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Muscle Activity in Lower Extremity during Single-Leg Squat: Role of Supination and Pronation

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Muscle Activity in Lower Extremity During Single-Leg Squat: Role of Supination and Pronation

by

Brett J Debele

A Scholarly Project Submitted to the Graduate Faculty of the
Department of Physical Therapy
School of Medicine
University of North Dakota

in partial fulfillment of the requirements for the degree of

Doctor of Physical Therapy

Grand Forks, North Dakota
May, 2011
This Scholarly Project, submitted by Brett J Debele in partial fulfillment of the requirements for the Degree of Doctor of Physical Therapy from the University of North Dakota, has been read by the Advisor and Chairperson of Physical Therapy under whom the work has been done and is hereby approved.

______________________________
(Graduate School Advisor)

______________________________
(Chairperson, Physical Therapy)
PERMISSION

Title                         Muscle Activity in Lower Extremity During Single-Leg Squat: Role of Supination and Pronation

Department                  Physical Therapy

Degree                       Doctor of Physical Therapy

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Date                           __________________________
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ABSTRACT

Introduction: Literature has consistently reported a high prevalence of ACL injury rates. A correlation between excessive subtalar joint pronation and ACL injury rates has been noted but research into plausible reasons for this relationship is limited. The purpose of this study was to establish potential cause-and-effect relationships between foot position and ACL injury risk. This study used single leg squats with simulated foot positions and examined resulting knee joint forces from motion and lower extremity muscle activation patterns that may cause ACL injury risk.

Methods: This study recruited male and female participants aged 18 to 30 from campus at the University of North Dakota. Subjects performed single-leg-squats with simulated foot positions using varying degrees of inclination while EMG electrodes recorded muscle activity and reflective markers tracked motion. ANOVA tests were run to compare individual muscle activity between subjects with identical foot positions as well as to compare identical foot positions and resulting gross muscle activity between subjects.

Results: This study was unable to produce significant results regarding differences in muscle activation patterns as a function of foot position. Significance of differences among subjects’ individual muscle activity with varying foot positions ranged from p = .299 to .749 (alpha = .05). Significance of difference between subjects’ gross muscle activity as a function of varying foot positions ranged from p = .462 to .992 (alpha = .05).
Discussion: This study had excessive variance between subjects due to number of participants and should be continued in an attempt to identify significant results unattainable to this point. Significant results could describe causative factors for the correlation between excessive pronation and high rates of ACL injury. Understanding these factors could be useful in the field of physical therapy to guide practicing clinicians in establishing appropriate ACL injury rehabilitation and prevention interventions.

Conclusion: No cause-and-effect relationships between foot position with resulting lower extremity muscle activation patterns and ACL injury risk could be postulated due to insignificant differences. Additional research is needed to examine the correlation between these two variables.
CHAPTER I
LITERATURE REVIEW

The anterior cruciate ligament (ACL) is reported to be one of the most commonly injured knee ligaments.\textsuperscript{1-3} ACL injuries are also particularly significant since they have been shown to be involved in 80\% of all knee ligament surgeries.\textsuperscript{1} Research consistently suggests females are more susceptible than their male counterparts to such injuries when participation is normalized.\textsuperscript{4-11} The most relevant areas of interest in regards to ACL injuries continue to focus on involvement in vigorous athletic activity. While largely source dependent, it has been estimated that female incidence is as high as four to six times greater than males playing the same landing and cutting sports.\textsuperscript{5} More specifically, it has been reported that the female-to-male incidence of ACL injury is 3.5 times greater in basketball and 2.8 times greater in soccer.\textsuperscript{7} Basketball, soccer, and volleyball have also been identified as high-risk sporting activities in regards to potential ACL disruptions.\textsuperscript{6, 7-9, 12-13} Regardless of sporting activity, noncontact mechanisms continue to be most often identified when detailing these injuries and appear to account for 70\% to 80\% of all reported cases.\textsuperscript{5, 13-21}

