	0.164	0.144	0.176	0.147	0.142	0.146	0.072	0.107	0.186	0.196
SO9	0.154	0.138	0.049	0.078	0.066	0.073	0.242	0.274	0.179	0.171	0.080	0.057	0.017	0.021	0.213	0.190
S10	0.175	0.182	0.187	0.200	0.028	0.051	0.225	0.183	0.151	0.149	0.106	0.093	0.026	0.032	0.101	0.109
S11	0.415	0.502	0.169	0.129	0.073	0.066	0.099	0.075	0.093	0.065	0.032	0.036	0.040	0.049	0.079	0.079
S13	0.338	0.339	0.088	0.085	0.021	0.048	0.112	0.075	0.171	0.117	0.145	0.208	0.074	0.082	0.051	0.047
S14	0.556	0.373	0.097	0.151	0.011	0.041	0.075	0.074	0.044	0.072	0.134	0.228	0.009	0.016	0.074	0.046
S15	0.120	0.115	0.149	0.145	0.046	0.065	0.167	0.162	0.140	0.141	0.217	0.211	0.057	0.052	0.105	0.109
S16	0.282	0.260	0.063	0.068	0.014	0.027	0.246	0.243	0.196	0.184	0.107	0.106	0.045	0.062	0.045	0.051

Table H.4 Raw data for percent contribution of total EMG area (X 100%).

Average Percent Contribution of Each Muscle Based on Total EMG Area																
	Gluteus Maximus		Adductor		Gastrocnemius		Vastus Medialis		Vastus Lateralis		Biceps Femoris		Semitendinosus		Erector Spinae	
Subjects	Trad	Non	Trad	Non	Trad	Non	Trad	Non	Trad	Non	Trad	Non	Trad	Non	Trad	Non
SO2	0.466	0.406	0.051	0.055	0.025	0.054	0.107	0.078	0.111	0.116	0.098	0.125	0.021	0.047	0.119	0.118
SO3	0.136	0.144	0.115	0.055	0.038	0.069	0.187	0.137	0.199	0.120	0.151	0.145	0.012	0.017	0.161	0.313
SO4	0.622	0.631	0.038	0.040	0.009	0.023	0.076	0.057	0.150	0.104	0.031	0.037	0.018	0.033	0.056	0.076
SO5	0.317	0.284	0.044	0.044	0.004	0.012	0.140	0.075	0.117	0.066	0.050	0.125	0.018	0.045	0.311	0.350
SO6	0.073	0.070	0.223	0.254	0.020	0.033	0.294	0.234	0.205	0.191	0.067	0.072	0.019	0.025	0.100	0.120
SO7	0.129	0.117	0.055	0.051	0.062	0.102	0.162	0.121	0.156	0.125	0.168	0.164	0.050	0.096	0.220	0.225
SO9	0.140	0.122	0.040	0.056	0.038	0.066	0.255	0.264	0.171	0.175	0.097	0.078	0.013	0.015	0.246	0.224
S10	0.222	0.238	0.157	0.162	0.022	0.043	0.200	0.173	0.156	0.137	0.113	0.102	0.025	0.031	0.104	0.113
S11	0.441	0.535	0.138	0.094	0.058	0.047	0.108	0.083	0.105	0.083	0.030	0.033	0.027	0.037	0.091	0.087
S13	0.333	0.340	0.108	0.105	0.017	0.028	0.110	0.087	0.140	0.109	0.169	0.192	0.066	0.077	0.057	0.061
S14	0.526	0.431	0.092	0.112	0.009	0.030	0.089	0.082	0.059	0.057	0.135	0.236	0.006	0.016	0.082	0.037
S15	0.127	0.125	0.133	0.130	0.024	0.042	0.177	0.167	0.157	0.164	0.211	0.206	0.045	0.049	0.127	0.116
S16	0.293	0.293	0.047	0.043	0.009	0.020	0.243	0.214	0.207	0.194	0.128	0.130	0.026	0.042	0.047	0.063

Table H.5 Raw data for COP and joint range of motions.

