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EMG Analysis of Core and Thigh Musculature Contribution During Double and Single Leg Squats on Both Stable and Unstable Surfaces

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EMG ANALYSIS OF CORE AND THIGH MUSCULATURE CONTRIBUTION DURING DOUBLE AND SINGLE LEG SQUATS ON BOTH STABLE AND UNSTABLE SURFACES

by

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ABSTRACT

EMG ANALYSIS OF CORE AND THIGH MUSCULATURE CONTRIBUTION DURING DOUBLE AND SINGLE LEG SQUATS ON BOTH STABLE AND UNSTABLE SURFACES

Julie M. Whitehead
Old Dominion University, 2005
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The purpose of this study was determine EMG activity of the hip stabilizers, thigh, and core muscles during various squatting exercises in order to better appreciate the contribution of the core and thigh during weight bearing functional activity. Surface EMG electrodes were placed over the rectus abdominis (RA), internal oblique (IO), external oblique (EO), erector spinae (ES), vastus medialis (VM), biceps femoris (BF), and gluteus medius (GM). The right leg was used for any single leg exercises performed. Each subject performed three double leg and three single leg un-weighted squats to 60 degrees of knee flexion on a stable surface, and then repeated the same squats on an unstable surface. Twenty-six recreationally active subjects (10 males, age = 21.9 $\pm$ 3.3 yrs, height = 177.5 $\pm$ 6.8 cm, mass = 79.7 $\pm$ 13.8 kg; 16 females, age = 22.5 $\pm$ 4.2 yrs, height = 168.6 $\pm$ 5.9 cm, mass = 68.9 $\pm$ 10.1 kg), who were free of lower extremity, back, or abdomen injury within the past six months, volunteered to participate in this study. Recreationally active was defined as participating in at least 20 minutes of athletic activity three or more times weekly. A 16.4" x 20" x 2.5" AIREX foam pad was used as the unstable surface. Seven MA-110 surface electrodes with preamplifiers from Motion Lab Systems, Inc (Motion Lab Systems, Inc., Baton Rouge, LA) attached to a DataQ acquisition board had a sampling rate of 1000Hz. Average root mean square (RMS) of muscle activity was found over 1000 milliseconds prior to reaching 60 degrees of knee flexion over the course of the three trials for each exercise and was used as a percentage of maximal voluntary isometric contraction (MVIC) for each muscle. EMG data were analyzed using both a 2 x 2 x 4 ANOVA (core) and a 2 x 2 x 2 x 3 ANOVA (thigh) in which the independent variables were gender (thigh only), surface, squat type, and muscle, and the dependent variable was the RMS measurement. Statistical significance was set at $p<0.05$. Within the core the internal oblique muscle was the most active during all activities ($p=.000$) followed by the erector spinae, external oblique, and the rectus abdominis. The single leg stance activity generated higher overall muscle activity than the double leg ($p = .021$). Within the thigh the vastus medialis produced the greatest muscle activity ($p = .000$) followed by the gluteus medius and biceps femoris. The single leg squat produced greater activity than the double leg squat ($p = .000$) and the vastus medialis activity was significantly higher for the single leg versus the double leg squat ($p = .000$). The vastus medialis for the females was significantly more active than the biceps femoris for the males and females ($p = .000$). The inclusion of single leg squat in a functional training program for the thigh (vastus medialis) and hip (gluteus medius) muscles is recommended based on observed muscle activity patterns. Additionally the single leg squat recruits the core musculature better than the double leg squat. These exercises are beneficial in recruitment of key abdominal stabilizers and thigh musculature and therefore should be incorporated into training programs.

Co-Directors of Advisory Committee: Dr. J. Onate

Prof. M. Walker

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CHAPTER I

INTRODUCTION

The muscles of the core, such as the transverse abdominis, rectus abdominis, internal and external obliques, erector spinae, and the gluteus group, activate to counteract the challenges made to spinal stability by lower limb activity. All activities that involve hip extension, flexion, abduction, or adduction will cause this co-activation of the core (Hodges, Richardson & Hasan, 1997). Few researchers have investigated how trunk dynamics might influence muscle activity (Davis & Marras, 2000).

The effect of the trunk muscles in relation to their contribution to trunk extension, flexion, and axial rotation has been studied (Ng, Parnianpour, Kippers, & Richardson, 2001). However, in functional athletic activity, very few active movements involve isolation of either the lower or upper extremity; in fact the movements of these limbs require the co-activation of the trunk musculature. Whenever a lower extremity movement occurs the entire body is involved in maintaining the posture and stability of the trunk (Hodges et al., 1997). While the trunk muscles may or may not be used in force generation during limb movement, increased activity in the core has been linked to the stability requirements of the entire body (Davis & Marras, 2000).

Studies that exist on the abdominal group have primarily evaluated muscular involvement during abdominal movement or exercises. However, through these studies it has been found that unstable surfaces can be used to further increase this core muscle activity. This increased muscle activity is due to the increased need for spine stability and body stability in order to maintain body position and center of gravity over a given surface (Vera-Garcia, Grenier, & McGill, 2000). Vera-Garcia et al. (2000) observed the differences in abdominal muscle activity when a curl-up was performed on both stable and unstable surfaces. It was found that the abdominal musculature increases in EMG muscle activity when performed on an unstable surface. Ng et al. (2001) examined the role of the abdominal muscles during axial rotation, and the effect of direction of axial rotation on abdominal muscle activity. Because the core must work in conjunction with the body during multi-joint exercises, it would be beneficial to note how their contribution changes based upon distal segment involvement.

Statement of the Problem

The purpose of this study was to determine EMG activity of the abdominal core muscles, contributing hip stabilizers, as well as the muscles of the thigh during various squatting exercises.

Research Hypotheses

1. The rectus abdominis, internal oblique, external oblique, and erector spinae would be recruited during the squat exercise as measured by EMG activity, the internal oblique being the most active.
2. All core muscle recruitment would increase according to EMG activity when either the double or single leg squat was performed on an unstable surface.
3. All core muscle recruitment, as recorded by EMG activity, would increase when the exercise was performed as a single leg squat.
4. The gluteus medius, vastus medialis and biceps femoris would be recruited during the squat exercise as measured by EMG activity, the vastus medialis being the most active.

5. All hip muscle activity would increase when the squats were performed on an unstable surface.
6. All hip muscle activity would increase when the squats were performed with the single leg technique.

Null Hypothesis

1. There will be no statistically significant differences in core and hip muscle activity for the various squat techniques on the two surfaces.

Dependent Variables

1. Electromyography (EMG) muscle activity measurement of the rectus abdominis, internal and external obliques, erector spinae, gluteus medius, vastus medialis, and biceps femoris. The measurements taken were the root mean square for peak contraction as a percentage of the maximum voluntary isometric contraction.

Independent Variables

1. Surface Type (stable vs. unstable)
2. Squat (Double leg squat vs. single leg squat)
3. Hip Muscles (gluteus medius, vastus medialis, biceps femoris)
4. Core muscles (rectus abdominis, internal oblique, external oblique, erector spinae)
5. Gender (male, female)

Operational Definitions

1. Core: The core consists of the rectus abdominis, external oblique, internal oblique, transversalis, latissimus dorsi, iliocostalis lumborum, and the multifidus.
2. Hip/Thigh Musculature: This musculature consisted of the gluteus medius (assists with hip stabilization) and biceps femoris and vastus medialis.
3. Electromyography: The study of the intrinsic electrical activity of muscle through the use of surface electrodes.
4. Double Leg Squat: Exercise performed with legs shoulder width apart and arms at 90 degrees of shoulder flexion. Knees simultaneously flexed to 60 degrees, and returned to full extension. The back was kept in the upright position with only slight trunk flexion, and the toes remained flat to the floor.
5. Single Leg Squat: Exercise performed on one leg with the non-weight bearing leg flexed at the hip so the leg was just in front of the plane of the body. Arms remained at 90 degrees of shoulder flexion. The weight bearing leg flexed to 60 degrees of knee flexion and returned to full extension.
6. Unstable Surface: The unstable surface consisted of an AIREX foam pad. Dimensions were as follows: 16.4" x 20" x 2.5".

Assumptions

1. All subjects accurately reported that they were without injury to the back, abdomen, hip, knee, or ankle at the time of testing.
2. All subjects gave their best effort at the time of testing.
3. The EMG was calibrated correctly and functioned properly.

Limitations

1. The subjects may have had varying levels of ankle dorsiflexion that may have affected the muscle recruitment patterns.
2. The levels of training that each subject participated in may have varied and therefore resulted in variance in the muscle recruitment patterns during testing that may have offset results.
3. Single leg squats were performed on the right leg regardless of dominance; which could have resulted in altered recruitment patterns.

Delimitations

1. The study consisted of healthy adults; both male and female, above the age of 18 and under the age of 35.
2. All subjects were recreationally active (participated in 20 minutes or more of athletic activity three or more times weekly).
3. Subjects were automatically excluded if they lacked the 60 degrees of knee flexion required to perform a squat.
4. This study was limited to individuals who stated that they were without back, abdominal, hip, knee, or ankle pain or injury within the six months prior to testing, and had had no previous surgery to any of these areas.

