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HAMSTRING MUSCLE ACTIVATION DIFFERENCES BETWEEN GENDER WHILE PERFORMING SINGLE LEG LANDINGS

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HAMSTRING MUSCLE ACTIVATION DIFFERENCES BETWEEN GENDER WHILE PERFORMING SINGLE LEG LANDINGS

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ABSTRACT

HAMSTRING MUSCLE ACTIVATION DIFFERENCES BETWEEN GENDER WHILE PERFORMING SINGLE LEG LANDINGS

By

Matthew K. D. Lewis

Females incur a disproportionate rate of non-contact type ACL injuries when compared to their male counterparts. Lower extremity neuromuscular mechanisms may be responsible for these injuries. Female athletes have been shown to land with greater dynamic knee valgus during sporting activities. Hamstring activity during dynamic movements may lead to posturing detrimental to ACL integrity. The purpose of this study was to examine the activation patterns of the hamstring musculature between genders when performing single leg landings from an elevated position. Twenty recreationally active college aged subjects (10 male and 10 female) performed three repetitions of a single leg drop landing procedure onto each leg (a total of six trials). Surface electromyographic data were collected from the medial and lateral hamstring musculature of each subject's involved lower extremity upon landing to measure mean IEMG (Integrated Electromyography), peak IEMG, and time-to-peak IEMG. A single force platform was synchronized with the EMG signal to indicate initial foot contact with the ground. Repeated Measures ANOVA indicated there were no main effects for gender, side, or muscle for any of the dependent variables ($p > 0.05$). The results of this study suggest that for the muscles studied, males and females possess similar neuromuscular activation strategies when landing from a jump. It appears that muscle activation is not a contributor to the ACL injury rate disparity.

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LIST OF ABBREVIATIONS

ACL	Anterior Cruciate Ligament
EMG	Electromyography
IEMG	Integrated Electromyography
Q-Angle	Quadriceps Angle
sEMG	Surface electromyography
r^2	Coefficient of Determination
Hz	Hertz
kΩ	Kilo ohms
cm	Centimeter
MVC	Maximal Voluntary Contraction
ANOVA	Analysis of Variance

CHAPTER I

LITERATURE REVIEW

Anterior cruciate ligament (ACL) injury is a catastrophic orthopedic injury. Within the United States, it is estimated that 100,000 ACL injuries occur annually.[1] This may represent a significant threat to the health care system as conservative estimates of health care costs for each injury may approach $17,000.[2] The long term effects of a knee injury results in a 10 fold greater propensity to develop osteoarthritis in the involved knee.[3] Orthopedic injuries have also been related to increased anger, tension and symptoms of depression, secondary to the physical limitations that result from them. Freedman et al.[4] observed that undergraduate university students with an ACL injury suffered a significant decline in academic performance compared to non-injured students. In addition, student athletes who incur injury to the ACL may be threatened with potential loss of playing time, and scholarship.

It is well established that non-contact ACL injury rates among female athletes are considerably greater than that of their male counterparts. The literature indicates that females are 2 – 10 times more likely to incur an ACL injury compared to males.[5, 6, 7] Approximately 70% of all ACL injuries are of the non-contact type, with “contact” being described by Olsen et al.[8] as a “direct blow to the knee”.

The purpose of this Literature Review is to summarize the evidence explaining how female anterior cruciate ligament injuries are occurring at a disproportionate rate relative to males. The literature suggests both extrinsic and intrinsic mechanisms with the final consensus being that the cause for an increased rate of ACL injury in females is multifactorial. This review will be directed toward the intrinsic mechanisms associated with ACL injury risk and how they contribute to the unequal injury rate in females. In addition to the knee, the hip and ankle will also be examined to determine any additional contributing factors. While it is recognized that hormonal influence may be an underlying cause to the injury rate discrepancy between genders, this review will focus on the areas mentioned above.

Anatomical Comparisons between the Genders

Females may be at an anatomical predisposition to ACL injury when compared to males. The literature suggests anatomical risk factors that may differentiate men from women including quadriceps-angle (Q-angle) and intercondylar notch differences. Several studies have investigated the size of the femoral intercondylar notch between males and females. Some have hypothesized that the intercondylar notch is related to the size of the ACL; therefore, a small notch will yield a smaller ACL. Dienst et al.[9] revealed a significant correlation between ACL cross sectional area and notch width. If an individual possesses a small ACL it is believed that it will be unable to attenuate loads effectively, eventually leading to failure. However, a cadaver study measured the intercondylar notch width and found no significant difference between genders.[10]

Shelbourne et al.[11] and Anderson et al.[12] similarly did not find a difference between male and female intercondylar notch width, however did find that differences existed between gender and ACL size. Anderson et al.[12] hypothesized that the size of the ACL is directly related to the strength of its antagonist, the quadriceps. While the hamstring musculature acts synergistically with the ACL to prevent anterior tibial translation on the femur, the quadriceps muscles place an anteriorly directed force on the tibia, stressing the ACL.[13] Females in this study were found to have weaker quadriceps and smaller ACL cross-sectional areas in comparison to males.