	Average COPy		ROM Knee (degrees)		ROM Hips (degrees)		ROM Ankle (degrees)		ROM Pelvis Tilt		ROM Torso Flexion	
Subjects	Trad	Non	Trad	Non	Trad	Non	Trad	Non	Trad	Non	Trad	Non
SO2	0.51	0.64	106.06	94.17	87.86	77.42	30.38	16.54	9.48	6.43	23.40	48.02
SO3	0.60	0.70	101.85	74.62	91.91	104.61	30.26	14.37	26.55	52.88	123.18	19.35
SO4	0.56	0.70	107.32	98.21	90.17	82.71	24.90	17.60	20.02	19.38	83.06	27.49
SO5	0.66	0.75	85.93	57.45	90.90	80.49	15.40	9.46	18.13	32.80	8.11	4.90
SO6	0.50	0.64	102.68	105.74	87.58	83.72	30.13	29.74	15.49	14.09	6.43	7.37
SO7	0.30	0.72	105.63	106.27	90.13	92.54	29.50	27.97	15.80	18.59	9.93	8.76
SO9	0.48	0.75	93.06	88.39	89.15	109.88	27.72	15.33	26.19	36.35	361.51	361.12
S10	0.48	0.66	106.06	105.72	119.06	123.22	24.35	27.07	35.95	39.20	134.78	20.40
S11	0.65	0.72	110.79	88.71	162.64	87.25	29.17	21.40	80.50	13.74	353.21	19.04
S13	0.46	0.65	104.20	93.36	130.22	117.02	25.49	20.25	52.15	49.25	365.79	373.80
S14	0.51	0.70	96.88	100.19	132.41	100.87	28.41	25.23	58.19	34.67	337.82	299.05
S15	0.57	0.76	101.91	110.25	139.43	124.28	22.13	25.05	57.90	42.55	314.76	64.60
S16	0.51	0.72	97.90	89.79	130.97	135.53	26.69	18.04	58.72	64.59	345.16	350.15

APPENDIX I

Statistics

Descriptive Statistics for Peak EMG

	Mean	Std. Deviation	N
TradGlut	4.7608	4.48452	13
NonGlut	4.4655	4.46856	13
TradAdd	1.6312	1.38187	13
NonAdd	1.6822	1.58602	13
TradGas	.4330	.25504	13
NonGas	.6742	.23338	13
TradVM	2.7072	2.92300	13
NonVM	1.8555	1.25187	13
TradVL	1.9829	1.06082	13
NonVL	1.7288	.92796	13
TradBF	1.3670	.82520	13
NonBF	1.6656	1.21692	13
TradSem	.4678	.32818	13
NonSem	.6388	.37499	13
TradES	1.4634	.71528	13
NonES	1.4949	.67840	13

Repeated Measures ANOVA

Tests of Within-Subjects Effects for Peak EMG

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Muscle	Sphericity Assumed	297.926	7	42.561	6.291	.000
Error(Muscle)	Sphericity Assumed	568.278	84	6.765		
Squat	Sphericity Assumed	.300	1	.300	.967	.345
Error(Squat)	Sphericity Assumed	3.723	12	.310		
Muscle * Squat	Sphericity Assumed	6.572	7	.939	2.092	.053
Error(Muscle*Squat)	Sphericity Assumed	37.700	84	.449		

Descriptive Statistics for Total Area EMG

	Mean	Std. Deviation	N
TradGlut	1048.0000	910.47723	13
NonGlut	893.3846	762.05663	13
TradAdd	310.1131	236.70210	13
NonAdd	284.8023	270.01179	13
TradGas	66.7615	43.74240	13
NonGas	103.1554	33.89250	13
TradVM	506.2631	338.56858	13
NonVM	371.7638	261.49472	13
TradVL	463.6731	265.41971	13
NonVL	353.8208	219.22547	13
TradBF	330.6854	206.57177	13
NonBF	344.3715	235.26143	13
TradSem	80.7823	55.45325	13
NonSem	111.8977	68.06849	13
TradES	349.7477	184.77451	13
NonES	336.8792	182.85065	13