CHAPTER II

REVIEW OF THE LITERATURE

Researchers have examined lower extremity muscle recruitment during various exercises (Augustsson & Thommee, 2000; Brask, Lueke & Soderburg, 1984; Earl, Schmitz & Arnold, 2001; Escamilla, Fleisig, Zhenig, Lander, Barrentine, Andrews, Bergemann & Moorman, 2001; Fagenbaum & Darling, 2003; Flanagan, Salem, Wang, Sanker & Greendale, 2003; Freedman, Wannstedt & Herman, 1976; Isear, Erickson & Worrell, 1997; Kroll, Spielholz, Bello, Bennie & Millett, 2001; Morrissey, Harman, Frykman & Han, 1998; Ninos, Irrgang, Burdett & Weiss, 1997; Rose & Delittok, 1992; Sheehy, Burdett, Irrgang & VanSwearingen, 1998; Worrell, Crisp & LaRosa, 1998; Zeller, McCrory, Kibler & Uhl, 2003), however, limited information exists regarding abdominal, or core muscle recruitment during these same activities (Hodges et al., 1997). It is important to know the extent to which the core contributes to lower extremity movement and stabilization for a variety of reasons. In preparation for activity, and rehabilitation for return to activity, the core is often overlooked from the strength and conditioning aspect. Knowing which core muscles contribute to movements specific to sport will allow strengthening programs to focus specifically on those groups. Additionally this knowledge applies in injury prevention, because it is possible that some lower extremity injuries occur as a result of compensation for poor core strength and stability. This review of literature will therefore encompass information concerning core musculature, the squat as an exercise, the difference between stable and unstable surfaces, and abdominal electromyography.

Core Musculature

The muscles of the core contribute to a variety of functions. The true abdominal muscles, the rectus abdominis, the internal oblique, the external oblique, and the transverse abdominis contribute to trunk stabilization (Hodges et al., 1997). The multifidus of the erector spinae group and the gluteus medius have also been identified as stabilizers of the trunk (Hodges et al., 1997; Ng et al., 2001). The prime contributors to axial rotation are the external and internal obliques, and the latissimus dorsi (Ng et al., 2001). When co-activating as stabilizers during functional activities the purpose of these muscles is two-fold. They not only contribute to the maintenance of the position of the center of mass over the base of support, but they also aid in the stability of the affected joints of the movement (Hodges et al., 1997).

Hodges et al. (1997) studied the sequence of contraction of the trunk and limb muscles for the maintenance of stability of the spine by evaluating the response of the lumbar multifidus, rectus abdominis, rectus femoris, tensor fascia latae, and gluteus maximus during hip flexion, abduction, and extension. The hip movement was randomly ordered, and involved the subject shifting their weight to the weight bearing leg and the subject would then complete the movement with the non-weight bearing leg. The study involved a visual stimulus to activate the assigned hip movement, therefore evaluating the sequence of contraction in a more functional point of view. The investigators concluded that the direction of limb movement effects the directions of resulting reactive forces in the trunk. Additionally it was found that with hip abduction the initial contraction of the transverse abdominis and the internal oblique occurred prior to the contraction of the primary limb mover. The same was true with hip extension when the transverse abdominis, rectus abdominis, and the internal oblique contracted prior to the initial contraction of the gluteus maximus. Ultimately their hypothesis was proved to be true, with the transverse abdominis contracting first in the sequence of contractions during hip flexion, abduction, and extension exercises.

Beith, Synnott, & Newman (2001) examined the patterns of recruitment of the abdominal muscles during the abdominal hollowing maneuver in both a four point kneeling stance and a prone position. This study included 20 healthy subjects, both male and female, between the ages of 19 and 30 years. In looking at the degree of activation, the internal oblique was activated in all hollowing maneuvers in both positions, while rectus abdominis activity during these same exercises was rarely seen. The external oblique acted in conjunction with the internal oblique during the four point stance, and even more so in the prone position.

Clark, Fater, and Reuteman (2000) discussed the core and its role in closed kinetic chain rehabilitation. The core was outlined as the lumbopelvic-hip complex where the center of gravity is located and where movement is initiated. The core is utilized to produce force, reduce force and stabilize dynamically against abnormal force. The authors also stated that in order for the body to optimally perform in the areas of strength, power, and neuromuscular control, the stabilization system must be functionally trained. It was emphasized that most individuals do not train their core to the extent that they train other muscular areas. An outline of a core training program was provided that focused on increasing proprioceptive demands by incorporating multimodal, unstable surfaces, while keeping strength gains as the goal.

Abdominal EMG

Electromyography has been used to complete kinesiologic analysis of muscles, as well as for various types of biofeedback. An EMG test or analysis can be completed using both surface electrodes, or indwelling needle electrodes, and the clinician must decided which electrode is appropriate for the study being conducted. Needle electrodes, while more invasive, have been previously considered to be more accurate than electrodes placed on the surface. However, it has been found that surface electrodes, if properly, placed can provide an accurate representation of electrical activity of deeper muscles (McGill, Juker & Kropf, 1996).

Surface EMG of the rectus abdominis during axial rotation has been examined and it was found that activity was not significantly being affected by the direction of exertion during trunk axial rotation. This was determined when 23 right-handed, male subjects without any history of back pain, completed three sub-maximal contractions at three different exertion levels in right and left axial rotation. The subjects were restrained at the legs, pelvis, and torso (Ng et al., 2001). Vera-Garcia et al. (2000) also evaluated the rectus abdominis, but during the curl-up exercise. It was concluded that rectus abdominis activity not only doubled when performing tasks on an unstable surface, it also worked in greater conjunction with the external oblique. This was demonstrated on EMG through greater amounts of muscle co-activation when comparing these two muscles. Ng et al. (2001) also compared the activity of the internal and external oblique during the study of axial rotation, and it was discovered that the direction of rotation did have a significant effect on the EMG activity of these two muscles. Vera-Garcia et al. (2000) ultimately discovered that the internal oblique was more active during activities on the unstable surface than was the external oblique based on EMG muscle activity comparisons. Ng et al. (2001) determined that the external oblique and internal oblique activity was significantly different between right and left axial rotation exertions. All of the comparisons made during these studies were based on the percent of the maximum voluntary isometric contraction.

The Squat Exercise

The role of resistance training in many athletic and rehabilitation programs is one of great importance. Many coaches and physical therapists agree that resistance training will result in improvements in functional activities. Closed kinetic chain exercises are preferred for resistance training since this type of exercise is more closely related to functional activities than are open kinetic chain exercises (Augustsson & Thommee, 2000). Closed kinetic chain exercises have become a fundamental part of lower extremity rehabilitation protocols (Ninos et al., 1997). The squat is a common core, closed kinetic chain exercise that is used by athletes to enhance performance in sport. It is a multi-joint exercise that has biomechanical and neuromuscular similarity to many athletic movements like running and jumping (Escamilla, 2001). The closed kinetic chain squat involves muscles working across several joints and is primarily used to improve lower extremity strength (Augustsson & Thommee, 2000). The squat is typically used to strengthen hip, thigh, and back musculature, which are all primary movers in running, jumping, and lifting motions. It is a common belief that the squat improves athletic performance and minimizes the risk of injury (Escamilla, 2001).

Ninos et al. (1997) found that peak activity of the vastus medialis, vastus lateralis, and biceps femoris groups occurred between 50-60 degrees of the descending portion and then 60-50 degrees of knee flexion during ascension when performing a squat. This study revealed that, while significant changes in the muscle activity of the hamstring group did not occur with knee flexion angles, lower levels of muscle activity were observed in connection with the eccentric phase of the squat as compared to the concentric phase.

The start of a squat involves an upright position to be assumed by an individual with both knees and both hips in full extension (Escamilla, 2001). Ninos et al. (1997) found that no significant difference in EMG activity exists whether the feet are in neutral or in a slightly turned out position. The individual begins the squat by flexing the knees and hips in a continuously downward motion until a desired squat depth is obtained and then in a continuous motion ascends back to the upright position. The squat can be performed with various amounts of knee flexion (Escamilla, 2001). This exercise should be done with the back upright and the feet shoulder width apart (Augustsson & Thommee, 2000).

Zeller et al. (2003) conducted a study to compare kinematic and EMG data during the single leg squat between genders. This study consisted of 18 subjects (nine males, nine females). They asked subjects to perform the single leg squat on their dominant leg with the arms folded across the chest and with the instructions to the subject to squat as far down as possible and return to upright without losing their balance. Kinematic data was obtained with the use of 6 video cameras, and then exported to OrthoTrak 4.2 software for analysis. This study determined that kinematically women tend to have different valgus/varus positions of the knee during a single leg squat as compared to men, as well as more ankle dorsiflexion and pronation, hip adduction, flexion, and external rotation. Surface EMG analysis of muscle activation was completed on rectus femoris, vastus lateralis, medial gastrocnemius, biceps femoris, gluteus maximus, gluteus medius, rectus abdominis, and erector spinae. The EMG data demonstrated that overall women had greater muscle activation than men, especially in the rectus femoris. This demonstrates the necessity of comparing muscle activation to the percentage of maximum voluntary isometric contraction in order to make data comparable between genders.

