

**THE EFFECT OF ECCENTRIC HAMSTRING EXERCISE ON EMG  
OUTPUT IN FEMALE ATHLETES DURING A FUNCTIONAL LANDING  
TASK**

by

Christopher J. Clyde

A thesis submitted to the Faculty of the University of Delaware in partial  
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## **ABSTRACT**

Decreased activity of the hamstring muscles during landing tasks has been implicated as a potential cause for the disparity in ACL injuries between males and females. Eccentric strength training of the hamstring muscles has been shown to be effective in improving muscle performance and activation. The purpose of this study is to determine if an 8-week eccentric training regimen in conjunction with an athlete's offseason training program can produce a significant decrease in the time-to-peak EMG activation of the hamstring muscle group during a functional landing task. A total of 38 female intercollegiate athletes participated in this study. All subjects were pre-tested for hamstring muscle activation (time-to-peak EMG) in a functional landing task. The experimental group (ECCT) completed an 8-week training cycle performing two eccentric exercises in addition to their normal training regimen. The control group (CONT) performed their normal off-season training routine. At the completion of the training cycle both ECCT and CONT completed post tests for average time-to-peak EMG activation. A two-way repeated measures ANOVA was used to compare groups and no significant effect was found in any muscle group. The results revealed that there were no significant differences in time-to-peak EMG between the CONT and ECCT groups. Despite no differences in EMG activity between the groups, both groups improved in their 1RM strength measurement following the training period. Strength and conditioning coaches should explore other eccentric strength training approaches in an attempt to further their capacity to improve muscle activation in the hamstring muscle group, especially in high risk athlete populations.



**Key Words:** activation, strength, conditioning, concentric, functional

## **Chapter 1**

### **INTRODUCTION**

The goal of strength and conditioning has always been to improve the performance of the athlete and reduce the risk of injury in the athlete. Resistance training is the method chosen to elicit the muscle adaptation that helps to achieve these two goals (2). From a muscle physiological standpoint there are four modes of improving muscle performance, which are hypertrophy, synchronization, recruitment and activation (2). Hypertrophy is the increase in actual muscular size, synchronization is the efficiency in which different muscles work together, recruitment is effecting the number of muscle fibers that are active during a task, and activation has to deal with the rate at which a muscle “turns-on” to complete a task (2).

There are documented physiological imbalances that occur that strength and conditioning professionals target in their training approaches. Hewett et al. outline four general imbalances that females commonly exhibit as possible predictors and causes for the increased incidence of ACL tears in females (12). These imbalances include ligament dominance, quadriceps dominance, leg dominance, and trunk dominance (12). With regard to ligament dominance; female athlete’s show more signs of being ligament dominant during functional movement activities by absorbing forces with ligaments and joints as opposed to muscle, which is more common in males (12). The second imbalance exhibited in female athletes more so than males is quadriceps dominance. This imbalance refers to the tendency of an athlete to stabilize forces about the knee using predominantly the quadriceps muscle. Females show a

tendency to have less knee flexion during functional landing movements resulting in a more dominant response to knee stability and stiffness within the quadriceps muscle (1). The third imbalance is leg dominance. Leg dominance refers to asymmetry in terms of strength and relative recruitment differences. Females have been shown to favor one leg compared to the other, and Hewett et al. pinpointed this as a pre-cursor to ACL injury (12). The fourth imbalance is trunk dominance. Trunk dominance is the inability to precisely control the trunk in a three dimensional space. Deficits in trunk proprioception and motion have been shown to be a measure for predicting future knee ligament injuries in females (12,16).

With the four imbalances outlined by Hewett et al., it is important to recognize that there are several methods that can be employed to try and counteract the potential negative side-effects of exhibiting one or several of them. A study conducted by Hakkinen et al. examined the effects of resistance training on agonist versus antagonist leg muscles in healthy individuals across different age groups (10). This study demonstrated that resistance training increases muscle activation significantly in all age groups. Ploutz et al. reported similar results in the rectus femoris muscle group, and resistance training (18). This study reported that fewer muscles were activated during the post testing, while muscle performance did not decrease. This neurological change was attributed to greater muscle fiber activation (18). Given the body of research supporting resistance training as an effective method to increase muscle activation, our study planned to analyze the effect of an alternative approach to resistance training with eccentrically emphasized work.

Strength and conditioning training that emphasizes the eccentric phase of an exercise has become increasingly popular considering the potential to elicit greater

strength, hypertrophy, and neuromuscular adaptations versus standard concentric-eccentric style training protocols (5,6). Non-contact ACL injury has been shown to occur at a point in the deceleration portion of cutting and landing movements; this is categorized as the eccentric loading phase of these common movements. Considering these findings, it is not unreasonable to suggest that an eccentric-training regimen targeting the hamstrings muscle group in females may be more effective at increasing hamstring activation to counteract the quadriceps dominance outlined by Hewett et al. (12).