The ACL arises from the anterior intercondylar area of the tibia, just posterior to the attachment of the medial meniscus and extends superiorly, posteriorly, and laterally to attach to the posterior part of the medial side of the lateral condyle of the femur.\textsuperscript{22} This course allows the ACL to resist posterior displacement of the femur on the tibia and hyperextension of the knee joint.\textsuperscript{22} Along with this primary function, due to its anatomical positioning, the ACL also assists in preventing medial and lateral rotation of the knee as well as excessive genu valgum moments.\textsuperscript{22}
It is important for clinicians and researchers to gain a better understanding of excessive knee joint forces leading to ACL integrity compromise. By understanding its structure and purpose, qualified individuals can subsequently identify when the ACL will be excessively stressed and thus susceptible to injury. Prospectively, a more complete understanding of the cause of these forces will allow clinicians to develop preventative intervention strategies to most effectively decrease the prevalence of such injuries as well as maximize effectiveness of rehabilitation after an injury has occurred.

Due to high prevalence, much research has been conducted in an attempt to better understand the variables that may give rise to ACL injury susceptibility. Along these lines, some research focuses on comparing male and female characteristics as they relate to the ACL due to the established gender discrepancy of incidence. Research has lead to numerous suggested reasons and risk factors to describe the inherent vulnerability of the ACL. Broadly, suggested reasons appear to center around static postural malalignments, lower extremity (LE) musculoskeletal strength, and neuromuscular control. Additionally, risk factors are primarily grouped into a few general categories: environmental, anatomical, hormonal, biomechanical, and neuromuscular.

Lower extremity musculoskeletal strength factors primarily involve decreased strength/endurance and abnormal hamstring:quadriceps strength imbalances. Hormonal influences can be used in an attempt to describe variations between genders, as it has been shown that there is a definite relationship between greater ACL laxity and surging levels of estrogen and progesterone during a normal female menstrual cycle. Anatomical risk factors center around LE alignment issues and range from pelvis width/Q-angle and positioning to knee joint
positioning to tibial rotation to foot/ankle make-up. Simple physiological laxity is also a male/female variable often identified when regarding ACL injury.

Biomechanical risk factors primarily involve LE make-up and resultant joint motions and forces caused by quick stopping, planting/cutting, and landing activity. Additionally, research regarding the efficacy of LE orthoses as a means to counteract these abnormal joint forces has been conducted with variable results. Specific to this study, research has indicated that both the period of pronation and the amount of maximum pronation can be significantly reduced by using a foot orthotic device, but other research found orthotic effects on eversion and tibial rotations to be small and unsystematic over subjects. Excessive hamstring tightness has also been used to describe ACL injury susceptibility due to resultant alterations in forces at the knee because of abnormal joint mechanics. Extensive biomechanical risk factor research has also identified the stresses placed on the ACL with knee kinetics during landing to be especially relevant as this is a time during which the ACL is exposed to large amounts of force and is subsequently vulnerable to injury. Along these same lines, excessive knee valgus moments during activity have also been identified through motion analysis studies as a primary cause of ACL injury with much research performed in this area. When considering that females inherently are more likely to experience greater valgus force at the knee during athletic-type maneuvers (squatting, running, cutting, jumping, landing, etc), one can attempt to explain gender discrepancies in incidence of ACL injury. Single-leg squat activity is sometimes used as an effective means to simulate jumping and landing activity in a more controlled, less stressful manner. Studies tend to concentrate on joint motion analysis, and at times combine it with muscle activity analysis in an attempt to integrate findings in a holistic manner. However, up to this point, no similar studies have been performed to
include alterations in foot position in order to examine the resultant effect on LE joint motion or muscular activation patterns.

Neuromuscular risk factors for ACL injuries are generally discussed relative to male and female comparisons. This is done in an attempt to describe possible causation factors, as injury incidence is noticeably skewed. Female neuromuscular risk factors tend to center around quadriceps reliance, variable hamstring activation characteristics, and utilized ankle strategies. Male to female discrepancies in hip muscle activity have also been linked to ACL injury.