Myer et al.[14] studied quadriceps and hamstring isokinetic strength among men and women athletes. The authors followed these subjects for a period of 2 years, and found that females who subsequently went on to injure their ACL demonstrated similar comparative quadriceps strength with a male control group. These women also showed decreased hamstring strength when compared with the male control group. The females who did not incur an ACL injury exhibited decreased quadriceps strength and comparative hamstring strength to their male counterparts. These findings suggest women with quadriceps dominant leg strength may be at increased risk for ACL injury. These findings may also suggest that regardless of ACL size, the hamstring muscles may be more important to maintaining ACL integrity. During dynamic movements the ACL may be stressed by inadequate co-contraction of the quadriceps and hamstring musculature.[14] This musculature imbalance may allow the tibia to shift anteriorly in relation to the femur. Rapid deceleration, pivoting, and landing from a jump are all dynamic movements where the hamstrings and quadriceps will be responsible for stabilizing the knee joint. Acting as an agonist for the ACL, the hamstrings will provide a posteriorly directed force to the proximal tibia, assisting to protect against excessive anterior translation. Forces from the quadriceps may assist with anterior translation jeopardizing ACL integrity.

The Q-angle is measured in the coronal plane by two line segments.[13] The first extending between the anterior superior iliac spine (ASIS) to the middle of the patella, and the second extends superiorly from the tibial tubercle to the middle of the patella. Females are believed to possess a relatively wider pelvis than males, thus producing a larger Q-angle.[13] Myer et al.[15] found that Q-angle measurements were not predictive of dynamic knee valgus when an athlete was placed in a position that would simulate a high ACL injury risk movement.

In addition to demonstrating greater anterior knee joint laxity,[16] females may also show greater ligamentous laxity distally at the foot. This laxity could potentially result in the talus falling into pronation during weight bearing. Trimble et al.[17] measured several suggested postural mechanisms to ACL injury concluding that foot pronation, measured by navicular drop, was a moderate predictor of anterior tibial translation among college-age subjects.

Lower Extremity Biomechanical Comparisons between Genders

During sporting activities, the typical position thought to stress the ACL includes a combination of a planted foot, tibial rotation, and a valgus force being placed at the knee as it nears full extension.[18] Typically, this position will occur while the individual is decelerating or pivoting. The position of the knee can be influenced by the musculature as well as the levers within the kinetic chain.

Weak hip musculature may contribute to body positioning placing the ACL at increased risk for injury[19]. Female athletes may experience higher ground reaction forces compared to men when landing from a jump, as indicated by Decker et al.[20] These authors showed that their female participants demonstrated significantly less hip extensor muscle activity to absorb the forces associated with jump landing. A separate study conducted by Zazulak et al.[21] found that females exhibited reduced hip muscle activation as indicated by surface electromyography (sEMG) data from the gluteus maximus musculature during single leg landings. These findings suggest that females utilize different landing techniques when compared to their male counterparts. While males utilize their hip musculature to absorb landing forces, energy attenuation strategy differences between genders may cause females to rely primarily on their knee and ankle musculature. Potentially, this could cause an inability of the knee musculature to decelerate the body and a reliance on the secondary support structures of the knee to stabilize the joint.

Coronal plane mechanics about the lower extremity appear to place the ACL at risk for injury in females when compared to males. A cadaver study examined knee kinematics while being subjected to a simulated "aggressive" quadriceps contraction.[22] Significant anterior translation of the tibia revealed that the quadriceps, when aggressively contracted, could be responsible for non-contact ACL injuries.[22] In a separate experiment, computer modeling of the knee showed that anterior shear forces placed on the shank were attenuated by a posterior force from ground reaction upon landing.[23] This study indicated that peak ACL loads could not be explained by the eccentric action of the quadriceps during drop landings. Random muscle activity perturbations to male and female subjects upon landing were not shown to cause anterior shear forces high enough to injure the ACL in males or females during cutting maneuvers.[24] However, it was revealed that dynamic knee valgus load values were reached that could jeopardize ACL integrity during side-stepping.[24] Additionally, these valgus load values were reached with greater frequency in the female subjects. When performing medially and laterally directed single-legged landings, Ford et al.[25, 26] found gender differences in lower extremity coronal plane angular joint excursion, where females were identified as landing with greater dynamic knee valgus. In a separate study comparing male and female high school basketball players, it was determined that once again, females landed with greater total dynamic knee valgus.[27]

Decreased activation of the hip musculature may lead to non-contact ACL injury by means of altered knee positioning.[28] The gluteus medius attaches to the greater trochanter, and when activated, acts to abduct the femur in the coronal plane. During dynamic movements this muscle would act to limit excessive knee joint valgus. however, a lack of gluteus medius activation does not appear to be the mechanism responsible for knee positioning differences, as gluteus medius activation was similar in male and females, and females demonstrated significantly more knee valgus than the males.[28] Some controversy exists in this area, as hip abduction peak torque and dynamic knee valgus were significantly different between genders in a separate study conducted by Jacobs et al.[19] Females demonstrated less hip isometric abductor strength and more knee valgus when landing from a jump. This study suggests that males may possess greater hip neuromuscular control during dynamic activities when compared to females.

Dynamic knee valgus moments and angles were predictive of ACL injuries, with a coefficient of determination (r^2) value of .88 in a prospective study performed by Hewett et al.[29] In this prospective study the authors found that female athletes who later incurred an ACL injury landed with 8 degrees greater knee abduction angles when compared to the non-injured female participants. The knee abduction moments were 2.5 times greater in the injured athletes, while ground reaction forces were 20% greater and stance times were 16% shorter. Combined, this created a scenario where greater forces and motions were acting over a shorter period of time in the injured female's knees. Knee flexion angles were not found to be predictive of ACL injury in this study, suggesting that dynamic knee valgus may be the significant mechanism to injury in these athletes.

The sub-talar joint may also play a role in gender differences contributing to ACL injury. Coronal plane joint movements at the sub-talar joint may account for this.