The purpose of this study was to determine if an 8-week eccentric training regimen, in conjunction with an athlete's offseason training program can produce a significant decrease in the time-to-peak EMG activation of the hamstring muscle group during a functional landing task. Our initial hypothesis was that an 8-week eccentric exercise training program, in conjunction with an athlete's offseason training regimen, would produce a significant decrease in the time-to-peak EMG activation of the hamstring muscle group in a functional landing task, as compared to athletes not involved in the eccentric training.

## **Chapter 2**

### **METHODS**

#### **2.1 Experimental Approach to Problem**

The experimental design used for this study was a pretest-posttest equivalent groups quasi-experiment. Subjects were assigned to two groups based on strength baseline numbers to ensure both groups had an equal strength average at the onset of training, as well as the time-to-peak EMG activation pre-test. A treatment was conducted on the experimental group in the form of additional eccentrically emphasized exercises over the course of an 8-week training regimen. The control group received no additional treatment and carried out standard off-season strength and conditioning protocols.

#### **2.2 Subjects**

Thirty eight student-athletes (age= $20.4 \pm 0.7$  yrs, height= $170.0 \pm 6.0$  cm, mass= $66.2 \pm 8.2$  kg) from a variety of intercollegiate athletic teams (track & field, rowing, tennis) were recruited to take part in this study. All participants were cleared for participation via the medical examination process (team physician). Subjects were asked to complete the required IRB consent form (UD IRB#241309-1) prior to all testing (Appendix A). Demographic data (age, height, mass, sport, hamstring injury history) was obtained on all subjects. Student-athletes who indicated hamstring injury within the past 6 months were excluded from this study. Two subjects were dropped

from the study for injuries unrelated to the study and the other left their respective team, leaving 19 in the experimental and 17 in the control group.

## **2.3 Procedures**

### **2.3.1 EMG Activation**

Surface EMG was collected from the medial and lateral hamstrings and the quadriceps to determine muscle activation and timing. The EMG recordings were collected during a simple functional landing task. Multi-Bio Sensors self-adhesive Ag/AgCl bipolar surface electrodes (Multi Bio Sensors Inc., El Paso, Texas) tethered to an EMG unit (Bortec Biomedical Ltd., Calgary, Canada) were used to record EMG with a real-time visual display on the monitor. Electrode placement was identified by bony landmarks and through palpation of the mid-belly of the contractile component of the muscle during an isometric contraction. Specifically, electrodes were placed on the rectus femoris (RF), vastus medialis (VM), biceps femoris (BF) and semitendinosus (ST). The reference electrode was placed on the patella. Each electrode is 10mm in diameter and were placed 25mm apart. The electrode placement site was shaven, abraded, and cleansed with an alcohol swab (70% ethanol solution) to decrease the impedance from the skin.

The EMG signal was converted from analog to digital data with an A/D card, and then passed to a computer where the raw EMG data will be sampled at 2,400 Hz and further analyzed with LABVIEW software (National Instruments, Austin, Tx). The EMG signal was then bandpass filtered at 20-400Hz and low-pass filtered at 5Hz to create a linear envelope. Using the linear envelope focuses on the actual muscular activity output while accounting for registered movement and noise artifacts. EMG

was normalized to the ensemble peak values for the muscles of both the hamstrings and quadriceps. The EMG outputs were then analyzed to determine the amplitude (area & peak) of muscle actions for both the hamstrings and quadriceps.

Ebben et al. (8) examined the hamstring to quadriceps ratio of EMG activation, analyzing gender differences in leg muscle activation during functional landing and cutting tasks; their test guidelines were used for the functional landing task in our study. Subjects began activation testing by performing a five-minute warm-up on a stationary bicycle. After completing the warm-up, the subjects were fitted with the EMG electrodes as described above on their dominant leg (leg they would kick a ball with). Each subject then performed ten simple step-down landing tasks from a height of 24" (Figure 1). Subjects were instructed to step off the 24" platform/step and land on both feet as they normally would from any jump activity.

Cohen et al. analyzed the peak EMG amplitudes of knee extensor and flexor muscles in endurance trained and untrained individuals (4). They reported that there were significant differences in peak amplitudes, time to EMG onset, and time-to-peak EMG in the trained individuals versus the untrained group. For this study time-to-peak EMG activation was calculated using the force plate contact as the timing mechanism to analyze the onset of activity and the time to peak activation value. The force plate is used as a timing mechanism to make sure the activation being analyzed is in response to the drop-landing. Cohen et al. reported rate of muscle activation as the first 30 milliseconds of activity (4). This study will analyze an activity window 250ms before plate contact (pre-landing for pre-activation), 250ms during initial contact (initial activation), and 250ms post contact. These windows will ensure that all modes of activation can be analyzed and compared in data analysis between testing

and groups. The time-to-peak EMG activation measure used in our present study was also used by Robbins et al. in a study that showed resistance training significantly decreased the muscle time-to-peak activation in an upper body training protocol (19).