Repeated Measures ANOVA

Tests of Within-Subjects Effects for Total Area EMG

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Muscle	Sphericity Assumed	1.379E7	7	1969396.499	8.713	.000
Error(Muscle)	Sphericity Assumed	1.899E7	84	226037.649		
Squat	Sphericity Assumed	102944.522	1	102944.522	7.080	.021
Error(Squat)	Sphericity Assumed	174474.415	12	14539.535		
Muscle * Squat	Sphericity Assumed	269828.607	7	38546.944	4.359	.000
Error(Muscle*Squat)	Sphericity Assumed	742761.954	84	8842.404		

Paired Samples T-test for Total Area EMG

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference: Lower	95% Confidence Interval of the Difference: Upper			
Pair 1	TradGlut - NonGlut	154.6153	325.59502	90.30381	-42.13972	351.37049	1.712	12	.113
Pair 2	TradAdd - NonAdd	25.31077	69.10490	19.16625	-16.44890	67.07044	1.321	12	.211
Pair 3	TradGas - NonGas	-36.39385	24.56228	6.81235	-51.23669	-21.55101	-5.342	12	.000
Pair 4	TradVM - NonVM	134.49923	111.94745	31.04864	66.85006	202.14840	4.332	12	.001
Pair 5	TradVL - NonVL	109.85231	107.65650	29.85854	44.79614	174.90848	3.679	12	.003
Pair 6	TradBF - NonBF	-13.68615	98.41031	27.29411	-73.15491	45.78260	-.501	12	.625
Pair 7	TradSem - NonSem	-31.11538	21.70935	6.02109	-44.23422	-17.99655	-5.168	12	.000
Pair 8	TradES - NonES	12.86846	84.87507	23.54011	-38.42103	64.15796	.547	12	.595

Descriptive Statistics for Contribution of Peak EMG per Muscle

	Mean	Std. Deviation	N
TradGlut	.2915	.18561	13
NonGlut	.2757	.17266	13
TradAdd	.1032	.05786	13
NonAdd	.1092	.07661	13
TradGas	.0367	.02630	13
NonGas	.0552	.02570	13
TradVM	.1745	.10095	13
NonVM	.1398	.07485	13
TradVL	.1397	.04639	13
NonVL	.1242	.04093	13
TradBF	.1004	.05314	13
NonBF	.1199	.06533	13
TradSem	.0335	.02229	13
NonSem	.0471	.02799	13
TradES	.1203	.07696	13
NonES	.1295	.08254	13

Repeated Measures ANOVA

Tests of Within-Subjects Effects for Contribution of Peak EMG per Muscle

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Muscle	Sphericity Assumed	1.046	7	.149	9.580	.000
Error(Muscle)	Sphericity Assumed	1.310	84	.016		
Squat	Sphericity Assumed	3.077E-7	1	3.077E-7	3.459	.088
Error(Squat)	Sphericity Assumed	1.067E-6	12	8.894E-8		
Muscle * Squat	Sphericity Assumed	.018	7	.003	2.785	.012
Error(Muscle*Squat)	Sphericity Assumed	.076	84	.001		

Paired Samples Test for Contribution for Peak EMG per Muscle

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Dev.iation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	TradGlut - NonGlut	.01585	.06122	.01698	-.02115	.05284	.933	12	.369
Pair 2	TradAdd - NonAdd	-.00600	.04081	.01132	-.03066	.01866	-.530	12	.606
Pair 3	TradGas - NonGas	-.01854	.01323	.00367	-.02653	-.01055	-5.054	12	.000
Pair 4	TradVM - NonVM	.03477	.06017	.01669	-.00159	.07113	2.084	12	.059
Pair 5	TradVL - NonVL	.01554	.02899	.00804	-.00198	.03306	1.933	12	.077
Pair 6	TradBF - NonBF	-.01954	.03371	.00935	-.03991	.00083	-2.090	12	.059
Pair 7	TradSem - NonSem	-.01354	.01421	.00394	-.02213	-.00495	-3.435	12	.005
Pair 8	TradES - NonES	-.00915	.03679	.01020	-.03139	.01308	-.897	12	.387