Augustsson & Thommee (2000) studied the ability of closed and open kinetic chain tests of muscular strength as a form of testing to assess functional performance. The study included 16 male subjects that were both healthy and generally physically active, (ranked on a scale of 1-8, 1 being sedentary and 8 being competitive). In closed kinetic chain testing involving multiple joints subjects performed the barbell squat exercise, while in open kinetic chain exercises involving a single joint the subject performed a concentric isokinetic knee extensions on a Kinetic Communicator II dynamometer. Subjects also completed a functional performance vertical jump test. The study compared the relationship between the values of the closed and open chain kinetic tests to those results of the functional vertical jump test. Strong significant correlations existed between the test of functional performance and the closed and open kinetic chain tests of muscular strength. It was concluded that the effect of training or rehabilitation interventions should not be based purely on tests of muscular strength, but that functional performance testing should be included as well.

When conducting EMG of the squat exercise, it is important to maintain uniformity of the stance between trials. Earl et al. (2001) conducted research on the effect of isometric hip adduction on the activation patterns of the VMO and VL during a mini-squat. Each subject performed two sets of three repetitions of a traditional mini-squat and a mini-squat with hip adduction (squeeze). EMG activity was recorded bilaterally for both the VMO and VL. It was found that adding hip adduction to the mini-squat significantly increased the activity of both quadriceps muscles.

A study was also conducted by Escamilla et al. (2001) to observe the knee biomechanics of the squat exercise. They examined tibiofemoral shear and compressive forces, patellofemoral compressive force, knee muscle activity, and knee stability by using EMG to quantify muscle activity and help estimate internal muscle forces. The subjects were 10 male weight lifters who were asked to perform both wide stance and narrow stance squats. It was determined that low to moderate posterior shear forces were restrained primarily by the posterior cruciate ligament (PCL) throughout the squat for all knee flexion angles. Low anterior shear forces, which were restrained primarily by the anterior cruciate ligament (ACL), were generated during 0-60 degrees of knee flexion. Finally quadriceps, hamstrings, and gastrocnemius activity generally increased as knee flexion increased during the parallel squat.

The unloaded squat exercise was studied by Isear et al. (1997). EMG analysis of the lower extremity muscle recruitment patterns was evaluated during this exercise. The purpose of this study was to determine the muscle recruitment patterns of the gluteus maximus, hamstrings, quadriceps, and gastrocnemius during this exercise, and also to describe the amount of hamstrings/quadriceps co-contraction when performing the unloaded squat. This study involved surface EMG while the subject performed three sets of four squats. It was found that the quadriceps group was significantly more active than the hamstrings during this particular study.

Ninos et al. (1997) performed an EMG analysis of the hamstrings and quadriceps during the squat performed both in lower extremity neutral and 30 degrees of lower extremity turn out from the neutral position. It consisted of 25 subjects, both male and female. It was found that the change in lower extremity position did not cause significant changes in muscle activity patterns. Additionally, it was concluded that peak muscle activity for the vastus medialis, vastus lateralis, and biceps femoris muscle groups occurred between 50-60 degrees of knee flexion in the descending phase, and 60-50 degrees of knee flexion in the ascending phase. The overall greatest level of muscle activity for all of these muscles occurred during the ascending phase of the squat.

Surface Stability

Exercises that are performed on an unstable surface require increased stabilization. This increase in muscle activity is due to the increased requirement to enhance spine stability and whole body stability to reduce the threat of falling off the surface (Vera-Garcia et al., 2000). The use of unstable surfaces appears to increase muscle activity levels and co-activation, further challenging endurance capabilities. Curl-ups completed on labile surfaces doubles muscle activity led as compared to those activities that were completed on a stable surface. Of the muscles tested the rectus abdominis was the most active during all exercises, especially those that were performed on the labile surface.

A more functional study completed on an unstable surface would include a weight bearing activity. Blackburn, Riemann, Myers, and Lephart (2003) provided a kinematic analysis of hip and trunk musculature during a bilateral stance on varying support surfaces. The study measured trunk flexion/extension, trunk lateral flexion, right and left hip flexion/extension and abduction/adduction angular variances using an electromagnetic tracking system during a double-leg stance on firm, foam, and multi-axial support surfaces. These were done both with and without vision. It was found that significantly greater amounts of motion occurred at all joints for multi-axial, eyes closed conditions compared to all other surface-vision conditions. During the eyes closed condition right and left hip flexion/extension and abduction/adduction magnitudes were significantly greater than those of trunk flexion and lateral flexion, and left hip flexion/extension was significantly more than right hip flexion/extension. Other than the eyes closed condition, it was found that the hips and trunk contribute equal amounts of motion when maintaining postural control.

Summary

Ultimately, limited research has been completed on the core muscle recruitment and co-activation during lower extremity movement to provide an accurate comparison of data. Studies of the squat exercise have primarily focused on lower extremity muscular EMG data, while abdominal EMG studies have consistently observed activity during abdominal exercises and movements. In order to properly formulate and carry out productive rehabilitation protocols and training procedures in order to prepare the athlete for functional activity on the athletic field research must be conducted to attribute the core's contribution to lower extremity tasks.

CHAPTER III

METHODOLOGY

Design

This research study was designed to examine the core and hip/thigh muscles' contribution to various lower extremity movements. The independent variables included squat with two levels: single leg and double leg; surface condition with two levels: stable and unstable (foam); core muscle with four levels: rectus femoris, external obliques, internal obliques, erector spinae; hip/thigh muscles with three levels: gluteus medius, biceps femoris, and vastus medialis; and gender. The dependent variable was % of MVIC from each of the muscles during the squatting maneuvers, as recorded by surface EMG.

Subject Characteristics

Twenty-six recreationally active subjects (10 males, age = 21.9 $\pm$ 3.3 yrs, height = 177.5 $\pm$ 6.8 cm, mass = 79.7 $\pm$ 13.8 kg; 16 females, age = 22.5 $\pm$ 4.2 yrs, height = 168.6 $\pm$ 5.9 cm, mass = 68.9 $\pm$ 10.1 kg) volunteered to participate in this study. Recreationally active was defined as participating in athletic activity for at least 20 minutes 3 or more times weekly. All subjects were free of abdominal, back, and lower extremity injuries within the 6 months prior to testing and had no history of instability to the ankle, knee, or hip. Informed voluntary consent was obtained prior to testing and the study was approved by the University Institutional Review Board.

Instrumentation

We used 6 MA-110 surface electrodes with preamplifiers from Motion Lab Systems, Inc (Motion Lab Systems, Inc., Baton Rouge, LA, 70816). Contact surfaces were 12 mm disks made of medical grade stainless steel. There was a fixed distance of 22mm between the centers of the active surfaces and the reference electrode was centered between them. The common mode rejection ratio will be 100Db.

Electrode placement was performed over the center of the muscle belly based on palpation for the vastus medialis and biceps femoris as described by Freedman et al. (1976). Electrodes for the rectus abdominis were placed one centimeter above the umbilicus and two centimeters to the midline. The electrode for the internal oblique was one centimeter medial to the ASIS, and for the erector spinae, directly over the muscle belly parallel to T12 (Ng, Parnianpour, Kippers & Richardson, 2003). Pad placement for the external oblique was just below the rib cage on the inferior ridge of the eighth rib as described by Beith et al. (2001). Before application of an electrode, the skin was prepared by dry-shaving the area and cleansing the skin with alcohol to reduce surface impedance. Electrodes were secured using three strips of clear bandaging tape over each electrode. MVIC was obtained for each muscle following electrode application by asking the subject to perform an isometric contraction against resistance while isolating each muscle in manual muscle testing positioning (Kendall, McCreary & Provance, 1993).

The electrodes were connected by coaxial cables to an amplifier, which was connected to a personal computer with a DataQ data acquisition board. The computer program that was used to collect, and analyze the EMG data was produced by DataQ Instruments (Akron, OH). Data was collected at a sample rate of 1000 samples per second per channel.

All squats were performed with a metronome set to 40 beats per minute, with a three-count allowed for each completed squat. A signifier was used to allow the researcher to determine at what point in the squat the subject was when reviewing computer generated EMG data. The subject was responsible for activating this signifier at the start of the squat, releasing at the bottom of the squat, activating again at the start of the ascending portion of the squat, and release again when they reached full extension. This allowed the researcher to pinpoint both the start and the midpoint of the squat motion. A 1000 millisecond RMS measurement was taken for each muscle from before the point of the signifier release at the base of the squat. This ensured that the measurement taken was during the deepest portion of the squat while the subject was still in motion.

A 16.4" x 20" x 2.5" AIREX foam pad was used as the unstable surface. This surface was chosen for its ability to accommodate a shoulder width stance.

Experimental Procedures

On arrival at the Gait Analysis laboratory, subjects underwent placement of the surface EMG electrodes over the seven muscles as previously described. They then performed one maximal voluntary isometric contraction for each of the seven muscles, holding each for five seconds, in positions for each muscle as described by Kendall et al. (1993) and resisted by the researcher. If, during this MVIC collection, the abdominal electrodes' output indicated any cross talk, the electrodes were removed, re-applied, and MVIC re-taken.

After muscle contraction data were collected, subjects were randomly assigned to a counterbalanced order of testing. The first testing order consisted of performing double leg and single leg squats while on a stable surface, while the second order consisted of performing double and single leg squats on a foam surface.