Navicular drop scores revealed that individuals with a previous ACL injury had significantly greater sub-talar pronation than controls.[30] Female subjects show greater ankle pronation during dynamic activities.[25] This information suggests that sub-talar pronation posturing may place the knee into a valgus position, thus putting individuals at increased risk for ACL injury. How this subtalar posturing occurs is uncertain.

Internal rotation of the femur during dynamic activities may also contribute to knee valgus. Hip musculature aids in controlling this motion. Specifically, the gluteus maximus externally rotates the femur, and during dynamic activities, will function eccentrically to attenuate vertical ground reaction forces.[21] Decreased activation of the proximal stabilizing musculature, such as the gluteus maximus, may allow greater loads to be distributed to the distal joints. Significantly lower gluteus maximus muscle activation was seen in female subjects when performing single leg landings when compared to their male counterparts.[21] The diminished hip muscle activation may allow the femur to fall into internal rotation, contributing to dynamic knee valgus, and increased ACL loads.

Neuromuscular Comparisons between Genders

Females demonstrate different muscle activation strategies compared to males.[13, 15, 30, 31] During dynamic activities, such as those associated with sport performance, females display deficits in lower extremity control potentially predisposing them to a decrease in knee joint stability, and therefore an ACL injury. Heightened neuromuscular control about the kinetic chain may assist in the lower extremity being placed in an efficient and safe position for the sport movement, thus attenuating loads contributing to ACL injury.

Hamstring and quadriceps muscle activation differences exist among genders. Females display significantly greater quadriceps muscle activity and decreased hamstring co-activation compared to males when performing dynamic tasks.[30, 32] Pflum and colleagues [23] found that anterior shear forces occurring at the tibiofemoral joint could be attributed to the pull of the patellar tendon throughout landing activities, potentially placing the ACL at risk of tearing. Co-activation of the hamstrings and quadriceps compress the tibiofemoral joint due to the medial and lateral meniscus providing concavity to the tibial plateau.[13] This compression may hinder anterior translation of the tibia on the femur and protect the ACL.

Gender differences in muscle activation patterns may load the lateral tibiofemoral joint while leaving the medial joint line open, predisposing the knee to valgus positioning and risking ACL integrity.[15] Females were shown to have a decreased ratio of medial to lateral quadriceps activation compared to males when performing an activity that may place the ACL at risk.[15] In a separate study, females demonstrated a four times greater activation of their lateral hamstring compared to males.[31] Combined, these muscular activations may cause the lateral tibiofemoral joint to be compressed, leaving the medial joint line open or gapped.

Muscle Activation Timing

The onset of muscle activation differs between genders during dynamic activities.[21, 31, 33, 34, 35, 36] Recreationally active females displayed significantly greater hamstring activation just prior to landing from a vertical stop jump, when compared to males. Interestingly, females demonstrated significantly less hamstring activation than the males following contact with the ground.[33] This may place the ACL in jeopardy, as the hamstrings would not sufficiently activate to attenuate the potential tibio-femoral anterior shear forces. Cowling and Steele [34] found that males displayed delayed semi-membranosis onset when compared to females during a pre-landing phase. These males were also able to reach peak semi-membranosis activity at a faster rate than the females. These findings suggest that males may be able to activate the hamstring musculature at a faster rate, potentially producing a faster posterior tibial drawer, and protecting the ACL from injury.

Zazulak et al.[21] reported that female Division I college athletes displayed greater rectus femoris peak muscle activity during drop landing pre-contact when compared to their male counterparts. The increased rectus femoris activation may place greater stress on the ACL via anterior tibio-femoral shear forces. These authors also found that females displayed decreased gluteus maximus peak activation subsequent to landing. This diminished hip extensor activation may place greater load attenuating demands upon the rectus femoris, furthering the potential anterior shear forces on the knee during landing.

Conclusions

Anterior cruciate ligament injuries are most likely the result of many factors acting independently or in any number of combinations. The anatomical differences between men and women discussed in this review have been suggested to contribute to the ACL injury rate disparity between genders; however, the evidence evaluated here does not entirely support these claims. Regardless of an anatomical contribution to ACL injury, these factors are innate in nature, and are not modifiable. Even if an anatomical predisposition to ACL injury was recognized across the genders, it would be difficult to simply keep those at risk from participating in sport activities.

Landing postures during dynamic activities between the genders have been attributed to biomechanical and neuromuscular differences. The entire kinetic chain must be observed when analyzing knee kinematics leading to ACL injury risk positions. Females who exhibit dangerous landing postures may potentially be identified early allowing measures to be taken preventing reoccurrence of these joint positions.

CHAPTER II

HAMSTRING MUSCLE ACTIVATION DIFFERENCES BETWEEN GENDER WHILE PERFORMING SINGLE LEG LANDINGS

(Submitted for publication to the Journal of Athletic Training)

Introduction

Anterior cruciate ligament (ACL) rupture is reaching epidemic proportions in female athletes. The results of these injuries are immediate and long-term health consequences, as well as placing a significant financial burden on the health care system. Female athletes engaged in high risk sports, such as basketball, soccer, and volleyball are 4-6 times more likely to suffer a non-contact ACL injury compared to their male counterparts.[6] Hewett et al. theorizes that more than 2200 collegiate female athletes will suffer an anterior cruciate ligament injury each year, and that the total health care costs associated with these injuries may amount to over 37 million dollars.[2]

Regardless of the method of treatment, ACL rupture results in a 10 times greater risk of knee osteoarthritis.[3] Although a variety of theories have been suggested in the literature, there is no known mechanism that solely explains the disproportional ACL injury rate between the genders. Previously investigated causes include: anatomical differences between genders, diminished ACL strength secondary to female hormones, and neuromuscular imbalances between the sexes.[15] Although there are many possible etiologies it is likely that this problem is due to a combination of factors.