Descriptive Statistics for Contribution for Total Area EMG per Muscle

	Mean	Std. Deviation	N
TradGlut	.2942	.17618	13
NonGlut	.2874	.17557	13
TradAdd	.0955	.05687	13
NonAdd	.0924	.06210	13
TradGas	.0258	.01848	13
NonGas	.0438	.02450	13
TradVM	.1652	.06871	13
NonVM	.1363	.06836	13
TradVL	.1487	.04304	13
NonVL	.1262	.04466	13
TradBF	.1114	.05632	13
NonBF	.1265	.06261	13
TradSem	.0266	.01708	13
NonSem	.0408	.02372	13
TradES	.1324	.08084	13
NonES	.1464	.09986	13

Repeated Measures ANOVA

Tests of Within-Subjects Effects for Contribution for Total Area EMG per Muscle

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Muscle	Sphericity Assumed	1.196	7	.171	11.505	.000
Error(Muscle)	Sphericity Assumed	1.247	84	.015		
Squat	Sphericity Assumed	.000	1	.000	.000	1.000
Error(Squat)	Sphericity Assumed	1.500E-6	12	1.250E-7		
Muscle * Squat	Sphericity Assumed	.015	7	.002	4.192	.001
Error(Muscle*Squat)	Sphericity Assumed	.044	84	.001		

Paired Samples Test for Contribution for Total Area EMG per Muscle

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Dev.iation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	TradGlut - NonGlut	.00685	.04366	.01211	-.01954	.03323	.565	12	.582
Pair 2	TradAdd - NonAdd	.00308	.02437	.00676	-.01165	.01780	.455	12	.657
Pair 3	TradGas - NonGas	-.01800	.01282	.00356	-.02575	-.01025	-5.063	12	.000
Pair 4	TradVM - NonVM	.02892	.02099	.00582	.01624	.04161	4.968	12	.000
Pair 5	TradVL - NonVL	.02246	.02521	.00699	.00723	.03769	3.213	12	.007
Pair 6	TradBF - NonBF	-.01515	.03504	.00972	-.03633	.00602	-1.559	12	.145
Pair 7	TradSem - NonSem	-.01415	.01237	.00343	-.02163	-.00668	-4.126	12	.001
Pair 8	TradES - NonES	-.01400	.04646	.01289	-.04208	.01408	-1.086	12	.299

Descriptive Statistics for Kinematics

	Mean	Std. Deviation	N
TradCOP	.5223	.09257	13
NonCOP	.7008	.04192	13
TradKnee	101.5592	6.68151	13
NonKnee	93.2977	14.51590	13
TradHip	110.9562	25.76456	13
NonHip	101.5031	19.24339	13
TradAnk	26.5023	4.22473	13
NonAnk	20.6192	6.08576	13
TradPelvis	36.5438	22.39360	13
NonPelvis	32.6554	17.38536	13
TradTorso	189.7800	156.62006	13

Descriptive Statistics for Kinematics

	Mean	Std. Deviation	N
TradCOP	.5223	.09257	13
NonCOP	.7008	.04192	13
TradKnee	101.5592	6.68151	13
NonKnee	93.2977	14.51590	13
TradHip	110.9562	25.76456	13
NonHip	101.5031	19.24339	13
TradAnk	26.5023	4.22473	13
NonAnk	20.6192	6.08576	13
TradPelvis	36.5438	22.39360	13
NonPelvis	32.6554	17.38536	13
TradTorso	189.7800	156.62006	13
NonTorso	123.3885	156.20278	13

Repeated Measures ANOVA

Tests of Within-Subjects Effects for Kinematics

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Kinematic	Sphericity Assumed	462439.135	5	92487.827	13.504	.000
Error(Kinematic)	Sphericity Assumed	410920.406	60	6848.673		
Squat	Sphericity Assumed	9511.175	1	9511.175	5.387	.039
Error(Squat)	Sphericity Assumed	21186.203	12	1765.517		
Kinematic * Squat	Sphericity Assumed	20487.707	5	4097.541	4.138	.003
Error(Kinematic*Squat)	Sphericity Assumed	59407.529	60	990.125		

Paired Samples Test for Kinematics

	Paired Differences					t	df	Sig. (2-tailed)
				95% Confidence Interval of the Difference				
	Mean	Std. Deviation	Std. Error Mean	Lower	Upper			