Subjects assumed a shoulder width stance, which was marked on the floor to assure that the same stance was used for all double leg exercise testing. An adjustable treatment table was placed behind the subject. The subjects performed a squat to 60 degrees and the table was adjusted so that it made contact with the subjects' buttocks at the deepest segment of this squat. This was to ensure that all subject performed each squat to the same depth. Each subject was allowed two practice squats prior to the performance of that variety of squat. All squats were performed with a metronome set to 40 beats per minute, with a three-count allowed for each completed squat. Subjects performed three double leg squats on the first surface type with feet shoulder width apart with their arms in 90 degrees of shoulder flexion. Subjects then performed three single leg squats on the right leg on the same surface, also with 90 degrees of shoulder flexion. This same testing procedure was then repeated on the other surface type with three squats performed for each type of squat.

Data Analysis

We utilized separate repeated measures ANOVA's to compare differences between core muscles (2 x 2 x 4) and hip/thigh muscles (2 x 2 x 3 x 2) for the two squat conditions across two surface conditions. Statistical significance was set at $p < 0.05$. Tukey's HSD were used for all post-hoc analyses. SPSS 12.0 (Chicago, IL) was used for all statistical analyses.

CHAPTER IV

RESULTS AND DISCUSSION

Results

All of the raw data from this experiment is displayed in Appendix A.

Core Musculature Findings

There was a main effect for muscle showing that the internal oblique muscle was the more active of the core musculature during all activities ($p = .000$, $F_{3,75} = 12.453$) followed by the erector spinae, external oblique, and rectus abdominis respectively (Figure 1). Tukey's HSD revealed no differences between muscles. This potentially signifies that each muscle within the system works together, and no one muscle contributes significantly more than any other. There was also a main effect for squat with the single leg stance exercise producing higher core muscle activity ($p = .021$, $F_{1,25} = 6.068$) than the double leg squat exercise (Figure 2). There were no other significant findings regarding the core musculature.

Lower Extremity Findings

In the lower extremity there was a main effect for muscle in which the vastus medialis produced the greatest muscle activity of the thigh musculature ($p = .000$, $F_{2,48} = 41.200$) followed by the gluteus medius and biceps femoris, respectively (Figure 3). Post hoc tests revealed that the vastus medialis was significantly more active than the biceps femoris. There was a main effect for leg with the single leg producing more muscle activity than the double leg squat ($p = .000$, $F_{1,24} = 72.770$) (Figure 4). There was an interaction for muscle and leg ($p = .000$, $F_{2,48} = 19.756$). Post hoc tests revealed that the vastus medialis during the single leg squat was significantly more active than the

Figure 1: Activity of the Core Musculature (Mean ± SE)

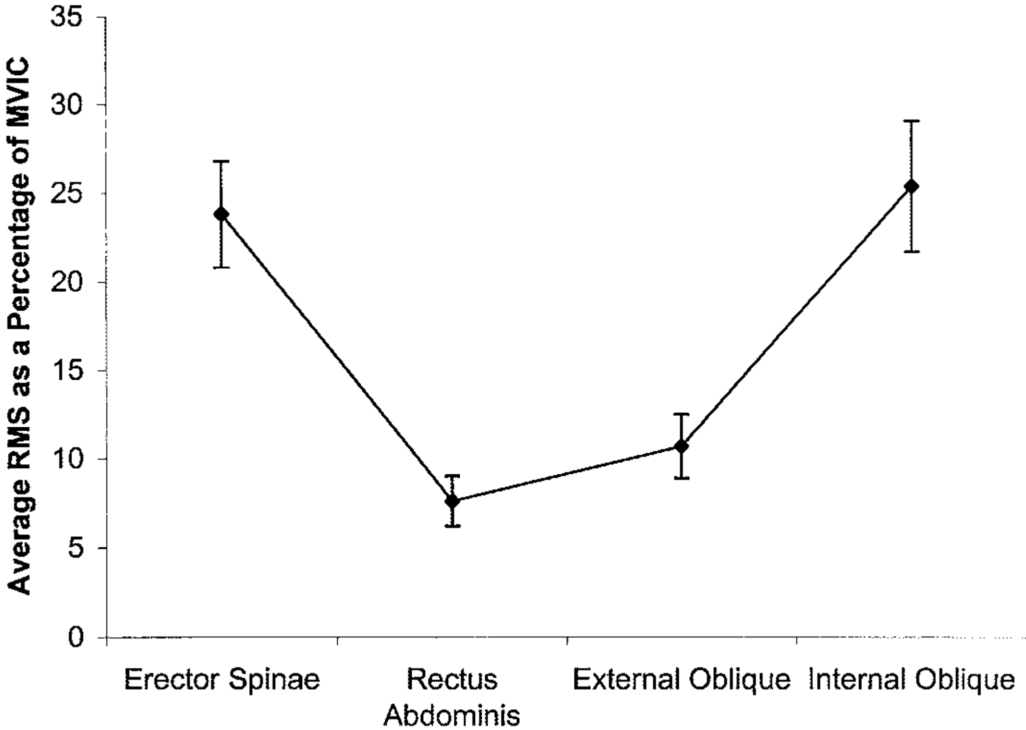
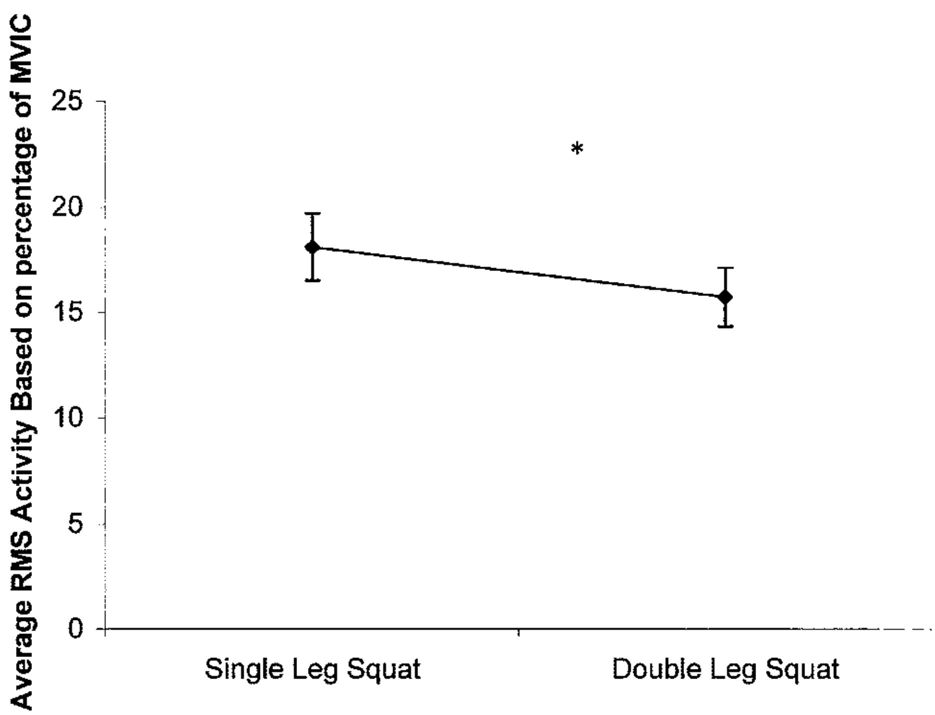
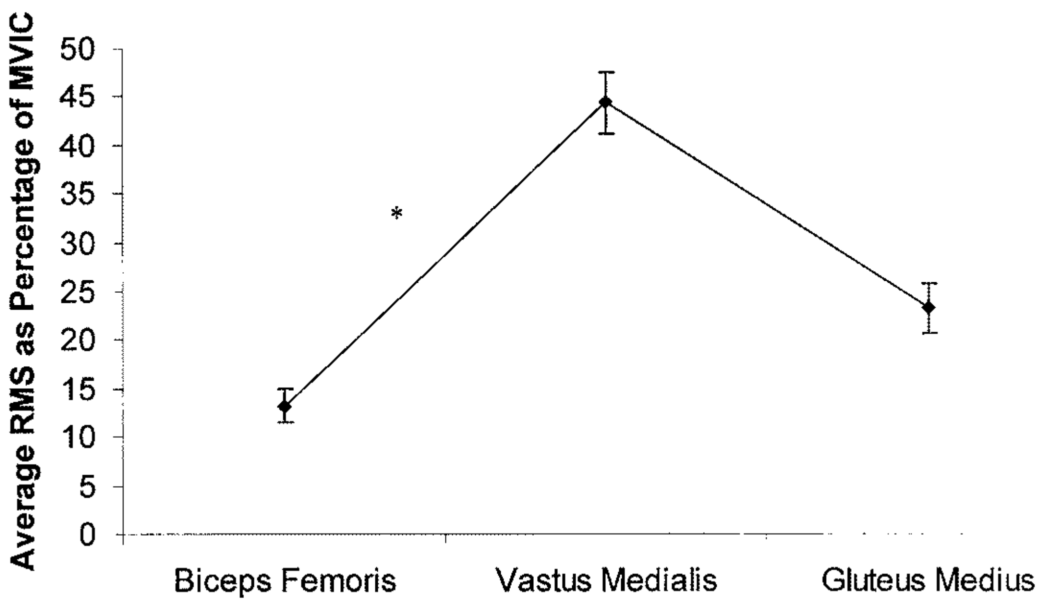


Figure 2: Comparison of Core Activity During Single and Double Leg Squats (Mean ± SE)