Currently, studies are successfully demonstrating the effectiveness of neuromuscular training programs as a means of decreasing the incidence of ACL injury (especially in the female athlete). Preventative intervention strategies including plyometric power, biomechanics and technique, strength, balance, and core stability training can induce neuromuscular changes and potential injury prevention effects. Knowing this, it is logical to assume that continuing to gain a more complete understanding of the neuromuscular influences at the knee joint will allow informed clinicians to develop more thorough intervention strategies in an effort to continue lowering the incidence of ACL injury.

Adjacent joints have been examined in an attempt to localize the proper sources that lead to such a high prevalence of ACL injuries. The hip joint generally receives more attention as a possible origin of risk factors as compared to the ankle. However, kinematic differences at the ankle have been identified as possible contributors to gender differences in ACL injury rates. More importantly, excessive subtalar joint pronation has been reported to be associated with ACL injury as early as 1992, and this finding has been reproduced on numerous occasions since that point. Unfortunately, the bases of these findings continue to primarily be
correlation with limited attempts to identify a describable relationship. It has been concluded that further investigation into possible preloading stresses on knee ligaments needs to be performed in an attempt to better explain why hyperpronation of the foot and ankle complex may increase the risk of injury to the ACL.\textsuperscript{14} Many previous studies identify excessive pronation, most often by navicular drop assessments, which have been found to be moderately reliable, and can correlate that measure with increased incidence of ACL risk.\textsuperscript{57} Additional studies have also demonstrated greater degrees of ankle pronation in females as compared to male counterparts, a consistent finding with respect to the identified variable correlation and incidence rates indicating ACL injury discrepancies across genders.\textsuperscript{7, 29, 45} In more related research, excessive ankle eversion (one component of ankle pronation) has been linked to increased valgus stress and anterior tibial translation, both of which have been shown to place excessive load on the ACL and thus increase risk of injury.\textsuperscript{29} In studies that do examine electromyographic activation around the ankle in subjects with pronated feet, results are not well correlated to ACL injury factors.\textsuperscript{58} It is also worth noting at this time that some studies have failed to associate subtalar joint position with ACL injuries in high-risk sports.\textsuperscript{8}

Due to extensive correlation and limited causation studies, it is necessary for additional research to focus on examining force characteristics around the knee and how they change with variable foot positioning. A greater understanding of these forces may enable proper identification of how they could potentially impact the ACL. The purpose of this study is to obtain supplemental understanding regarding the relationship between foot position and LE muscle activity during athletic maneuvers. It will combine anatomical, biomechanical, and neuromuscular elements in an attempt to fully investigate the potential role of foot position in ACL injuries. This study’s aim is to expand upon correlation findings between foot position and
ACL injury by attempting to describe plausible causation factors as they relate to these findings. Lower extremity electromyography (EMG) activity was examined in subjects while performing a single-leg squat with a variety of ankle positions. This assessment will assist in determining if muscle activity and the resultant knee forces experienced dependent upon altering ankle positions can indeed influence risk of ACL injury due to abnormal biomechanics and subsequent excessive ligament stress. The ankle positions under study in this research project were varying simulated positions of subtalar joint pronation (defined as a combination of eversion, abduction, and dorsiflexion movements of the foot and ankle) and subtalar joint supination (defined as combination of inversion, adduction, and plantar flexion movements of the foot and ankle). Positions designed to simulate subtalar supination and pronation were induced by one foot placement in appropriate orientation on a wedge of 5 or 10 degrees of inclination.

Subtalar joint “normal” is generally defined in a dynamic nature based on positioning during typical gait patterns (as opposed to a resting position). The subtalar joint is inverted (primary component of supination) approximately 2 to 3 degrees at the time of heel contact and immediately undergoes rapid eversion (primary component of pronation) reaching a maximal position of approximately 2 degrees at midstance. However, the talonavicuar joint provides substantial mobility to the medial (longitudinal) column of the foot with much of this mobility expressed in inverting and everting moments. Research involving simulated foot positions using inclined platforms (replicated supination and pronation) has shown that after calculating resulting joint deviations from the neutral position the largest amounts of motion occurred in the talonavicuar joint. Additionally, leg rotation can play a role in inversion and eversion moments, as research has shown that external rotation of the leg can induce motion mainly in the talonavicuar joint. Given all of these considerations, with the greatest emphasis on the
predominance of the talonavicular joint in regards to inversion and eversion, in combination with altered LE mechanics with running (as compared to walking), it has been measured that total calcaneal eversion relative to the tibia can reach upwards of 11 degrees (noting argument of overestimation due to marker placement recording midfoot eversion rather than pure heel eversion). While actual degrees of measurement for foot positioning were not taken in this study, it is assumed based on intensity of wedge inclination that simulated foot positions exceed “neutral” positioning and accurately replicate the extensive joint movements that occur during high intensity activity such as running.