Pair 1	TradCOP - NonCOP	-.17846	.09091	.02521	-.23340	-.12353	-7.078	12	.000
Pair 2	TradKnee - NonKnee	8.26154	11.80633	3.27449	1.12705	15.39603	2.523	12	.027
Pair 3	TradHip - NonHip	9.45308	23.88050	6.62326	-4.97777	23.88392	1.427	12	.179
Pair 4	TradAnk - NonAnk	5.88308	5.96775	1.65516	2.27680	9.48935	3.554	12	.004
Pair 5	TradPelvis - NonPelvis	3.88846	22.60851	6.27047	-9.77373	17.55065	.620	12	.547
Pair 6	TradTorso - NonTorso	66.39154	110.34425	30.60399	-.28883	133.07190	2.169	12	.051

APPENDIX J

Charts
(Produced from averaged data but not discussed in results)

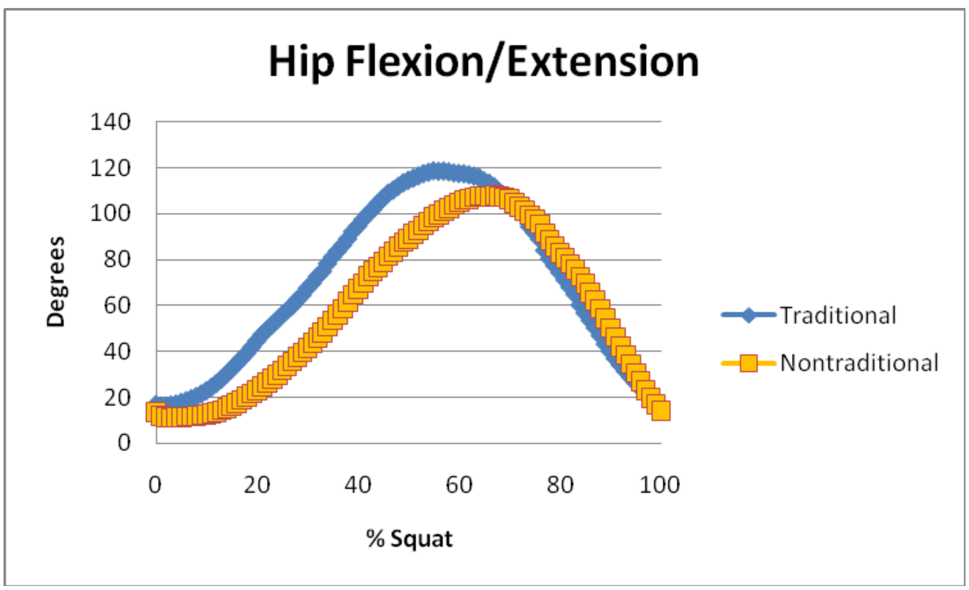


Figure J.1 Average hip flexion/extension.