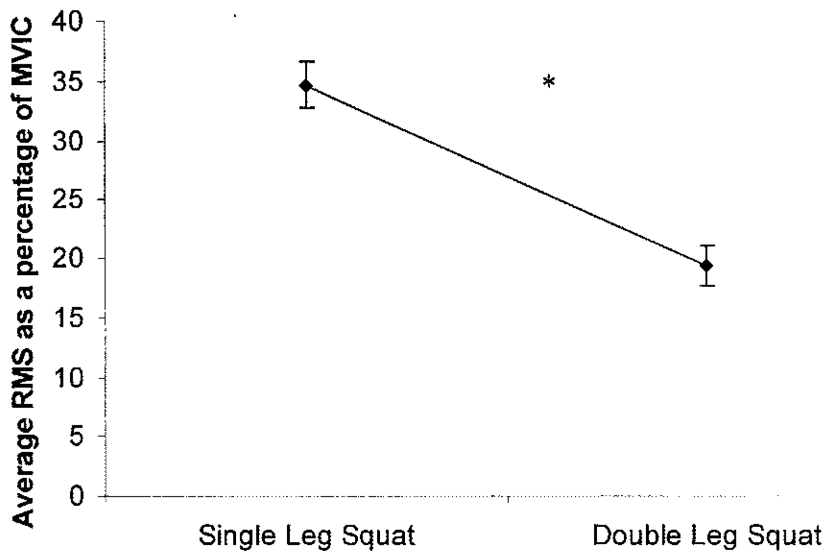
* p<.05 Core musculature during single leg squat is significantly more active than during the double leg squat

Figure 3: Overall Lower Extremity Muscle Activity (Mean ± SE)



*p<.05 vastus medialis is significantly greater than the biceps femoris

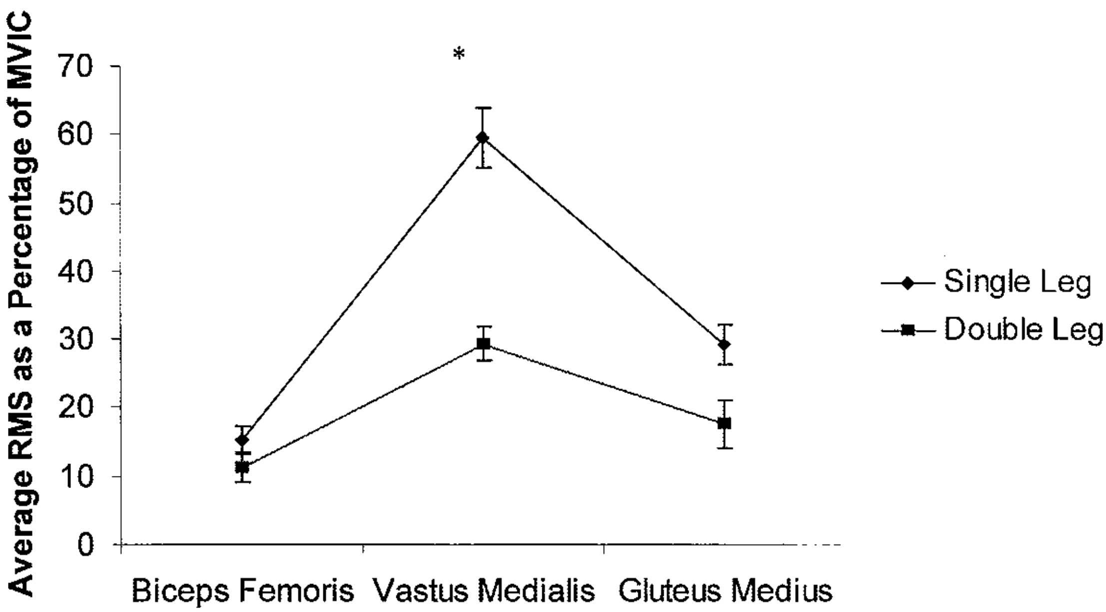
Figure 4: Lower Extremity Activity During Single and Double Leg Squats (Mean $\pm$ SE)



* $p<.05$ Lower extremity muscle activity was significantly more active during the single leg squat as compared to the double leg squat

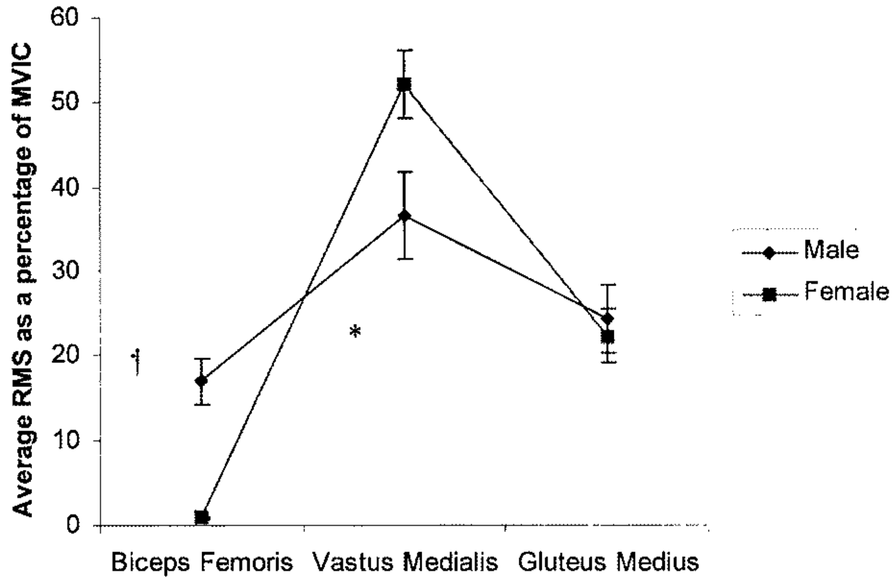
biceps femoris single leg, biceps femoris double leg, vastus medialis double leg, gluteus medius single leg, and gluteus medius double leg (Figure 5). There was an interaction for muscle by gender ($p = .005$, $F_{2, 48} = 5.915$). Post hoc testing indicated that vastus medialis activity was significantly greater than biceps femoris activity for females, and that vastus medialis activity for females was significantly greater than biceps femoris activity for males (Figure 6). There was a muscle by leg by surface interaction ($p = .026$, $F_{2, 48} = 3.929$). Post hoc test revealed that there were differences existing between various conditions, however no differences were found between surface conditions (Table 1).

Figure 5: Lower Extremity Muscle Activity During Double and Single Leg Squats (Mean $\pm$ SE)



* p<.05 vastus medialis during the single leg squat was significantly more active than was the biceps femoris single leg, biceps femoris double leg, vastus medialis double leg, gluteus medius single leg, and gluteus medius double leg

Figure 6: Overall Lower Extremity Activity for Males and Females (Mean ± SE)



* p<.05 vastus medialis activity for females was significantly greater than biceps femoris activity for females

† p<.05 female vastus medialis activity was significantly greater than males

Table 1: Lower Extremity Muscle Activity x Exercise Stance x Surface Type

Muscle	Leg	Surface	Mean (RMS%)	Standard Error
Biceps femoris	Single	Stable	13.2	1.6
		Unstable	17.5	2.5
	Double	Stable	11.4	2.4
		Unstable	10.7	2.2
Vastus medialis	Single	Stable	62.9	5.3
		Unstable	56.1	4.2
	Double	Stable	29.5	2.7
		Unstable	29.2	2.8
Gluteus medius	Single	Stable	28.6	3.5
		Unstable	29.8	3.2
	Double	Stable	18.9	4.4
		Unstable	16.0	3.2

Discussion

The Core

We hypothesized that the core musculature would be activated during lower extremity activity and that this activation would increase when the squat exercise was performed on one leg. We also hypothesized that core activation would increase when the squat exercises were performed on unstable surfaces as compared to stable surfaces. We found that no one muscle within the core is significantly more active than another. It was determined that the core was significantly more active during single leg squats as compared to double leg squats.

The core is frequently included in rehabilitation protocols, including protocols for lower extremity injuries. However, the core's contribution to lower extremity activity has not been significantly studied to determine its role during such activities. Hodges et al. (1997) determined that the core musculature, specifically the transverse abdominis, rectus abdominis, and internal oblique, contract prior to the main joint mover for a motion in order to stabilize the trunk during the movement. This study demonstrated the onset of muscle activation, but did not examine the peak muscle activation during the joint movement.

The core has been studied extensively as to the individual muscles' role in trunk movement during abdominal activities. Beith et al. (2001) determined that the internal oblique was the most active during trunk hallowing maneuvers (18.5 % MVC in 4-point stance, 34.7 % MVC in the prone position) followed by the external oblique (8.5 % MVC in 4-point stance, 9.5% in the prone position), which was significantly active in the two maneuvers. However, this study did not determine if this level of activity was similar for exercises involving the extremities. We sought to determine EMG activity of the abdominal core muscles, contributing hip stabilizers, as well as the muscles of the thigh during various squatting exercises. Similar to Beith et al.'s, (2001) findings we found that the internal oblique was more active than the other core muscles during the squat exercises. Additionally, we found that the rectus abdominis was less active than the rest of the corresponding trunk musculature. This was similar to Ng et al.'s (2001) findings when examining axial trunk rotation and it was determined that the rectus abdominis had no significant difference in activity between left and right axial rotation. Since the rectus abdominis primarily serves as a trunk flexor it is reasonable that it was the least active in both studies. The squat exercise typically requires more activation of the erector spinae to hold the torso upright, therefore not requiring the rectus abdominis to be as active.