### **2.3.2 Strength Pre and Post Testing**

A 1-Repetition Maximum (1RM) strength output was determined using a Life Fitness Strength (Life Fitness, Schiller Park, IL) prone hamstring-curl apparatus. This test required the subject to perform a hamstring curl at a low weight while increasing the weight by 5 lbs. until they could only perform one repetition before failure, thus resulting in the 1RM value. This value was then used to determine the group assignments for the training portion of the study. Once all subjects were baseline tested they were assigned to either the Control (CONT) or Eccentric Training (ECCT) groups based on the 1RM values obtained. For example the top two 1RM outputs were assigned #1 to CONT and #2 to ECCT, #3 to ECCT and #4 to CONT, and so on until all subjects had been assigned (19 in each group).

### **2.3.3 Training Protocol**

Subjects in both groups performed their normal workout routine after which they executed additional training congruent with their group. Athletes assigned to the CONT group were asked to perform an additional 10 minutes of alternative core exercises and stretching that did **NOT** target the hamstring and quadriceps muscles. Subjects in the ECCT group performed two different eccentric strength training exercises targeting the hamstring muscle group over the 8 week period. Both exercises required approximately 10 minutes of additional time per session twice weekly. The initial 4 weeks of training involved exercises utilizing body-weight



resistance only, while the last 4 weeks of training involved the same exercises utilizing additional weight resistance.

During the first 4 weeks of training, ECCT followed a bodyweight eccentric training protocol. Participants performed reverse lunges with no additional weight emphasizing the eccentric phase of the exercise. This was done by alternating repetitions for each leg. Participants performed 3 sets of 8 repetitions for the first two weeks and 4 sets of 8 repetitions over the next two weeks. These exercises were performed once a week for the initial 4 week period. The second exercise was an eccentrically emphasized glute-ham raise. The subjects got into a glute-ham developer station with their hands across their chest and started with their torso upright and rigid. The subjects then lowered their body slowly against gravity towards the ground using their hamstrings to control their descent at a 5 second count pace until they were fully lowered; a training partner then assisted the participant by lifting their torso back to the starting upright position so there was no concentric work performed. This constituted one repetition. The eccentrically emphasized exercise protocol is outlined in Table 1.

During the final 4 weeks of training, the ECCT subjects participated in a weight resisted eccentric training protocol. Participants performed weighted reverse lunges emphasizing the eccentric phase of the exercise. This was done by alternating repetitions for each leg, consistent with the bodyweight protocol of weeks 1-4, while holding additional resistance in the form of dumbbells in each hand. To ensure the dumbbell weight resistance was appropriate, subjects indicated their level of intensity during the exercise using a modified Borg scale. Our goal threshold on that scale was 5-7, thus resistance was either added or subtracted to maintain this level. If a subject

could perform all sets of 8 repetitions without failure during any week, the dumbbell weight used increased by 5 pounds each for the next training session. These exercises were performed twice a week for the final 4 weeks (Table 1). An alternative method of increasing the intensity for both exercises was to increase the time-under-tension for the movements. Schuenke et al. conducted a study analyzing the differences in muscular adaptations performing a leg press, squat and knee extension exercise protocols at different speeds (20). This study reported slow-speed resistance training elicited a greater neural adaptation than normal-speed resistance training (20). Headley et al. reported that increasing the time-under-tension, by way of slowing down the tempo of the repetitions of a given set, elicits similar muscular and hormonal adaptations to maximal effort lifts with faster tempos, which supports the method of slow tempo, sub-maximal lifting used in our study (11).

#### **2.3.4 Data Analysis**

There were two groups in the study: control (CONT), and experimental (ECCT). The dependent variable was time-to-peak EMG activation and it was evaluated on the interval scale of measurement. Data were analyzed using a repeated measures analysis of variance (ANOVA). Time was the within-subjects (repeated) measure and it was evaluated on two occasions: pretest (before training protocol) and post-test (after training protocol).

## Chapter 3

## RESULTS

### 3.1 EMG Activation

Table 2 presents means and standard deviations for the two groups on the dependent variable and it does so separately by time period. Figure 2 provides a visual representation of the EMG activation results.