The most commonly reported mechanism of injury for ACL sprains in high school females is of the non-contact type. Many female basketball and soccer players at the high school level reported that their injuries occurred while performing some form of jumping/landing activity.[27] Inadequate neuromuscular control may lead to poor lower extremity positioning and therefore compromise knee joint stability, thereby increasing the risk of ACL strain. In a recent study, Hewett et al.[6] concluded that measures of dynamic knee valgus predicted non-contact ACL injury risk in female athletes with an accuracy approaching 90%. This is of particular interest considering females demonstrate greater dynamic knee valgus;[3, 22, 30, 37] and tibial external rotation when landing from a jump than males.[6]

Muscle activation patterns at initial ground contact when landing from a jump may prove vital to understanding the cause of dynamic knee valgus and subsequently knee joint stability. Compression of the tibio-femoral joint may aid in protecting the ACL during dynamic loads.[15] Females land in a more erect posture than males [20, 33] and therefore the hamstring line of pull is unable to restrain anterior translation of the tibia on the femur. What may prove advantageous however is that these muscles would act to compress the tibio-femoral joint, and protect the ACL. Female athletes demonstrate significantly greater lateral hamstring peak activity compared to males when landing from a jump.[31] This may act to load the lateral tibio-femoral joint, leaving the medial joint line open in females. Compounding this detrimental effect is the external tibial rotation associated with the firing of the lateral hamstring, placing the ACL at further risk of injury. These findings suggest that medial and lateral hamstring neuromuscular imbalances may be the determining factor in developing dynamic knee valgus during dynamic movements such as during jump landing.

The purpose of this study was to examine the activation patterns of the hamstring musculature between genders when performing single leg landings from an elevated position. The hypothesis of this investigation is that muscle activation patterns generated at landing would be different between the genders. These neuromuscular differences may contribute to a greater valgus knee position in females during dynamic movements and increase the risk of ACL injury.

Methods

Subjects

Ten male and ten female recreationally active college students were recruited from the campus of Northern Michigan University for this study. Subjects were excluded from the study if they reported less than at least 60 minutes of physical activity per week or previous history of lower extremity injury or disorder. Mean age, height, and weight of the subjects were assessed and are presented in Table 1. The use of human subjects was approved by Northern Michigan University's Human Subjects Research Review Committee (# HS08-233). The approval letter can be found in Appendix A. Informed consent forms, and a joint pain questionnaire were reviewed and signed by each subject prior to data collection. These materials may be seen in Appendix B and C, respectively.

Instrumentation

This study used bipolar surface electrodes connected to an amplifier (MP 150, BioPac Systems Inc, Goleta, CA) to determine muscle activity when landing from an elevated position. Data were collected at a sample rate of 1000 hertz (Hz) for a period of 5 seconds. A 10-500 Hz band pass filter was employed. Data were then saved to a personal computer (IBM Thinkpad) for later analysis. Prior to interpretation, the raw electromyography (EMG) data was rectified using the root mean square. The rectified data was then integrated by averaging over every 20 samples. Analysis of this data was performed using AcqKnowledge 3.9.1 (BioPac Systems Inc, Goleta, CA, USA).

The electrode sites were prepared by shaving leg hair with a disposable razor, abrading the epidermal skin layer, and swabbing the sites with isopropyl alcohol to reduce impedance of the skin to <5-kilo ohms (kΩ). Disposable self adhesive Ag/AgCl snap electrodes (Noraxon, Scottsdale, AZ, USA) were secured, bilaterally, over the muscle bellies of the biceps femoris and semi-tendinosis (see Figure 1). The conductive surface of each electrode measured 1 cm, with an inter-electrode distance of 2 centimeters (cm). Ground electrodes were placed bilaterally, over the ipsilateral medial and lateral tibial condyle.

Preceding the landing trials, normalization EMG data were obtained relative to a maximal isometric contraction (MVC) of the hamstring musculature for comparison between the subjects and side (left/right). Subjects were asked to sit on an Isokinetic Dynamometer (Biodex Shirley, NY, USA) with their knees and hips flexed to 90 degrees. EMG data were captured while the participant was encouraged to perform a single leg maximal hamstring isometric contraction for 5 seconds on each lower extremity. Following the MVC's, each subject was allowed to rest while standing for approximately 5 minutes.

A single force plate (OR6-7-2000, AMTI, Watertown, MA, USA) was used in this study to determine the moment of initial contact when landing occurred. Vertical ground reaction forces (VGRF) during the landings were recorded at a sampling rate of 1000 Hz utilizing Netforce 2.0 software (AMTI Watertown, MA, USA). Both EMG and VGRF signals were chronologically synchronized to one signal during data collection for later analysis. Time to peak integrated electromyography (IEMG) for the four muscles was calculated as the time when muscle activity reached peak amplitude following initial contact.

Procedure

Drop landing trials required the subjects to hang from an elevated position by both hands. A 50 cm multipurpose straight bar was suspended from an adjustable zinc coated chain that was secured to the building structure located directly above the subject. For each subject, the bar was adjusted so that the subject's feet were 33 cm above the force platform while hanging, with the plantar surface of the feet parallel with the force platform (see Figure 2). A total of six trials of the landing task were performed (3 onto each leg). When instructed, the subject would release their hands from the straight bar and drop onto the force platform. Landing side (right vs. left) was randomly assigned for each trial. Subjects were asked to maintain balance upon landing to the best of their ability.