This study attempted to more accurately define the relationship between foot positioning and resultant muscular forces at the knee. By interpreting the balance between these forces, an improved understanding can be reached regarding increasing and decreasing risk of ACL injuries based on foot positioning. In an effort to achieve this goal, this study pursued answers to the following questions: Does LE muscle activity change during single leg squats with varying ankle positions? And if so, could the changes influence degree of risk for ACL injury due to variably exposed forces at the knee?
CHAPTER II

METHODS

This study was approved by the University of North Dakota (UND) Institutional Review Board (#IRB-201004-316). Research subjects were volunteers recruited to participate by word-of-mouth advertising within the UND Physical Therapy Department from June 2010 to July 2010. All subsequent research volunteers were first and second year physical therapy students. The sole inclusion criterion was that subjects were between the ages of 18 and 30 years old. Exclusion criteria included subjects with recent lower extremity injury and those who were pregnant. Subjects with prior knee injury or surgery were noted to allow comparison between injured and uninjured extremities.

Upon admittance to the study, subjects reported to the Physical Therapy Department in the UND School of Medicine. Prior to participation, all subjects were required to complete an informed consent form as well as an intake survey (lower extremity injury and/or surgical history, gender, and if applicable pregnant and date of last menstrual cycle). Subjects’ height, weight, and leg length were also measured and recorded. Research indicates that when limited to a noncontact injury mechanism, females are more likely to injure the ACL in their supporting leg, whereas males tend to injure their kicking leg.\textsuperscript{64} Due to discrepancies, for the purpose of this study, subjects’ dominant leg was defined as the leg spontaneously stood on when requested to kick a ball. This election of dominance (LE spontaneously chosen for support during a kick) was selected because of extremity performance of the same action (support) as during when ACL injuries tend to occur in landing and cutting activities. Following identification, the dominant leg
was prepped for electrode placement. Prior to placement, excess hair was removed from areas of interest, the skin was lightly abraded using 400 grain sandpaper, and the entire area was wiped with rubbing alcohol. Disposable silver/silver chloride surface electrodes were placed in a bipolar configuration over the gluteus maximus, gluteus medius, rectus femoris, biceps femoris, tibialis anterior, and lateral gastrocnemius with a ground electrode over the head of the fibula. A standard interelectrode distance of 1 cm was used. Electrode placement was determined by using standard surface electromyography (EMG) charts by Cram and Kasman. Following electrode placement, skin impedance was assessed using a Noraxon impedance analyzer (Noraxon, Scottsdale, AZ) and was found to be under 10 kOhm at all sites. Finally, electrodes were connected by lead wires to a Telemyo 900 transmitter (Noraxon) which was attached near the subject’s waist. Eventual EMG signals were transmitted to the Telemyo 900 receiver and stored on a laptop computer (Hewlett-Packard Company, Palo Alto, CA).

Subjects were also outfitted with self-adhesive, retroreflective markers for motion analysis prior to performing any activity. Markers were placed bilaterally in a Helen Hayes marker configuration. Briefly, markers were placed bilaterally over the subject’s acromion, lateral epicondyle of the elbow, distal radius and ulna, back of the hand, anterior superior iliac spine, posterior superior iliac spine, greater trochanter, lateral femoral condyle, medial and lateral malleoli, and 2nd metatarsal head.