Beith et al. (2001) and Ng et al.'s (2001) studies both concluded that all of the muscles of the core were somewhat active during the activities performed. This was similar to the outcome in our study in which all of the muscles of the core contributed to the movement. It is theorized that the core consists of global and local muscles that contribute to the stability of the body (Bergmark, 1989). Global muscles, including the rectus abdominis, external obliques, internal obliques, and the lumbar extensors, are responsible for producing large torque and provide general trunk stabilization (Bergmark, 1989). The use of the single leg squat exercise requires increased muscle activity within the core since the single leg stance requires the control of the body over a planted leg, and may require compensation for poor hip strength and control (Zeller et al., 2003).

Our results did not indicate a significant difference in muscle activity when this exercise was performed on an unstable surface as compared to a stable surface. Vera-

Garcia et al.'s (2000) study resulted in an increase in rectus abdominis activity when the curl-up exercise was performed on an unstable surface. The resulting increase in activity may have been present since the exercise being performed was a designed abdominal exercise in addition to requiring increased stabilization needs following a surface change. It is possible that we did not find an increase in core muscle activity on the unstable surface since we were investigating a primarily lower extremity activity. It is possible that the AIREX foam pad may have elicited a different postural control strategy, but that the ankle stabilizers, or other muscles within the lower extremity, instead of those within the core, initiated this strategy. Additionally, it may be possible to alter the activity performed in this study to elicit more core activity, such as incorporating a throwing/catching activity, resisting the squat, or observing the subject as they transfer surface types. Since it is possible that the change of surface may have altered onset to activity patterns, or muscle activity patterns in the lower leg or ankle, further research is warranted regarding surface stability changes and muscle activation patterns to truly understand the core's role in these exercises.

It is the suggestion of our findings that it is important to consider all muscles of the core during strengthening and rehabilitation programs, since all of the muscles within the core were active during this lower extremity activity. Since it was determined that the core works as a system during this exercise it is important for the clinician to consider exercises that do not isolate individual muscles, but activates the system as a whole. The single leg squat exercise is a good example of this type of exercise in that it places the body in a position in which the core and hip must compensate for any inherent weaknesses.

Lower Extremity

We hypothesized that the involved lower extremity musculature would increase in activity when the exercise was performed as a single leg squat as compared to the double leg squat. We also hypothesized that lower extremity muscle activity would be greater with exercises performed on an unstable surface as compared to the exercise performed on a stable surface.

The results of our study indicated that the vastus medialis was the most active muscle, and that vastus medialis activity during the single leg squat was significantly more active than were the other lower extremity muscles during both exercise types. Additionally, we found the vastus medialis activity for females was significantly higher than the biceps femoris activity for both females and males.

Changing the stance of the squat exercise from a double leg stance to a single leg stance significantly increased lower extremity activity. These findings were similar to Earl et al. (2001) who found that altering the stance during squatting activities increased the activity of all of the quadriceps muscles. Their study examined subjects performing the squat with different amounts of hip abduction. When creating a more narrow base of support the muscles must be more active in order to maintain the body's position. This was also true in our study as the positioning of subjects in a single leg stance caused a very narrow base of support, therefore the musculature increased activity to maintain body position in addition to supporting all of the body weight.

Zeller et al.'s (2003) findings when studying the electromyographic activity between men and women during a single-legged squat determined that the vastus lateralis was among the most active of the muscles studied, whereas the biceps femoris was found to have a much lower muscle activity. Additionally, Isear et al. (1997) compared the hamstrings and quadriceps during an unloaded squat activity and found that the vastus medialis, as well as the rectus femoris and vastus lateralis, was significantly more active than the hamstring group. Their study also consisted of a controlled squat that was held at the deepest point for a period of time. They attributed the higher quadriceps activity during the descending portion of the squat to the eccentric loading of the hip flexors and knee extensors. Our results were similar in that we found the vastus medialis to be significantly more active than the biceps femoris, and our measurements were taken during this same eccentric loading phase. It is possible that measurements taken during the ascending (concentric hip extension) phase would have somewhat higher biceps femoris activity.

The results of our study indicated significant differences in muscle activity between genders. These results were congruent with those of Zeller et al. (2003) who found that females performing a single leg squat exercise had greater overall muscle activity than the muscle activity of males, especially within the quadriceps. They attributed these results to the understanding that females tend to rely more on their quadriceps, while males rely more on their hamstrings.

Our results indicate that the single leg squat elicits greater lower extremity muscle activity than does the double leg squat. The single leg squat places the body in a position of a narrow base of support that requires the musculature to compensate in addition to supporting the entirety of the body weight. The squat exercise can be performed both as part of training regimens, as well as rehabilitative programs. Incorporation of the single leg squat can serve as a progression in difficulty as it recruits greater overall muscle activity.

Limitations

One of the limitations of this study was the squat technique used. Subject were instructed to squat using their preferred technique, only controlling the timing and the depth of the squat, therefore making it difficult to ensure that all subjects squatted with the same amount of trunk flexion, hip abduction/adduction, and/or knee valgus/varus. Additionally, subjects were told to assume a comfortable shoulder width stance. The stance was controlled within subjects, but was not controlled for between subjects. Finally, our measurements were limited since MVIC was taken in a non-weight bearing position (Kendall et al., 1993) and the RMS measurements were taken during a weight bearing exercise. However, the manner in which measurements were taken was consistent across all subjects. Despite these limitations this study found significant results that should be investigated further.

CHAPTER V

CONCLUSIONS

It is common practice for clinicians to include core strength and stability training when treating a variety of lower extremity injuries, however there is little documented research to support how active the core may actually be during lower extremity exercises. This study examined the EMG activity of the abdominal core muscles, contributing hip stabilizers, as well as the muscles of the thigh during various squatting exercises.

We found that both the lower extremity and the core were significantly more active during single leg squats as compared to double leg squats. In the lower extremity the vastus medialis was the most active of the lower extremity muscles. Between genders, females had higher vastus medialis activity compared to biceps femoris activity of both genders.

Overall our results revealed that the single leg squat is a more effective exercise than the double leg squat in muscle activity recruitment for both the core and the lower extremity muscles. This occurs when the body is placed in a position in which the lower extremity must support the weight of the entire body and the core must compensate for poor hip stability while on a narrow base of support. It is important for athletes to train the muscles of the hip and the core to be prepared to support the body in this harder position since this position simulates common landing position for functional athletes.

Suggestions for Future Research

Future studies should examine the interaction of the core in relation to the lower extremity muscles. Additionally, future research should include onset to activation in order to gain a more thorough understanding of the core's contribution to lower extremity movement. Future researchers may wish to implement training protocols to ensure that all subjects perform the exercise in the exact same way. Research would also benefit from including stabilization instructions during testing. Finally, future studies would be beneficial to examine more functional lower extremity exercises such as running or cutting movements, or the resisted squat exercise.

REFERENCES

Augustsson, J, Thommee R. Ability of closed and open kinetic chain tests of muscular strength to assess functional performance. *Scand J Med Sci Sports.* 2000;10:164-168.

Beith ID, Synnott RE, Newman SA. Abdominal muscle activity during the abdominal hollowing maneuver in the four point kneeling and prone positions. *Man Ther.* 2001;6(2):82-87.

Bergmark A. Stability of the lumbar spine, a study in mechanical engineering. *Arta Orthop Scand Suppl.* 1989;230(60):20-24.

Blackburn TJ, Riemann BL, Myers JB, Lephart SM. Kinematic analysis of the hip and trunk during bilateral stance on firm, foam, and multiaxial support surfaces. *Clin Biomech.* 2003;18:655-661.

Brask B, Lueke RH, Soderburg GL. Electromyographic analysis of selected muscles during the lateral step-up exercise. *Phys Ther.* 1984;64(3):324-9.

Clark MA, Fater D, Reuteman P. Core (trunk) stabilization and its importance for closed kinetic chain rehabilitation. *Orthop Phys Ther Clin North Amer.* 2000;9:2.

Beith ID, Synnott RE, Newman SA. Abdominal muscle activity during the abdominal hollowing maneuver in the four point kneeling and prone positions. *Man Ther.* 2001;6(2):82-87.

Davis KG, Marras WS. The effects of motion on trunk biomechanics. *Clin Biomech.* 2000;15(10):703-717.

Earl JE, Schmitz RJ, Arnold BL. Activation of the VMO and VL during dynamic mini-squat exercises with and without isometric hip adduction. *J Electromyogr Kinesiol.* 2001;11:381-386.

Escamilla RF, Fleisig GS, Zhenig N, Lander JE, Barrentine SW, Andrews JR, Bergemann BW, Moorman CT. Effects of technique variations on knee biomechanics during the squat and leg press. *Med Sci Sports Exerc.* 2001:1552-1566.

Escamilla RF. Knee biomechanics of the dynamic squat exercise. *Med Sci Sports Exerc.* 2001;33(1):127-141.

Fagenbaum R, Darling WG. Jump landing strategies in male and female college athletes and the implications of such strategies for anterior cruciate ligament injuries. *Amer J Sports Med.* 2003;31(2):233-240.

Flanagan S, Salem GJ, Wang M, Sanker SE, Greendale GA. Squatting exercises in older adults: kinematic and kinetic comparisons. *Med Sci Sports Exerc.* 2003;35(4):635-643.