Statistical Procedure

The dependent variables observed in this study were time to peak integrated EMG amplitude from initial landing contact, mean integrated EMG amplitudes, and percent MVC for the medial and lateral hamstring (semi-tendinosis and biceps femoris). Means and standard deviations were calculated for the dependent variables. A 2×2×2 (gender × side × muscle) mixed design ANOVA, where the landing side and muscles were repeated measures, was used to evaluate the main effects of each independent variable on biceps femoris muscle activation as well as the main effects on semi-tendinosis muscle activation. Because one male and two females reported left leg dominance, leg dominance was used as a covariate to remove any effect it may have had.

Results

Subject mean IEMG activity is shown in Table 2. Results revealed no significant differences between men and women for mean IEMG activity following initial contact ($p>0.05$). No significant differences were found when examining mean IEMG activity after initial contact between side ($p>0.05$). Mean IEMG activity subsequent to initial contact showed no significant differences between the semi-tendinosis and biceps femoris ($p>0.05$). In addition, no significant interactions between the three independent variables existed when examining mean IEMG activity following initial contact ($p>0.05$).

Mean peak IEMG values are presented in Table 3. Peak IEMG following initial contact was expressed as a percentage of the subject's MVC. Semi-tendinosis and biceps femoris percent MVC were not shown to be significantly different between males and females ($p>0.05$). No significant differences were found when examining percent MVC at peak IEMG following initial contact between landing side ($p>0.05$). The two hamstring muscles examined in this study were shown to not be statistically different when comparing percent MVC of peak IEMG after initial contact ($p>0.05$). Finally, no significant gender-side, gender-muscle, side-muscle, or side-muscle-gender interactions were noted when analyzing the percent MVC at peak IEMG following initial contact.

Table 4 shows mean time to peak IEMG. Time to peak IEMG after initial contact examination between genders confirmed that there was no statistical difference ($p>0.05$). There were no differences between landing leg when analyzing time to peak IEMG after initial contact ($p>0.05$). Both the semi-tendinosis and biceps femoris demonstrated peak IEMG activation below the level of significance ($p>0.05$). Also, there were no independent variable interactions to note with time to peak IEMG activity ($p>0.05$).

The effects of gender, side, and muscle on the three dependent variables are summarized in Table 5.

Discussion

Prior to conducting this study, it was hypothesized that females would demonstrate different hamstring muscle activity when landing on a single leg when compared to their male counterparts. Disproportionate medial/lateral hamstring activation differences could potentially explain the ACL injury rate disparity between the genders. Subsequent to landing, unbalanced medial and lateral hamstring activation may jeopardize knee joint positioning. Activation of the lateral hamstrings prior to, or with greater force than that of the medial hamstrings could load the lateral tibio-femoral joint and leave the medial joint line open, placing the knee in a valgus position, and vulnerable to ACL injury. An increased activation of the medial or lateral hamstrings could also produce a rotary component at the tibio-femoral joint further destabilizing the knee joint.[15] The findings of this investigation do not support this hypothesis, suggesting another mechanism may be responsible for the disproportionate ACL injury rate identified between the genders.

Myers et al.[15] evaluated the gender differences of quadriceps muscle activation during a maneuver that mimics a high ACL injury risk position. They placed participants in a position of external tibial rotation with the knee flexed to resemble a posture commonly seen with sudden directional change in many athletic events. Significant differences in medial/lateral quadriceps muscle activation between genders were identified with females demonstrating greater activation in the lateral quadriceps muscle. In comparison, the current investigation failed to show any significant differences in medial/lateral hamstring muscle activation during single leg landing with a relatively neutrally aligned tibia. Tibial alignment may explain the disparity in results between the two studies. Perhaps the results of balanced medial/lateral hamstring activation during the landing procedure is due to the hamstrings protecting against tibial rotation as well as an anterior drawer. Unbalanced quadriceps activity may not be as detrimental to the ACL due to the quadriceps common insertion onto the tibial tuberosity. Based on the insertion points of the quadriceps muscles and the hamstring muscles, there is presumably less medial/lateral tibial rotational influence from the quadriceps in comparison to the hamstring muscles.

Anterior translation of the tibia in relation to the femur places the ACL at risk for injury.[32] The hamstring musculature acts synergistically with the ACL to prevent this anterior translation.[13] If landing postures are such that the knee is minimally flexed, the hamstring musculature will have a poor "line of pull" upon its tibial insertion. Malinzak et al.[32] found that males and females utilized different knee flexion angles when performing a variety of athletic tasks. Females displayed significantly less knee flexion angles than their male counterparts across all movement tasks that were analyzed. These findings suggest that the hamstring musculature of female athletes will be unable to provide sufficient posterior tibial drawer to protect against anterior tibial translation during athletic tasks.