Prior to subject activity, the Vicon motion analysis system with eight Vicon MX40 cameras (Vicon Motion Systems Inc, Centennial, CO) was configured to obtain optimal data capture within testing parameters. Cameras were interfaced with the Vicon MXNet (Vicon) component for data collecting and eventual motion was stored on a desktop computer (Dell Inc, Round Rock, TX).
Once fully prepped, subjects were placed barefoot (with sanitary sheets covering all areas of foot contact) in the test field quarters. Activities of interest were then performed with data collection. Subjects were instructed to perform a single-leg squat (SLS) to a comfortable (avoiding excessive loss of balance) depth of approximately 50 to 60 degrees of knee flexion (example provided by researchers upon subject request). Subjects were given an opportunity to practice the described activity prior to data recording with researchers providing corrective cueing as necessary. Upon demonstrated competency, subjects were instructed to perform 3 SLSs with a standard foot position (on level ground). Since no maximal voluntary contraction (MVC) was officially established for monitored muscle groups in this study, selected SLSs in this level ground position represented the standard EMG measure against which the simulated testing positions were compared. During initial and subsequent squatting, subjects were instructed to perform activity at a consistent 2-second per cycle pace (down in 1 second and back up in 1 second) as guided by a metronome. Motion analysis data was collected at a rate of 100 frames per second and EMG activity was collected at 1500 Hz, each by previously described equipment.

Following completion of the standard SLS phase, subjects performed SLSs in a similar fashion with 4 varying foot positions. Using wooden wedges of varying degrees of inclination, 10 and 5 degrees of both ankle supination (lateral to medial incline) and pronation (medial to lateral incline) were simulated while subjects performed 3 SLSs in each of these positions. The order in which these altered foot position squats was performed was randomized. Motion analysis and EMG activity data continued to be collected in all 4 positions (to be compared to initial, standard position data).
Upon successful completion of SLS series in all 5 positions, subjects were assisted in removing all surface electrodes and videoanalysis markers and were provided with towels to wipe away any self-adhesive gel that may have remained. At this time, subjects were released from the study.

Motion analysis data was then processed using the Nexus 2.1 core processing software (Vicon). Stored EMG data was interpreted using Noraxon MyoResearchXP software (Noraxon). Raw EMG data was rectified, smoothed, and normalized for ease of interpretation. Subsequent EMG data analysis was done using SPSS version 17 software (SPSS Inc an IBM company, Chicago, IL).
CHAPTER III

RESULTS

Six subjects (3 female, 3 male) with a mean age of 23.83 ± 2.14 years old (22 – 28) participated in this study. Subjects’ mean height: 171.33 ± 7.99 cm (161 – 184), and weight: 71.13 ± 11.82 kg (56 – 85.6).

The following represents EMG analysis results. Group mean EMG activity (based on individual mean activity throughout selected SLS recorded as % MVC) for all examined muscles was determined relative to foot position (see Table 1). Multiple between-subjects, univariate analysis of variance (ANOVA) tests were conducted to compare significant differences in mean individual muscle activity (dependent variable) as a function of foot position (independent variable) (see Table 2). No significant differences (NSDs) were found for any of the six examined muscles when tested with respect to the five varying foot postitions: tibialis anterior p = .415, lateral gastrocnemius p = .749, rectus femoris p = .385, biceps femoris p = .498, gluteus medius p = .587, gluteus maximus p = .299 (for all tests selected alpha = .05). Since NSDs were found collectively for any of the muscles, no post-hoc analysis to determine degree of individual differences between specific positions and muscle activity was pursued.