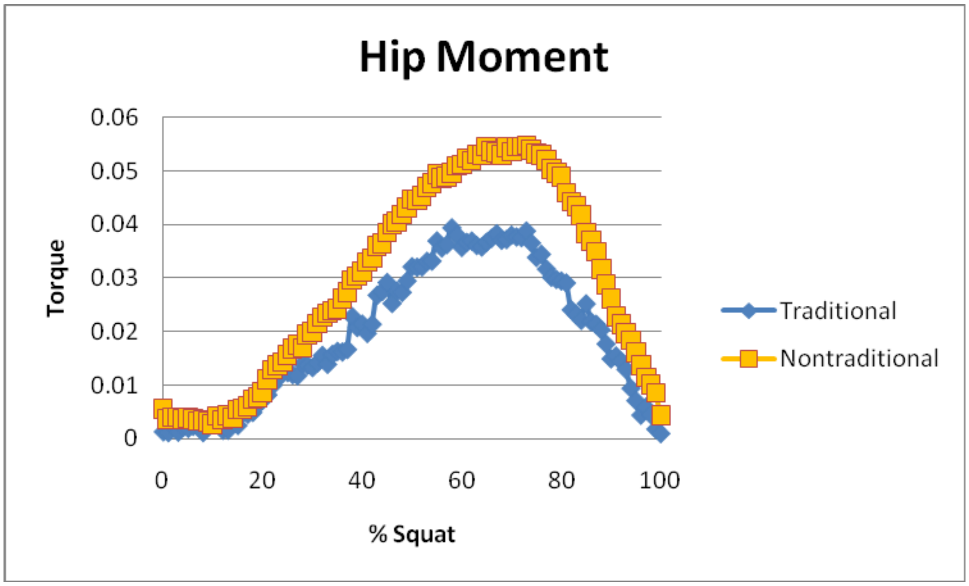
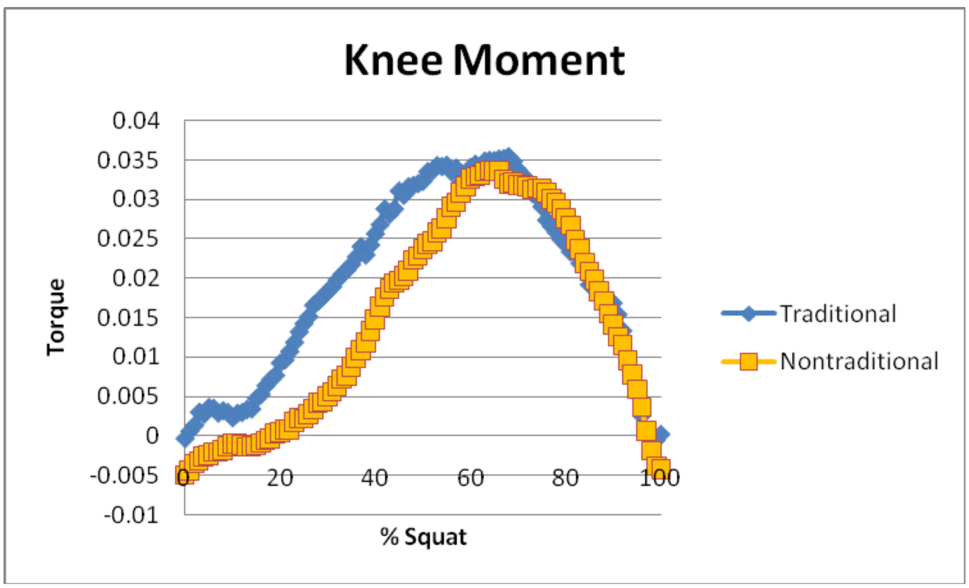
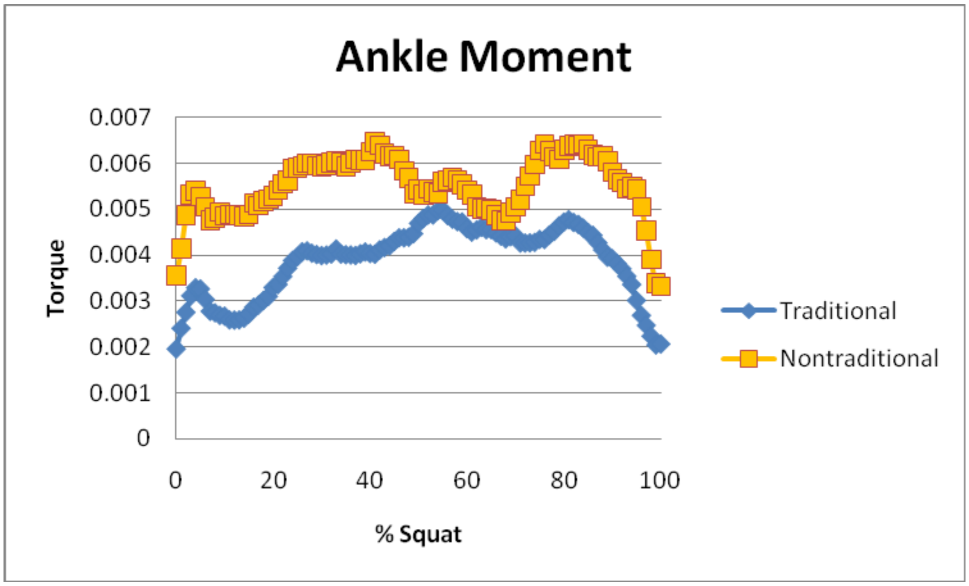


Figure J.2 Average hip moment.



Figures J.3 Average knee moment.



Figures J.4 Average ankle moment.