Result for the rectus femoris (RF) muscle revealed a main effect for group-by-time was not significant ( $F = .086$ ,  $df [1]$ ,  $p = .771$ ). The obtained effect for group-by-time represented a small effect size (i.e., partial eta squared = .003). Alternatively, neither the main effect for time or group were significant (respectively,  $F = .028$ ,  $df [1]$ ,  $p = .327$ ;  $F = 1.504$ ,  $df [1]$ ,  $p = .028$ ).

Result for the vastus medialis (VM) muscle revealed a main effect for group-by-time was not significant ( $F = .237$ ,  $df [1]$ ,  $p = .630$ ). The obtained effect for group-by-time represented a small effect size (i.e., partial eta squared = .007). Alternatively, neither the main effect for time or group were significant (respectively,  $F = .696$ ,  $df [1]$ ,  $p = .410$ ;  $F = .103$ ,  $df [1]$ ,  $p = .751$ ).

Result for the biceps femoris (BF) muscle revealed a main effect for group-by-time was not significant ( $F = 1.556$ ,  $df [1]$ ,  $p = .221$ ). The obtained effect for group-by-time represented a small effect size (i.e., partial eta squared = .044). Alternatively, neither the main effect for time or group were significant (respectively,  $F = .008$ ,  $df [1]$ ,  $p = .929$ ;  $F = .034$ ,  $df [1]$ ,  $p = .855$ ).

Results for the semitendinosus (ST) muscle revealed a main effect for group-by-time was not significant ( $F = .376$ ,  $df [1]$ ,  $p = .544$ ). The obtained effect for group-by-time represented a small effect size (i.e., partial eta squared = .011). Alternatively, neither the main effect for time or group were significant (respectively,  $F = .543$ ,  $df [1]$ ,  $p = .466$ ;  $F = .813$ ,  $df [1]$ ,  $p = .374$ ).

With a post-test power analysis completed reporting that a subject pool of 66 athletes would have given the study an appropriate number of subjects to report any significant differences, we can only assume a potentially significant difference between the ECCT time-to-peak EMG post-test data and the CONT time-to-peak EMG post-test data. The results outlined above lend only to a possible trend, but no significance.

### **3.2 Strength**

The independent samples t-test results showed there was a significant difference ( $p=0.042$ ) between eccentric group and control group in strength outputs pre to post training protocol testing. The eccentric group averaged a 10% strength increase while the control group experienced only a 5% strength increase (Table 3). This was expected and is supported by previous research by Hortobagyi et al. (7, 8) and Colliander et al. (5,6).

## **Chapter 4**

### **DISCUSSION AND CONCLUSION**

The aim of the present study was to compare the effect of two different 8-week, strength and conditioning training protocols on the hamstring muscle EMG time-to-peak activation in female athletes. The results revealed that there were no significant differences between the control and experimental groups created by the different training protocols on the EMG time-to-peak activation levels of both hamstring muscles analyzed.

There is an estimated 95,000 cases of anterior cruciate ligament (ACL) ruptures per year, or 1 out of every 3,500 people participating in competitive sports (12). The topic of ACL injury prevention has grown increasingly important as there are more participants in various sports involving sprinting, cutting, jumping and landing every year (8,16,17). Along with a greater overall number of athletes at risk of a possible ACL injury, females have a four to six times greater chance of incidence of injury in comparison to male athletes. With this higher risk of ACL rupture and increase in female athletic participation since the instituting of Title IX in 1972, the number of such injury incidences has increased at greater rates every single year (12).

In a recent review, Hewett (12) detailed physiological imbalances that could be possible factors leading to ACL injury in females. The imbalance examined in the present study was categorized as “quadriceps dominance.” This imbalance refers to the tendency of an athlete to stabilize forces about the knee using predominantly the quadriceps musculature, while relying less on the hamstring muscles to provide knee

joint stability. Females show a tendency to have less knee flexion during functional landing movements resulting in a more dominant response to knee stability and stiffness within the quadriceps muscles (12). In terms of the present study, we chose to analyze this imbalance during a functional landing task to mimic the dynamic knee stability required in athletics.

Higbie et al. analyzed the effect of an eccentric training regimen on the strength, hypertrophy, and neural activation of the vastus lateralis and vastus medialis in comparison to a concentric training regimen in a control group (13). Differences in this study were attributed to hypertrophy when statistically analyzed, with no significant neural activation differences between groups (13). Data from the present study are consistent with the Higbie et al. findings, which showed that strength training had an inconsistent effect on the EMG activation of analyzed muscles (13). Furthermore, our results suggest that the eccentric training and standard training protocols had no effect on these same measures in trained, female athletes.

A study conducted in 2006 by del Olmo et al. (18) contradicted the results of the present study. In this study, analyzing the biceps and triceps brachii muscle groups, it was reported that neural adaptations significantly increased as a result of strength training (18). In our study the strength training protocol was carried out for only 8 weeks, in the study conducted by del Olmo et al. subjects were analyzed after 2 years of resistance training in comparison to untrained individuals (18). A longer, more focused training protocol would be ideal for possible future studies and will be discussed in a later section.