Freedman W, Wannstedt G, Herman R. EMG patterns and forces developed during step-down. *American Journal of Physical Medicine.* 1976:55(6);275-290.

Hodges PW, Richardson CA, Hasan Z. Contraction of the abdominal muscles associated with movement of the lower limb. *Phys Ther.* 1997;77(2):132-144.

Isear JA, Erickson JC, Worrell TW. EMG analysis of lower extremity muscle recruitment patterns during an unloaded squat. *Med Sci Sports Exerc.* 1997;29(4):532-539.

Kendall FP, McCreary EK, Provance PG. *Muscles Testing and Function with*

Posture and Pain. 4th ed. Baltimore, MD: Williams & Williams; 1993:140,147-150,209,213,221.

Kroll PG, Spielholz NI, Bello BG, Bennie LJ, Millett K. Recruitment of the hamstring and quadriceps muscles during two knee muscle strengthening exercises. *Physl Ther.* 2001;81(5):A26.

McGill S, Juker D, Kropf P. Appropriately placed surface EMG electrodes reflect deep muscle activity (psoas, quadratus lumborum, abdominal wall) in the lumbar spine. *Biomech.* 1996;29(11):1503-1507.

Morrissey MC, Harman EA, Frykman PN, Han KH. Early phase differential effects of slow and fast barbell squat training. *Amer J Sports Med.* 1998;26(2):221-230.

Ng FKJ, Parnianpour M, Kippers V, Richardson CA. Reliability of electromyographic and torque measures during isometric axial rotation exertions of the trunk. *Clin Neurophysiol.* 2003;114(12):2355-2361.

Ng FKJ, Parnianpour M, Kippers V, Richardson CA. Functional roles of abdominal and back muscles during isometric axial rotation of the trunk. *J Orthop Res.* 2001;19(3):463-471.

Ninos JC, Irrgang JJ, Burdett R, Weiss JR. Electromyographic analysis of the squat performed in self-selected lower extremity neutral rotation and 30 degrees of lower extremity turn-out from the self-selected neutral position. *J Orthop Sports Phys Ther.* 1997;25(5):307-315.

Rose SJ, Delittok RS. An electromyographic analysis of two techniques for squat lifting and lowering. *Phys Ther.* 1992;72(6):439-449.

Sheehy P, Burdett RG, Irrgang JJ, VanSwearingen J. An electromyographic study of vastus medialis oblique and vastus lateralis activity while ascending and descending steps. *J Orthop Sports Phys Ther.* 1998;27(6):423-9.

Vera-Garcia FJ, Grenier SG, McGill SM. Abdominal muscle response during curl-ups on both stable and labile surfaces. *Phys Ther.* 2000;80(6):564.

Worrell TW, Crisp E, LaRosa C. Electromyographic reliability and analysis of selected lower extremity muscles during lateral step-up conditions. *J Athl Train.* 1998;33(2):156.

Zeller BL, McCrory JL, Kibler BW, Uhl TL. Differences in kinematics and electromyographic activity between men and women during the single-legged squat. *Amer J Sports Med.* 2003;31(3):449-456.

Subject	1	2	3	4	5	6	7	8	9	10	11	12	13
Age	18	24	18	24	21	28	20	30	23	21	19	22	19
Gender	2	1	1	2	2	1	2	2	1	2	2	2	1
Height	170	185	175	160	174	174	171	176	186	158	166	164	172
Weight	62.7	98.6	62.3	61.4	62.3	75.5	67.7	85.5	108	60.5	71.4	61.4	71.4
bfsnsb	9.8	17	12	7.1	13.4	30.2	17.9	6.6	16.8	3.8	4.2	26.1	9.5
vmsnsb	54.4	75.6	59.2	89.3	106	67.6	32.9	137	65.2	91.9	100	30.9	28.7
gmsnsb	15.7	63.4	39.9	64.2	31.8	17.7	10.1	19	31.1	16.8	20.4	13.6	9.8
essnsb	57.7	27.1	52.6	38.6	22.1	19.6	4.2	49.3	35.6	2.3	31.1	12.1	4.5
rasnsb	2.4	7.5	1	22.2	6.1	1	6.7	7.4	13.1	9.5	17.5	4.1	2.8
eosnsb	28.6	28.7	6.9	13.5	7.4	2.3	17.1	14.9	25.2	16.1	36.8	4.6	8.7
iosnsb	19.8	9.3	7.6	15.2	23.4	32.2	29	31	76.9	18.1	23.3	21.1	22.3
bfdbsb	3.7	30.8	8.2	4.1	6.9	12.6	5.3	2.4	7.4	2.7	8.2	5.8	3
vmdbsb	23.1	20.1	34.1	37.1	57.7	49.9	14.6	37.7	28.8	53.7	41.8	24.4	10.1
gmdbsb	6	71.1	1.8	86.7	9.7	6.9	4.3	5.7	23.8	34.2	45.6	18.4	42.6
esdbsb	61.9	28.3	52.9	45.5	21.7	22.4	4.9	16.5	10.2	5.1	34.5	29.2	15.8
radbsb	2	7.7	0.6	24	3.6	0.8	4.7	4	7.5	8.2	13.4	10.8	1.5
eodbsb	8.7	14.9	10.9	12.1	5.2	2.7	8.6	5.4	28.5	17.6	30.6	3.9	2.2
iodbsb	10.2	4.6	5.1	12.2	11.7	45.8	9.3	8.7	62.1	24.1	27.5	7.1	13.2
bfsnusb	7.6	56.3	13.9	11.7	12.3	46.9	22.1	5.7	19.6	1.5	18.1	30.8	9.6
vmsnusb	45.1	46.7	51	70.7	80	86.2	37.2	90.5	75.3	80	88.2	26.8	21.6
gmsnusb	15.8	43.2	14.2	19.9	22.9	25.4	14.2	11.7	66	25	14.8	13.7	46.2
essnusb	49.4	19.4	60.3	57.9	18.4	32.3	8.1	34.9	13.7	2.6	4.1	11.3	7.6
rasnusb	2.4	7.7	0.7	24.7	4.1	1.3	16.2	7.2	6.8	10.3	16.5	4.6	1.8
eosnusb	10.6	57.4	12.1	15.8	5.3	2.3	37.9	9.1	31.8	18.4	36.7	4.7	7.7
iosnusb	16.2	13.8	6.6	19.9	10	79.5	50.8	14.9	41.8	14.6	21.9	12.5	50.3
bfdbusb	2.9	46.1	5.9	4.4	4.4	9.9	8.7	2.6	36.5	3.3	9.4	8.1	1.6
vmdbusb	20.2	16.7	24.7	25.7	37.2	63.8	56.9	46.3	30.8	42.9	47.5	23	7.8
gmdbusb	4	48.2	1.4	15.6	5.5	15.2	18.9	5.4	15.9	18.1	48.8	5.7	29.7
esdbusb	51.9	26.7	47.6	60.4	73.3	45	7.5	11.8	10.4	8	2.7	18	32.5
radbsusb	1.7	7.2	0.7	21.4	5.2	1.1	6.4	4.6	5.3	7.8	14	3.5	2.2
eodbusb	7.9	17.4	3.6	12.9	5.8	1.9	19.5	9.6	42.5	10.3	31.3	3.9	10.2
iodbusb	8.7	4.3	3.8	11.2	14.8	76.9	22	15.2	61.4	21.2	28.7	11.8	22.3