Ford et al.[27] has shown that females exhibit greater coronal plane knee valgus than men when performing a dynamic landing activity. The results of the present study suggest that recreationally active females utilize similar hamstring activation strategies compared to males when performing single leg landings from a drop jump. With the hamstrings activating in synchrony the medial and lateral tibial plateau would be loaded equally by its respective femoral condyle. These muscle activation strategies may actually act to stabilize the knee joint within the coronal plane by controlling valgus motion. In addition, forces created by medial and lateral hamstrings activating concurrently may compress the tibio-femoral joint, thereby making the joint resistant to shear forces and protecting the ACL.[15]

Participants from the current study also performed bilateral lower extremity landings to be used for a separate investigation by Abe et al.[39] comparing 3 dimensional (3D) kinematics during single leg and bilateral leg drop landings between genders. Despite a lack of significance found between the genders, females demonstrated greater peak knee flexion angles during the bilateral landing procedure when compared to their male counterparts. These results may indicate that females utilize different landing patterns to attenuate vertical loads when landing with both lower extremities, while both genders may use similar landing postures when landing on a single limb. The comparable knee angles seen with single leg landings in Abe's study may have contributed to the hamstring muscle activity results between genders seen during our separate study. The greater knee angle differences noticed between genders during the bilateral leg landings may have equally resulted in different hamstring activity. Further examination appears warranted to determine if hamstring muscle activity differs between males and females during bilateral drop landings. Future studies should examine 3D knee kinematics in conjunction with lower extremity muscle EMG data to establish if females utilize different landing techniques than males, and how these techniques are influenced by muscle activity.

The similar hamstring muscle activity found between genders in this study may impact the direction of ACL injury prevention strategies. Recognizing that hamstring muscle activity acts to protect the ACL against anterior tibial translation, the results of the current study suggest that minimal attention should be placed on hamstring neuromuscular enhancement as males and females did not differ in this area. Instead, attention should be directed toward other neuromuscular mechanisms, where gender differences have been shown to exist.

Femoral internal rotation may be a contributing factor to dynamic knee valgus differences between the genders,[21] and thereby may contribute to the ACL injury rate disparity between genders.[2] The gluteus maximus aids in controlling this motion. Specifically, the gluteus maximus externally rotates the femur, and during dynamic activities, will function eccentrically to depress the rate of internal rotation. Zazulak et al. examined gluteus maximus activation during single leg landings between genders and found that the female gluteus maximus activation was significantly lower than that of males.[21] The diminished hip muscle activation may allow the femur to fall into internal rotation, placing the knee into valgus and jeopardizing the ACL. Focusing ACL injury prevention initiatives on the development of female hip stabilization may help to reduce the occurrence of female ACL injuries.

Table 1. Mean age, height, and weight of the recreationally active subjects.

	Gender	N	Mean	Standard Deviation
Age	Female	10	22.5	4.7
(yr)	Male	10	24.2	4.0
Height	Female	10	168.75	5.83
(cm)	Male	10	179.50	10.52
Weight	Female	10	65.60	8.96
(kg)	Male	10	77.34	15.09

Table 2. Mean IEMG activity shown in volts.

	Mean IEMG Muscle Activation			
	Left Biceps Femoris	Right Biceps Femoris	Left Semi-Tendinosis	Right Semi-Tendinosis
Male	0.01375 ± 0.00867	0.01031 ± 0.00406	0.01404 ± 0.00838	0.01515 ± 0.01045
Female	0.00968 ± 0.00470	0.01002 ± 0.00378	0.01214 ± 0.00441	0.01331 ± 0.00544

Table 3. Peak IEMG shown as % MVC following initial contact.

	Peak IEMG Muscle Activation (% MVC)			
	Left Biceps Femoris	Right Biceps Femoris	Left Semi-Tendinosis	Right Semi-Tendinosis
Male	50.858 ± 33.536	43.031 ± 22.260	49.448 ± 17.591	42.860 ± 20.173
Female	40.586 ± 21.469	47.291 ± 23.046	45.125 ± 13.409	50.304 ± 17.970

Table 4. Time (seconds) from initial contact when landing a jump until peak muscle activity.

	Time-to-Peak Muscle Activation			
	Left Biceps Femoris	Right Biceps Femoris	Left Semi-Tendinosis	Right Semi-Tendinosis
Male	0.42197 ± 0.13571	0.36703 ± 0.17835	0.36533 ± 0.15983	0.30400 ± 0.13608
Female	0.32225 ± 0.20975	0.35910 ± 0.15507	0.29963 ± 0.19071	0.39303 ± 0.14864

Table 5. The effect of gender, muscle and side on the dependent variables.

	Mean IEMG	Peak IEMG	Time-to-Peak IEMG
Gender	$p = 0.412$	$p = 0.879$	$p = 0.619$
Muscle	$p = 0.252$	$p = 0.181$	$p = 0.696$
Side	$p = 0.722$	$p = 0.959$	$p = 0.986$