Conversely, studies by Cohen et al. (4), and Hortobagyi et al. (15,16) reported significant increases in neural activation as a result of eccentric training when

compared to standard training practices. These studies (4,15,16) analyzed isolation movements within physiological planes of motion using a controlled range-of-motion. In addition, their eccentric exercises were completed on weight-stack machines. This approach differed to that of the present study because our study utilized compound movements, which are multi-joint, free weight resisted and standing. It is possible that the exercises used in the present study did not isolate the targeted muscles of the BF and ST enough to result in a similar effect on neural adaptation as shown by the studies of Cohen et al. (4) and Hortobagyi et al. (15,16).

Regarding strength outputs, our results are in accordance with previous studies that investigated the influence of eccentric emphasized training practices in comparison with standard, concentric training practices (5,6,15,16). Colliander et al. (5,6) and Hortobagyi et al. (15,16) analyzed the effects of eccentric emphasized strength training on strength outputs in the rectus femoris, vastus lateralis, and vastus medialis muscles. The authors reported that eccentric training led to greater strength increases than standard training practices. Similarly, both groups in our study saw expected strength increases after the 8-week training protocols, but only the eccentric training group (ECCT) exhibited a significant increase (Table 3). The eccentric group had an average strength increase of 10% of the 1RM on a maximum effort strength test, while the control group had an average strength increase of 5% of the 1RM.

Although we've attempted to discuss the results of our study as indicated, it is important to point out that our time-to-peak EMG activation values in the ECCT did decrease pre to post-test, but were not significantly different. Perhaps this trend was a result of our study being underpowered. The original sample pool of 38, and eventually 36 was underpowered by 28 subjects. A post hoc test power analysis

revealed that a medium effect size would be achieved with a sample size of 66 athletes.

Future considerations for an expanded study following a similar scientific approach include other modifications as well. A training log to monitor the progress of the athletes in both groups more precisely should be kept to better coordinate the strength training protocol in later weeks and make sure the training is appropriate and optimal. It would also be ideal to devise a formula to delineate a weight resisted progression based on the athletes' maximum ability in a baseline exercise, instead of progressing the weight training based on the Borg scale of perceived exertion, to eliminate outside factors that may limit or improve training. This would help to eliminate the obvious subjectivity of the Borg scale. Outside factors that could have compounding effects on a day to day basis in terms of training are emotional, mental and physical stresses experienced outside of the weight room and training environment. Without these factors accounted for on a day to day basis, we speculate that our training protocol did not remain optimal for all 8 weeks.

#### **4.1 Practical Applications**

At the conclusion of the eight week eccentric training protocol, the ECCT group exhibited a greater strength increase in the hamstring muscles when compared to the CONT. Although strength was impacted, time-to-peak EMG activation was not influenced by the enhanced eccentric 8-week training protocol. We argue that a longer, more carefully monitored, enhanced eccentric training protocol may alter the outcome of the EMG activation output of future studies.



## Chapter 5

### LEGEND



Figure 1: Subject Execution of Functional Landing Task

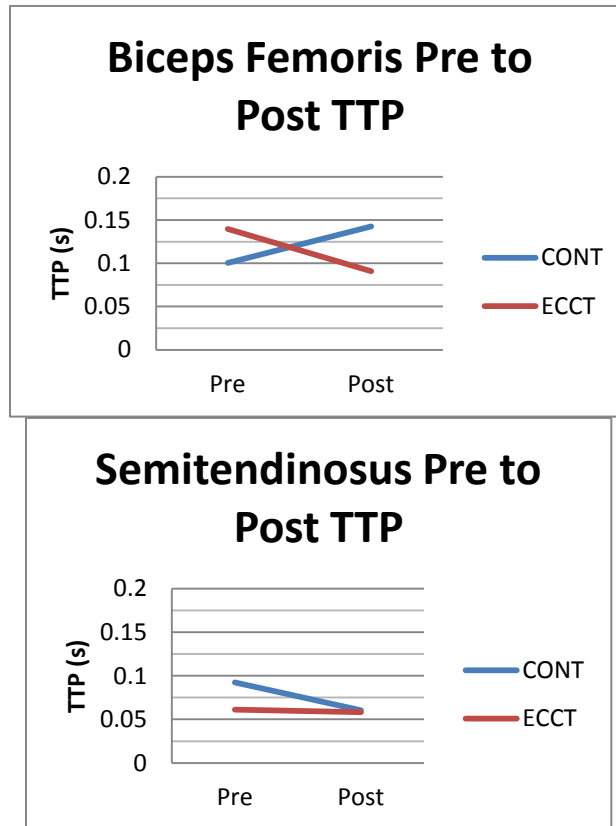


Figure 2: Plot of Marginal Means by Group across Time

Table 1: Eccentric Training Group 8-Wk Protocol

Week	Sessions/Week	Sets	Reps
1	2	3	8
2	2	3	8
3	2	4	8
4	2	4	8
5	2	3	8
6	2	3	8
7	2	4	8
8	2	4	8