Multiple between-subjects, univariate ANOVA tests were also conducted to compare significance of differences in collective muscle activity based on foot position (see Table 3). NSDs between muscles were found for any of the research simulated foot positions: supination 5 p = .874, supination 10 p = .992, pronation 5 p = .462, pronation 10 p = .793 (for all tests selected alpha = .05).
Table 1: Group Mean EMG Activity for 6 Muscles Relative to 5 Foot Positions

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Foot position</th>
<th>Mean EMG (% MVC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tibialis anterior</td>
<td>Standard/neutral</td>
<td>74.7</td>
</tr>
<tr>
<td></td>
<td>Supination 5</td>
<td>78.5</td>
</tr>
<tr>
<td></td>
<td>Supination 10</td>
<td>92.5</td>
</tr>
<tr>
<td></td>
<td>Pronation 5</td>
<td>67.6</td>
</tr>
<tr>
<td></td>
<td>Pronation 10</td>
<td>71.9</td>
</tr>
<tr>
<td>Lateral gastrocnemius</td>
<td>Standard/neutral</td>
<td>84.6</td>
</tr>
<tr>
<td></td>
<td>Supination 5</td>
<td>90.7</td>
</tr>
<tr>
<td></td>
<td>Supination 10</td>
<td>89.0</td>
</tr>
<tr>
<td></td>
<td>Pronation 5</td>
<td>105.5</td>
</tr>
<tr>
<td></td>
<td>Pronation 10</td>
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<tr>
<td>Rectus femoris</td>
<td>Standard/neutral</td>
<td>75.2</td>
</tr>
<tr>
<td></td>
<td>Supination 5</td>
<td>99.7</td>
</tr>
<tr>
<td></td>
<td>Supination 10</td>
<td>85.0</td>
</tr>
<tr>
<td></td>
<td>Pronation 5</td>
<td>95.2</td>
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<tr>
<td></td>
<td>Pronation 10</td>
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<tr>
<td>Biceps femoris</td>
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<td>84.5</td>
</tr>
<tr>
<td></td>
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<td></td>
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<tr>
<td></td>
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<td></td>
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<tr>
<td>Gluteus medius</td>
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<td></td>
<td>Supination 5</td>
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<td></td>
<td>Supination 10</td>
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<td></td>
<td>Pronation 5</td>
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<td></td>
<td>Pronation 10</td>
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<tr>
<td>Gluteus maximus</td>
<td>Standard/neutral</td>
<td>72.8</td>
</tr>
<tr>
<td></td>
<td>Supination 5</td>
<td>89.9</td>
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<tr>
<td></td>
<td>Supination 10</td>
<td>86.4</td>
</tr>
<tr>
<td></td>
<td>Pronation 5</td>
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</tr>
<tr>
<td></td>
<td>Pronation 10</td>
<td>81.1</td>
</tr>
</tbody>
</table>

* based on individual mean activity throughout selected SLS
Table 2: Significance of Mean Muscle EMG Differences as Function of Foot Position (ANOVA – Between-Subjects Effects)

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tibialis anterior</td>
<td>.415</td>
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<td>Lateral gastrocnemius</td>
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<td>.587</td>
</tr>
<tr>
<td>Gluteus maximus</td>
<td>.299</td>
</tr>
</tbody>
</table>

* computed using alpha = .05

Table 3: Significance of Differences Between Examined Muscles’ EMG Activity During Simulated Foot Positions (ANOVA – Between-Subjects Effects)

<table>
<thead>
<tr>
<th>Foot position</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supination 5</td>
<td>.874</td>
</tr>
<tr>
<td>Supination 10</td>
<td>.992</td>
</tr>
<tr>
<td>Pronation 5</td>
<td>.462</td>
</tr>
<tr>
<td>Pronation 10</td>
<td>.793</td>
</tr>
</tbody>
</table>

*computed using alpha = .05
CHAPTER IV

DISCUSSION

This research project, while incomplete in nature, has not yet been able to successfully identify any significant changes in muscle activation patterns dependent on varying simulated foot positions. Researchers continue to believe that additional effort should be put into this study based on the potential identified by background literature (primarily the excessive pronation increased risk of ACL injury correlation that has been under examined in regards to tracking actual muscle activity).