Subject	14	15	16	17	18	19	20	21	22	23	24	25	26
Age	25	19	19	22	19	21	34	22	21	23	20	21	26
Gender	2	1	1	1	2	2	2	2	2	2	2	1	1
Height	171	170	177	168	168	172	176	169	177	162	164	182	186
Weight	84.1	69.1	78.6	72.3	69.5	93.2	68.2	61.4	60	69.1	63.2	82.7	78.6
bfsnsb	15.3	15.7	6	13.1	29.2	10	7.6	11.1	21.4	7.7	8.8	18.2	0.7
vmsnsb	79	55.8	41	17.4	45.5	88.3	81.6	69.4	58.9	93.2	34.1	53.5	48.3
gmsnsb	31.5	5.8	11.7	21.8	33.3	33.9	46.4	34.5	18.4	68.3	38.5	17.8	42.7
essnsb	59.8	33	40	26.5	8.2	29.7	18.1	7.2	25.6	7.9	10.2	16.5	5
rasnsb	12.4	3.7	3.6	4.9	29.1	25.2	2.8	7.7	2.2	10	3.3	1.9	2.2
eosnsb	12.8	4.7	4.8	3.2	6.1	25.6	4.9	6.3	3.7	11.5	4.8	2	2.3
iosnsb	49	10.7	8	13.4	83.3	86.6	33.3	29.2	23.3	13	10.2	7.4	6.1
bfdbsb	10.7	19.4	2.3	51.2	6	5.9	2.9	5.4	38.3	2.1	3	19.8	1.7
vmdbsb	55.3	28.6	16.6	8.8	19.4	51.5	29.6	35.7	30	40	13.9	20.8	18.1
gmdbsb	14.5	1.4	5.8	25.2	6.2	9.9	10.7	5.7	19.5	11.4	8.1	5.5	9
esdbsb	45.4	14	19.7	52.8	6.6	23.9	21.1	10.6	20.5	9.5	14.3	2.9	9.6
radbsb	10.8	2.8	4	7.1	23.1	26.4	2.2	4.2	1.6	5.3	2.7	4.7	2.1
eodbsb	15.7	3.7	4.4	7.3	4.3	13.3	5	1.5	2.8	9.6	3.3	2.9	2.1
iodbsb	54	8.5	7.8	25.3	65.6	64.1	39.6	16.9	17	8.1	16.1	25.7	7.7
bfsnusb	17.2	13.2	5.7	38.7	14.8	11.4	14.4	11.5	7.8	9.3	9.8	14	3.3
vmsnusb	62.4	40	45	20	54.4	59.4	89.3	59.5	88.9	69.6	37.5	39.7	47.4
gmsnusb	33.3	6.8	14.9	39.3	38.9	26.5	56.3	39.7	17.6	49.9	42.5	17.3	46.8
essnusb	49	16.4	59	58.7	7.1	16	17.8	10.2	28.8	8.6	8.7	12.7	5.5
rasnusb	11.4	3.4	7.8	7.4	30.2	27.2	3.2	7.6	2.3	14.4	2.7	1.6	2.1
eosnusb	10.6	4.2	6.2	4.2	5.9	12.9	5.4	5.9	5.4	22.3	5.2	1.8	2.7
iosnusb	39.7	7.4	7.8	17.9	68.8	62	38.6	27.6	18.1	40.7	11	4.9	13.4
bfdbusb	6.1	6.1	2.7	38	3.6	5.3	3.6	4.6	12.7	2.4	3.7	3.1	10.9
vmdbusb	35.2	33.2	18	9.6	15.6	43.8	38.4	22.5	37.2	37.7	14.2	18.8	20.4
gmdbusb	6.2	2.4	5.2	66.9	6.1	9.4	13.5	5.6	13.2	10.6	7.2	3.1	11.5
esdbusb	12.3	18.1	21	29.9	6.1	23.7	21.8	12.4	33.5	9.4	13.6	3.9	11.5
radbsusb	8.8	3.4	4.2	11.3	22.8	21.9	2.3	3.5	1.7	5.9	1.8	1.4	1.9
eodbusb	6.4	5.2	4.4	7.1	3.4	10.1	4.6	1.5	2.8	11.9	2.7	1.6	2.1
iodbusb	20.3	8.1	8.1	51.8	58.3	57.8	36.1	11.2	14.5	12.2	11.8	3.6	33.1

APPENDIX B

UNIVERSITY APPROVED INFORMED CONSENT

INFORMED CONSENT DOCUMENT
OLD DOMINION UNIVERSITY

PROJECT TITLE: An EMG Analysis of Core Muscle Contribution During Both Double and Single Leg Squats on Stable and Unstable Surfaces

INTRODUCTION

The purposes of this form are to give you information that may affect your decision whether to say YES or NO to participation in this research, and to record the consent of those who say YES. The Study is titled: An EMG Analysis of Core Muscle Contribution During Both Double and Single Leg Squats on Stable and Unstable Surfaces. This study will take place in room 112 of William B. Spong Jr. Hall.

RESEARCHERS

Julie M. Whitehead, BS, ATC, Old Dominion University, Graduate Athletic Training Student, College of Education, Department of ESPER
Bonnie Van Lunen, PhD, ATC, Old Dominion University, College of Education, Department of ESPER
Jimmy Onate, PhD, ATC, Old Dominion University, College of Education, Department of ESPER
Martha Walker, PT, Old Dominion University, College of Health Sciences, Department of Physical Therapy

DESCRIPTION OF RESEARCH STUDY

Several studies have been conducted looking into the subject of the activity of the abdominal and back muscles during various trunk activities. None of them have explained the role that these muscles play in movement involving the extremities, such as a squat exercise. The purpose of this study is to analyze the onset of activity, and amount of activity of various core and leg muscles when performing both the double and single leg squat on two different types of surfaces.

If you decide to participate, then you will join a study involving research using surface electrodes to measure muscle activity. You will be hooked to surface electrodes, which are small pieces of metal that will be taped to your skin. If there is excessive hair where electrodes need to be attached, the hair will be shaved. These electrodes will be attached to 3 muscles on your stomach, 1 on your back, 1 on the side of your buttocks, 1 on the front of your thigh and one on the back of your thigh. First you will be asked to maximally contract each muscle while resistance is being applied and information will be recorded. This will be done in a different position for each muscle and you will perform three repetitions in each of the positions. You will then perform a series of double leg squats and single leg squats on 2 different types of surfaces. The surfaces will consist of a hard flat surface and a foam surface. If at any point you become uncomfortable or unsure, you may stop testing to ask questions, or end testing all together.

If you say YES, then your participation will last for 1 visit of approximately 30 minutes at the gait analysis laboratory, room 112 of Spong Hall. Approximately 50 recreationally active students will be participating in this study.

EXCLUSIONARY CRITERIA

All subjects must be between the ages of 18 and 35, and be recreationally active (participate in athletic activity 3 or more times a week). To the best of your knowledge, you should not have any history of injury to the lower extremities, back, or abdomen within the past 6 months that would keep you from participating in this study.

RISKS AND BENEFITS

RISKS: If you decide to participate in this study, then you may face a risk of personal injury if you are to lose you balance and fall during activities. The researcher tried to reduce these risks by having you keep your eyes open at all times to aid in maintaining your balance, as well as allowing you to step and regain your balance if at any point you feel you are at risk for falling. You may also run the risk of some additional muscle soreness since you will be performing several exercises. This risk would be similar to any muscular soreness following general athletic activity, and will be minimized by having you perform only a limited number of exercises. And, as with any research, there is some possibility that you may be subject to risks that have not yet been identified.

BENEFITS: There is no direct benefit to you for participating in this study. Others may benefit through the information that is provided concerning the muscle activation patterns during these activities.

COSTS AND PAYMENTS

The researchers want your decision about participating in this study to be absolutely voluntary, yet they recognize that your participation may pose some inconvenience. However, the researchers are unable to give you any payment for participating in this study.

NEW INFORMATION

If the researchers find new information during this study that would reasonably change your decision about participating, then they will give it to you.

CONFIDENTIALITY

The researchers will take reasonable steps to keep private information, such as any divulged medical history, and any laboratory findings confidential. The researcher will remove identifiers in the information you give. The results of this study may be used in reports, presentations, and publications; but the researcher will not identify you. Of course, your records may be subpoenaed by court order or inspected by government bodies with oversight authority.

WITHDRAWAL PRIVILAGE
It is OK for you to say NO. Even if you say YES now, you are free to say NO later, and walk away or withdraw from the study -- at any time. Your decision will not affect your relationship with Old Dominion University, or otherwise cause a loss of benefits to which you might otherwise be entitled.

COMPENSATION FOR ILLNESS AND INJURY
If you say YES, then your consent in this document does not waive any of your legal rights. However, in the event of harm, injury, or illness arising from this study, neither Old Dominion University nor the researchers are able to give you any money, insurance coverage, free medical care, or any other compensation for such injury. In the event that you suffer injury as a result of participation in any research project, you may contact the researchers, Bonnie Van Lunen at 683-3516 or Julie Whitehead at 607-624-7993, or Dr. David Swain the current IRB chair at 683-6028 at Old Dominion University, who will be glad to review the matter with you.

VOLUNTARY CONSENT
By signing this form, you are saying several things. You are saying that you have read this form or have had it read to you, that you are satisfied that you understand this form, the research study, and its risks and benefits. The researchers should have answered any questions you may have had about the research. If you have any questions later on, then the researchers should be able to answer them:

Julie Whitehead jwhit089@odu.edu
Bonnie Van Lunen bvanlune@odu.edu

If at any time you feel pressured to participate, or if you have any questions about your rights or this form, then you should call Dr. David Swain, the current IRB chair, at 757-683-6028, or the Old Dominion University Office of Research, at 757-683-3460.

And importantly, by signing below, you are telling the researcher YES, that you agree to participate in this study. The researcher should give you a copy of this form for your records.

Subject's Printed Name & Signature	Date

INVESTIGATOR'S STATEMENT
I certify that I have explained to this subject the nature and purpose of this research, including benefits, risks, costs, and any experimental procedures. I have described the rights and protections afforded to human subjects and have done nothing to pressure, coerce, or falsely entice this subject into participating. I am aware of my obligations under state and federal laws, and promise compliance. I have answered the subject's

questions and have encouraged him/her to ask additional questions at any time during the course of this study. I have witnessed the above signature(s) on this consent form.

Investigator's Printed Name & Signature	Date

VITA

Julie M. Whitehead

Department of Study

Old Dominion University
Department of ESPER
HPE Building
Norfolk, VA 2329

Education

May 2005	Master of Science in Education Old Dominion University Norfolk, VA 23529
May 2003	Bachelor of Science State University of New York at Cortland Cortland, NY

Professional Experience

8/04-12/04, 1/05-5/05

Graduate Teaching Assistant for Advanced First Aid (HE 224) and Prevention and Care of Athletic Injuries (EXSC 340), Old Dominion University. Responsibilities included assisting in the preparation of the syllabus, lectures, and oral and written examinations for undergraduate students

8/03-5/05

Graduate Assistant Athletic Trainer, Christopher Newport University. Responsible for prevention, recognition, and rehabilitation of athletic injuries and provided event and practice medical coverage for athletic teams.