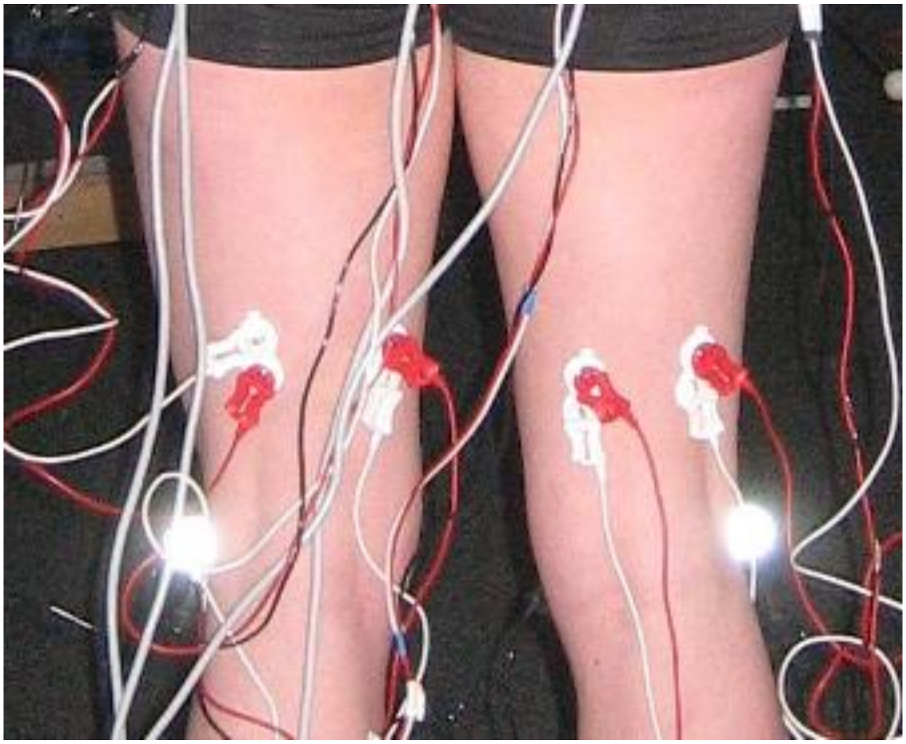

Figure 1: Subject fitted with surface EMG electrodes prior to drop-landing procedure.

Figure 2: Subject positioned with hands grasping the “hang-bar” in preparation for drop landing procedure.

CHAPTER III

SUMMARY AND RECOMMENDATIONS FOR FUTURE RESEARCH

SUMMARY

The hypothesis of this study was that hamstring muscle activation patterns generated at landing would be different between the genders. Neuromuscular differences may play a role in females demonstrating greater valgus knee posturing during dynamic movements, and increase the risk of injury to the ACL. The results of this investigation suggest that males and females exhibit similar hamstring muscle activity when landing from an elevated position, and therefore muscle activity differences do not contribute to a mechanism responsible for the ACL injury rate disparity identified between men and women.

RECOMMENDATIONS FOR FUTURE RESEARCH

The results of this study do not indicate an imbalance in hamstring muscle activation when landing from a drop jump, however; only a portion of the landing activity was examined. Chappell et al.[33] found hamstring activation differences between male and female recreational athletes just prior to landing from a stop-jump task. These authors also identified lower extremity kinematic differences between the genders in the pre-landing phase. Future studies should be directed at examining coronal plane knee joint kinematics immediately prior to landing. Concurrently these studies should also investigate hamstring, quadriceps, and gluteal muscle activation patterns. This may aid in determining if a preprogrammed knee valgus posturing can be identified in females prior to landing predisposing them to ACL injury.

Previous investigations have utilized a variety of jumping activities in their procedure. This study used a drop jump landing while the subject was suspended from an overhead bar. The primary interest of this procedure was how the results could benefit a recreationally active population. There is very little practical application of this landing procedure to functionality. Many sporting activity involve dynamic landings from an elevated position, however, these landings can involve perturbations, direction changes, or a combination of these. Future investigations may find the vertical drop-jump procedure, as described by Chappell et al.[33], to be more appropriate when examining these functional activities. A vertical drop jump may replicate many sporting activities better than the hanging-drop-jump used in this experiment.

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APPENDIX A

Human Subjects Research Review Committee Approval

Northern Michigan University

Continuing Education
1401 Presque Isle Avenue
Marquette, MI 49855-5301

12/16/08 Application Approved - CP

December 10, 2008

TO: Matthew K. D. Lewis
HPER

FROM: Cynthia A. Prosen, Ph.D. CP
Dean of Graduate Studies & Research

RE: Human Subjects Proposal # HS08-233
"Hamstring Muscle Activation Differences between Genders while performing single leg landings"

The Human Subjects Research Review Committee has reviewed your proposal and has given it final approval. To maintain permission from the Federal government to use human subjects in research, certain reporting processes are required. As the principal investigator, you are required to:

A. Include the statement "Approved by HSRRC: Project # (listed above) on all research materials you distribute, as well as on any correspondence concerning this project.

B. Provide the Human Subjects Research Committee letters from the agency(ies) where the research will take place within 14 days of the receipt of this letter. Letters from agencies should be submitted if the research is being done in (a) a hospital, in which case you will need a letter from the hospital administrator; (b) a school district, in which case you will need a letter from the superintendent, as well as the principal of the school where the research will be done; or (c) a facility that has its own Institutional Review Board, in which case you will need a letter from the chair of that board.

C. Report to the Human Subjects Research Review Committee any deviations from the methods and procedures outlined in your original protocol. If you find that modifications of methods or procedures are necessary, please report these to the Human Subjects Research Review Committee before proceeding with data collection.

D. Submit progress reports on your project every 12 months. You should report how many subjects have participated in the project and verify that you are following the methods and procedures outlined in your approved protocol.

E. Report to the Human Subjects Research Review Committee that your project has been completed. You are required to provide a short progress report to the Human Subjects Research Review Committee in which you provide information about your subjects, procedures to ensure confidentiality/anonymity of subjects, and the final disposition of records obtained as part of the research (see Section II.C.7.c).

F. Submit renewal of your project to the Human Subjects Research Review Committee if the project extends beyond three years from the date of approval.

It is your responsibility to seek renewal if you wish to continue with a three-year permit. At that time, you will complete (D) or (E), depending on the status of your project.

kjm

Telephone: 906-227-2103 ■ FAX: 906-227-2108
E-mail: contedu@nmu.edu ■ Web site: www.nmu.edu/ce

Appendix B

Informed Consent

<u>Title of Research</u>: Hamstring Muscle Activation Differences between Genders while performing single leg landings

Investigator: Matthew Lewis

Before agreeing to participate in this research investigation, it is important that you read the following explanation of this study. This statement describes the purpose, procedures, benefits, risks, discomforts, and precautions of the program. Also described is your right to withdraw from the study at any time. No guarantees or assurances can be made as to the results of the study.