At this time, the major shortcoming of this study is excessive variance in EMG activity between subjects. Most likely, this problem is primarily the result of testing too few subjects and may be alleviated to some degree by continuing to run more trials with different subjects and integrating the new data.67

This study could also likely benefit from some modifications during future trials. Depth regulation of the SLS was not well monitored in this study. Only subjective instructions such as “to a comfortable level” or “to approximately fifty to sixty degrees” (which may or may not mean much to student research subjects) were provided to participants. Researchers would provide appropriate feedback and necessary cueing if depth of squat was clearly inadequate, but no objective measurements were taken. While some studies indicate high levels of accuracy for a clinicians ability to “eyeball” joint range of motion,68-70 other studies suggest visual estimates of knee motion add more error to measurements than when taken with a goniometer.71 Therefore, it may be unreasonable to assume that student research subjects would be able to accurately assess
depth of a SLS (a highly dynamic activity) with no outside cueing and that researchers observing from afar would be able to recognize excessive discrepancies requiring extrinsic feedback. Resultant variations in squat depth could very well account for some variance in EMG activity. Varying depth may require different muscle groups to work harder, or not as hard, in order to overcome the forces they are counteracting (in this case gravitational forces related to body position). This discrepancy in work load will cause variable recruitment patterns of local motor units. Subsequently, surface EMG activity will be altered because the source of signal is the motor unit action potentials. In future studies, standardization of squat depth using an adjustable chair (set based on goniometric measurements for depth of knee bend by each particular subject) may be a beneficial attempt to further minimize between-subject variance.

This study may also benefit in the future from attempting to identify participants’ current and/or past level of athletic activity. In this study, all participants have been physical therapy students, and the primary recruitment pool includes students in medical-related fields. While one may make the assumption that individuals such as these have a relatively high tendency/likelihood to have a present or past athletic background and thus gravitate towards such fields, this can not be fully verified without further questioning. Since the problem with ACL injury is primarily addressed with athletes (with the greatest proportion being highly intensive), knowing participant level of athletic activity may be beneficial in generalizing study results to the more highly-active, athletic population. Future research participants could be asked to complete a subjective questionnaire asking about current level of athletic activity (sports involvement, training, etc). A simple ordinal scale could then be established to rate “level of athletic activity” which could potentially be used as another paired variable when analyzing study results. However, as performed, if variable muscle activation based on foot position is a
relevant factor in ACL injury risk, it is hoped that it will be identifiable to some degree across a wide spectrum of individuals (from non-athletic to highly athletic) and thus results may be generalized to a large population.

As currently conducted, tibialis anterior EMG activity was highly erratic (mean measurements by foot position ranging from 67.6 – 92.5, demonstrating a greater range than all other muscles recorded). This may be due to balance requirements, and potential deficits, of the given task faced by participants not used to simulated foot positions. Initial postural adjustment strategies are highly reliant upon primary ankle dorsiflexors and plantarflexors (lateral gastrocnemius also showed large mean range between positions, 84.6 – 105.5). Through analysis, researchers attempted to analyze SLS trials in which balance problems were minimized but did not have a highly accurate method of doing so. Even though no significant differences were found for tibialis anterior or lateral gastrocnemius EMG activity as a function of foot position, additional effort could have been given to limiting confounding variables related to their activation patterns (anything not dependent upon subtalar joint positioning). In the future, researchers may want to consider providing additional “practice time” for subjects (beyond the three allotted practice repetitions) to increase task proficiency in an attempt to minimize effects of poor balance on EMG outcomes. Another option would be to provide a support structure that subjects could grasp onto for increased stabilization.