Table 2: Means and Standard Deviations ( $M \pm SD$ ) for Time-to-Peak EMG (in seconds) by Group and Time. CONT = control group, ECCT = eccentric training group

Muscle	Group	<i>Pre</i>	<i>Post</i>
Rectus Femoris	CONT	.0945(.0408)	.1179(.0425)
	ECCT	.1219(.1281)	.1347(.0522)
Vastus Medialis	CONT	.1989(.0969)	.1876(.0797)
	ECCT	.2065(.1970)	.1637(.0708)
Biceps Femoris	CONT	.1006 (.1369)	.1427 (.1113)
	ECCT	.1397 (.2284)	.0910 (.0633)
Semitendinosus	CONT	.0923 (.0966)	.0603 (.0578)
	ECCT	.0611 (.1074)	.0582 (.0885)

Table 3: Pre and Post Test 1RM Strength Values (in kg)

	<b>Pre-Test</b>	<b>Post-Test</b>	<b>% Change</b>
<b>STRENGTH</b>			
<b>Control</b>	30.05 $\pm$ 5.54	31.56 $\pm$ 4.98	+5%
<b>Experimental</b>	30.62 $\pm$ 5.21	34.07 $\pm$ 6.04	+10%

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## **Appendix A**

### **APPROVED INFORMED CONSENT FORM**

**RESEARCH STUDY:** The Effect of Eccentric Hamstring Exercise on EMG Output in Female Athletes During a Functional Landing Task.

**INVESTIGATORS:** Christopher J. Clyde, BS (graduate student) and Thomas W. Kaminski, PhD (professor) in the Department of Kinesiology and Applied Physiology

#### **INTRODUCTION**

You are invited to take part in a research study to gain information that may help reduce knee injuries in sport. You qualify based on your status as a student-athlete for the University of Delaware and range in age from 18-24 years.

#### **PURPOSE**

The purpose of this study is to determine if there are differences in EMG activation (muscle electrical activity) in the hamstring muscle group as measured during a simple landing task (step down from 2' height) following 8 weeks of eccentric hamstring strength training in a group of intercollegiate female athletes.

#### **PROCEDURES**

You are one of 30 student athletes volunteering to participate in this study during your offseason. With your approval, the sports medicine staff (John Smith and Dr. Reisman) will review your medical records and determine if you are eligible to participate in this study. Student athletes with any injury at the time of (or during) the study will be excluded from participating. You will be asked to arrive for testing wearing running shoes and shorts. You will report to the Human Performance Lab at the University of Delaware to complete baseline testing. The baseline and post-training testing sessions of this study will take approximately 1 hour. If you participate an additional 10 minutes will be added to your normal training regimen that will help to improve your athletic performance.

Your age, height, weight, and sport will be recorded. You will then perform a five-minute warm-up on a stationary bicycle followed by a stretching routine for your thigh muscles. When your warm-up is complete you will perform a simple landing task with EMG electrodes on your thigh muscles to measure muscle activity. The following describes the baseline testing that will be performed:

## (A) Baseline Testing

### *EMG Testing:*

After completing the warm-up, the subjects will be fitted with the EMG electrodes on your thigh muscles to measure your muscle activity. Each subject will then perform five (5) simple step-down landing tasks from a height of 24" (Figure 1). One minute of rest will be given between each trial. Subjects will be instructed to step off the 24" platform/step and land on both feet as they normally would from any jump activity.

### *1-Repetition Max Hamstring Test*

Upon completing the step-down landing test, subjects will transfer over to the DFH weight training room to perform the isotonic 1RM testing. Isotonic 1RM will be tested on the Life Fitness Strength isotonic prone hamstring-curl (Figure 2) using a standardized 1RM protocol. The protocol will be executed with both limbs separately. This test will require the subject to perform a hamstring curl at a low weight and then keep increasing the weight by 5 lbs. until they can only perform one repetition before failure, thus resulting in the 1RM value. This value will then be used in the determination of the group assignment for the training portion of the study. At the conclusion of the session the subjects will be asked to perform a series of cool-down stretching exercises for the hamstring muscles (Figure 3).

At the conclusion of the session you will be asked to perform a series of cool-down stretching exercises for the hamstring muscles (Figure 3).