<u>Explanation of Procedures</u>

The purpose of this study is to examine the activation patterns of the hamstring musculature: 1) between genders when landing from an elevated position onto the lower extremities, and 2) to determine if leg dominance effects muscular activation.

<u>Surface EMG Preparation</u>

Upon arriving to Northern Michigan University's Biomechanics Laboratory you will be fitted with surface electromyography electrodes over the muscle belly of the biceps femoris and semi-membranosis (located on the back of your upper leg) of each leg. Fitting of the electrodes will include exfoliating a small area of skin no larger than twice the size of the electrode (approximately two inches) and cleansing the area with isopropyl alcohol. These electrodes will then be attached to an amplifier and then linked to a personal computer to collect EMG data from the muscles during hamstring contractions while seated on the Biodex Isokintetic Dynamometer, as well as during the landing procedure.

<u>Isokinetic Testing</u>

You will be asked to perform contractions of the quadriceps and hamstring musculature at two separate speeds while seated on the Biodex Isokinetic Dynamometer. This machine will ensure that your leg moves at a set speed during the contractions. Preparation and testing will take approximately 45-60 minutes in total.

<u>3-Dimensional Motion Preparation &Testing</u>

Reflective markers will be taped at specific points over each of your legs. General areas of placement include the: front of the hip, side of the hip, mid-thigh, inside and outside of the knee, just below the knee, mid shin bone, lower shin bone, inside and outside ankle, outside of the foot, and top surface of the mid-foot. Five high-speed video cameras will be placed around the “landing area” to record joint movement patterns during the landing procedure.

Landing Procedure

You will be asked to step up on a 33 cm (approximately13 inches) platform which will be placed atop of a force platform. You will grasp a steel bar hanging from overhead with your hands while the platform is removed. At the appropriate time, you will drop from the elevated position onto the force platform. You will be asked to repeat the drop landing a total of 6 times (3 onto your dominant leg & 3 onto your non-dominant leg).

Risks and Discomforts

As with any physical test, certain risks and discomforts may apply. The risks involved in this investigation may include muscle strains, and ligament sprains to the lower extremities. In order to minimize the risk of these injuries, you will be allowed an appropriate "warm-up" session prior to data collection. Another possible risk is of an unanticipated fall from the bar that you will hang from by your hands. Meticulous care will be taken by the investigator to ensure you are assisted to the "hanging position", and that the area is free of objects that may cause you any serious injury if an unanticipated fall occurs. Finally, skin surface irritations may occur due to the surface electrode preparation, placement, and removal.

Participant Responsibilities

As a participant, you should disclose any information regarding your individual health status that may affect your safety during the testing procedure. It is your responsibility to inform the investigator if you experience any shortness of breath, chest pain, joint pain, or any other discomfort during the testing procedure.

Benefits

You may benefit from volunteering as a subject in this investigation by gaining further knowledge in the field of biomechanics. Observing the process of data collection may also be beneficial to you. There is also the potential for adding to a body of knowledge in the area of ACL injury rate disproportion among gender.

Confidentiality

All information gathered from the study will remain confidential and kept in a secure location. Your individual scores will not be disclosed outside of the testing personnel. The results of this study may be published for scientific purposes, however your identity will not be revealed.

Withdrawal Without Prejudice

Participation in this study is voluntary. You are free to withdraw consent and discontinue participation in this project at any time without prejudice from the investigator or Northern Michigan University.

Costs and/or Payments to Subject for Participation in Research

There will be no costs for participating in the research. There will be no benefits in the form of monetary compensation to you for your involvement in this study.

Payment for Research Related Injuries

Northern Michigan University has made no provision for monetary compensation in the event of injury resulting from the research. In the event of such injury, the investigator will provide assistance in locating and accessing appropriate health care services. The cost of health care services is the responsibility of the participant.

Questions

You are encouraged to contact Matthew Lewis at matlewis@nmu.edu or Dr. Randall Jensen at rajensen@nmu.edu, 906-227-1184 with questions concerning the research project or in the case of injury from the testing procedure. Questions regarding rights as a person in this research project should be directed to Dr. Cynthia Prosen (Dean, Human Subjects Research Review Committee) at cprosen@nmu.edu, 906-227-2300.

Agreement

This agreement states that you have received a copy of this informed consent. Your signature below indicates that you agree to participate in this study.

Signature of Subject Date

Subject name (printed)

Signature of Researcher Date

APPENDIX C

Joint Pain Questionnaire

Have you been diagnosed by a physician as having “flat-feet” (pes planus)?

☐ YES
☐ NO

Do you participate in at least one hour of physical training (exercise) per week?

☐ YES
☐ NO

Approximately how much time do you spend per week exercising? ___________hrs.

Has your doctor ever told you that you have a bone or joint problem(s), such as arthritis that has been aggravated by exercise, or might be made worse with exercise? _____

☐ YES
☐ NO

Do you suffer from any problems of your lower extremities, i.e., chronic pain, or numbness?

☐ YES
☐ NO

Have you ever suffered an injury to ligaments of your knee or ankle that required long term care from a health care professional (i.e., surgery, casting/splinting, physical therapy, etc.)?

☐ YES
☐ NO

Have you experienced any injury to your lower extremities in the last 2 weeks?

☐ YES
☐ NO

Are there any other physical problems associated with your legs that you feel should be addressed?

☐ YES
☐ NO

If YES, please explain:
____
____
____

____
Participant's Signature

___________________________________ ___________________
Name (please print legibly) Date