While this study has thus far been unable to produce any significant results, some very basic patterns can be identified that may be worth paying attention to with future research (although at this time not yet a statistical trend). In general, rectus femoris group mean EMG activity increased from the standard/neutral position to the pronation 10 position (74.7% MVC to 81.5% MVC) and biceps femoris group mean EMG activity decreased from the standard/neutral
position to the pronation 10 position (84.5% MVC to 78.2% MVC). These tendencies, while insignificant at this point, are consistent with some previous theories. Excessive pronation appears to correlate with increased risk of ACL injury and neuromuscular theories of ACL injury risk have identified quadriceps:hamstring activation ratios to play a role in injury risk (increased risk involves greater quadriceps activity and less hamstring activity, thus increasing anterior tibial shear force on the femur and subsequently stressing the ACL). This comparative muscle activation discrepancy continues to be a dominant theory relevant to ACL injury risk despite some research indicating women produce significantly greater EMG peak amplitude of the lateral hamstring muscle when landing as a compensatory method for increased knee joint laxity. When integrating the two previously stated primary independent theories (excessive pronation and quadriceps dominance) and considering result tendencies of this study, some very early cause and effect factors begin to arise that will to worth monitoring (noting changes in significance with additional subjects) as this study continues in the future (although findings are also inconsistent on a continuum at this time as pronation 5 does not reveal progressive tendencies). Along with this, researchers may also want to consider closely monitoring hip muscle activity (even though no significance or identifiable trends stand out at this time) as a factor of foot position. Males are at less risk of ACL injury and seem to rely on hip musculature for stability to a greater degree as compared to females. This is another neuromuscular theory of ACL risk that could potentially be tied to the correlational effect of foot position to formulate a cause and effect relationship.

Had significant results been obtained during this study, or if they are found in subsequent research, they can be used to individualize treatment intervention for ACL injury that has previously been shown to be effective. For example, as previously highlighted, if desired
quadriceps and hamstring activation is found to be distorted as a function of foot position, plyometric training with quadriceps biofeedback could be utilized in an attempt to increase muscle activity and thus decrease injury risk. Biofeedback training has been successfully used in an attempt to treat other theoretically similar dysfunctions regarding inappropriate muscle activation timing during dynamic physical activity. In addition to the neuromuscular plyometric training, local proprioceptive training could be integrated into treatment intervention. It has been shown that women demonstrate a significantly longer time to detect the knee joint motion moving into extension and further postulated that excessive joint laxity of women appears to contribute to diminished joint proprioception. This research suggests an alternative possibility to explain diminished hamstring activation in women during athletic activity. Additionally, including proprioceptive training in intervention strategies has been shown to be effective in decreasing the number of ACL injuries. This is just one of many possibilities regarding the use of neuromuscular training programs that could be designed and specially tailored for individuals with identifiable risk factors based on predisposing conditions if this study’s hypothesis that foot position is directly related to injury risk due to resultant muscular activity/forces is ever confirmed.

As the current study continues and is potentially expanded, any noted trends/patterns that begin to appear with future research could potentially be very important to the field of physical therapy. Cause and effect findings that can tie foot position to established theories of ACL injury risk could have a big impact on both preventative interventions as well as rehabilitation protocols to reduce the risk of initial injury or reinjury. As specifically described above, by relating foot position to the actual neuromuscular and joint force changes that occur, practicing clinicians will have a better idea of how to treat individuals with such predisposing conditions.
training and strengthening intervention strategies can be set up to specifically address the identified problem. This should build upon the positive outcomes previously shown for preventative and rehabilitation therapy and lead to improved clinical results.\textsuperscript{51-54} In addition to physical intervention strategies, the importance of corrective orthotics as a means of therapeutic intervention could be highlighted if when continued this study is able to produce significant results. By better defining the resultant force abnormalities (excesses) present regardless of specific cause, the theory for use of corrective orthotics will be better defined as a means to offset or minimize some of those destructive forces and thus decrease the likelihood of injury.
CHAPTER V

CONCLUSION

Despite literature-established correlations between excessive foot pronation and ACL injury risk, this study was unable to establish any causative factors when examining LE EMG activity during SLSs with varying foot positions. No significant differences were noted when analyzing EMG activity in six LE muscles as a function of five varying foot positions. With inconclusive evidence regarding variations of muscle activation with respect to simulated foot positions, no formal identification of excessive muscular-based forces leading to ACL stress and possible strain could be made. This shortcoming made it impossible to postulate any cause and effect relationships between foot position and ACL injury risk with respect to LE muscle activity.

This study had many limitations, with the most notable being excessive variance due to too few subjects. Further future research on this topic should be conducted in an effort to establish more consistent findings before abandoning the possibility of producing significant results. Any additional research resulting in discovery of significant findings should be directed towards an appropriate population and be subsequently used to formulate appropriate ACL injury prevention and rehabilitation interventions.
REFERENCES