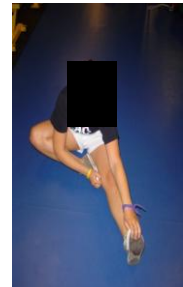
**Figure 1.**



**Figure 2.**



**Figure 3.**



## (B) Group Assignment

After you complete the baseline testing you will be randomly placed into one of two groups. One group (Group A) will execute their normal training in the weight room with an additional set of stretching exercises to increase post-exercise recovery, while the other group



(Group B) will perform training with additional exercises targeted at the thigh muscles utilizing their bodyweight for the first four (4) weeks, and for the final four (4) weeks they will perform exercises utilizing additional weight resistance. These additional training sessions for each group will require 10 minutes of time to complete. At the end of 8 weeks all the groups will return to the Human Performance Lab for post-training EMG testing identical to the baseline testing and to the DFH for a strength post-test identical to the baseline testing. These procedures are the same as described above in (A). Post-training testing will require 30 minutes to complete.

#### CONDITIONS OF SUBJECT PARTICIPATION

All of the data will be kept confidential. Your information will be assigned a code number. The list connecting your name to the code number will be kept in a locked file. When the study is completed and the data have been analyzed, that list will be destroyed, but the coded data will be kept indefinitely on a secured electronic file device (in case the results are needed in future analysis). Your name will not be used in conjunction with this study. In the event of physical injury during participation, you will receive first aid. If you require additional medical treatment, you will be responsible for the cost. You will be removed from the study if you experience any injury that interferes with the results or prevents you from completing it. There are no consequences for withdrawing from the study and you can do so at any time.

#### RISKS AND BENEFITS

Potential risks in this project are minimal. As with any exercise or challenging movements, risks include fatigue, localized muscle soreness, and the potential for strains and sprains of muscles and joints of the lower leg. There is a slight risk to you of suffering bone, muscle, or joint injuries during the testing protocol. In the event of an acute injury, you will receive immediate first aid. Follow-up care will be at your own expense. If you become too fatigued or uncomfortable, you may stop the test at any time.

The results of the study may influence how lower body strength training routines are developed in the future.

#### FINANCIAL CONSIDERATIONS

There will be no compensation for participating in this study. There will be no cost to you, the subject, for participating in the study. Transportation is provided on campus to the testing site and all materials will be provided by the researcher.

## CONTACTS

Christopher Clyde (914) 500-9019 or [chris.j.clyde@gmail.com](mailto:chris.j.clyde@gmail.com) & Dr. Thomas W. Kaminski (302) 831-6402 or [kaminski@udel.edu](mailto:kaminski@udel.edu) Questions regarding the research study can be directed to the above email addresses.

For questions of concerns about the rights to the individuals who agree to participate in the study:

Human Subjects Review Board, University of Delaware (302) 831-2137

## ASSURANCE

Participation in this study is completely voluntary. You may stop at any time during the testing without penalty. Refusal or choosing to discontinue participation in this study is the right of the individual, with no loss of benefits to which the subject is otherwise entitled.

## CONSENT SIGNATURES

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Subject Consent Signature

Date

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Principal Investigator Signature

Date

Signed consent forms will be retained by the researcher for three years after completion of the research.

## **Appendix B**

### **SPECIFIC AIMS**

There is an estimated 95,000 cases of anterior cruciate ligament (ACL) ruptures per year, or 1 out of every 3,500 people participating in competitive sports. The topic of ACL injury prevention has grown increasingly important as there are more participants in various sports involving sprinting, cutting, jumping and landing every year.<sup>10,39</sup> Along with a greater overall number of athletes at risk of a possible ACL injury, females have a four to six times greater chance of incidence of injury in comparison to male athletes. With this higher risk of ACL rupture and huge increase in female athletic participation since the instituting of Title IX in 1972, the number of such injury incidences has increased at greater rates every single year.<sup>22</sup>

There are several possible reasons for such a greater incidence of ACL injuries in the female athlete population. Hewett et al. outline four general imbalances that females commonly exhibit as possible main predictors and causes for the increased incidence in females.<sup>22</sup> These imbalances include ligament dominance, quadriceps dominance, leg dominance, and trunk dominance.<sup>22</sup> With regard to ligament dominance; female athlete's show more signs of being ligament dominant during functional movement activities by absorbing forces with ligaments (and joints) as opposed to muscle, which is more common in males. The second imbalance exhibited in female athletes more so than males is quadriceps dominance. This imbalance refers to the tendency of an athlete to stabilize forces about the knee using predominantly the quadriceps muscle. Females show a tendency to have less knee flexion in functional

landing movements resulting in a more dominant response to knee stability and stiffness within the quadriceps muscle. The third imbalance is leg dominance. Leg dominance refers to asymmetry in terms of strength and relative recruitment differences, which is a proportional strength and neural recruitment discrepancy in one leg versus the other.<sup>22</sup> Females have been shown to favor one leg compared to the other, and Hewett et al. pinpointed this as a pre-cursor to ACL injury.<sup>22</sup> The fourth imbalance involves trunk dominance, and is defined as the inability to precisely control the trunk in three dimensional spaces. A lack of trunk proprioception and motion was shown to be a valid measure in females for predicting future knee ligament injuries.<sup>11</sup>

The focus of this research endeavor will involve quadriceps dominance in female athletes. Dynamic knee joint stability includes an agonist-antagonist relationship between the quadriceps and hamstring muscles. When athletes contract their quadriceps they extend their knee. The quadriceps serves to stiffen or compress the tibiofemoral joint. The common quadriceps tendon attaches at the superior patella, and then attaches via the infrapatellar tendon to the tibial tubercle on the anterior tibia. As the quadriceps contract they pull the tibia anterior relative to the femur.<sup>22</sup> The resultant biomechanical problem is that the ACL serves to maintain the posterior nature of the tibia (or check anterior movement), and when an athlete uses their quadriceps to stabilize the joint it causes an anterior shear stress to the tibia thus putting additional stress on the ACL.<sup>22</sup> This anterior shear stress is reduced by the co-contraction of the hamstring muscles to hold the quadriceps' forces in check. Males are found to be more hamstring dominant than females in lower body force absorbing tasks; such as jump landing and cutting. Youdas et al. reported that males

had a 3.5 times larger hamstring-to-quadriceps ratio of electromyography (EMG) peak activation than females in a stable surface squat.<sup>41</sup> That study cited this discrepancy in female hamstring activation as a possible factor in the significantly higher percentage of non-contact ACL injuries in females versus males.<sup>41</sup> These results suggest that eliciting greater strength and activation of the female hamstring muscles in relation to their quadriceps activation could facilitate a reduction in ACL shear force and possibly reduce the significantly higher percentage of female non-contact ACL injury.

To increase muscle strength and activation athletes have been turning to strength and conditioning professionals to help improve performance and prevent injuries. Training that emphasizes the eccentric phase of an exercise has become increasingly popular considering their potential to elicit greater strength, hypertrophy, and neuromuscular adaptation outputs versus standard concentric-eccentric style training protocols.<sup>7-8</sup> Non-contact ACL injury has been shown to occur at a point in the deceleration portion of cutting and landing movements; this is otherwise known as eccentric loading phases. Considering these findings it is not unreasonable to suggest that an eccentric-training regimen targeting the hamstrings muscle group in females may help to reduce the incidence of non-contact ACL injuries.<sup>1</sup>

The purpose of this study is to determine if an 8-week eccentric training regimen in conjunction with an athlete's offseason training program can produce a significant decrease in the average time-to-peak EMG activation of the hamstring muscle group during a functional landing task. This study will address the following:

**B.1 Specific Aim 1:**

To determine if an 8-week eccentric exercise program in conjunction with an athlete's offseason training regimen can produce a significant change in average time-to-peak EMG activation in the hamstring muscle group during a functional landing task.

**B.2 Hypothesis 1:**

We hypothesize that an 8-week eccentric exercise training program in conjunction with an athlete's offseason training regimen can produce a significant decrease in the average time-to-peak EMG activation of the hamstring muscle group in a functional landing task as compared to athletes not involved in the eccentric training.

## **Appendix C**

### **BACKGROUND AND SIGNIFICANCE**

#### **C.1 Introduction**

There is an estimated 95,000 cases of anterior cruciate ligament (ACL) ruptures per year, or 1 out of every 3,500 people participating in competitive sports.<sup>22</sup> The topic of ACL injury prevention has grown increasingly important as there are more participants in various sports involving sprinting, cutting, jumping and landing every year.<sup>12,39,41</sup> Along with a greater overall number of athletes at risk of a possible ACL injury, females have a four to six times greater chance of incidence of injury in comparison to male athletes. With this higher risk of ACL rupture and increase in female athletic participation since the instituting of Title IX in 1972, the number of such injury incidences has increased at greater rates every single year.<sup>10</sup>

Hewett et al. outline four general imbalances that females commonly exhibit as possible predictors and causes for the increased incidence of ACL tears in females.<sup>22</sup> These imbalances include ligament dominance, quadriceps dominance, leg dominance, and trunk dominance.<sup>22</sup> With regard to ligament dominance; female athlete's show more signs of being ligament dominant during functional movement activities by absorbing forces with ligaments and joints as opposed to muscle, which is more common in males.<sup>22</sup> The second imbalance exhibited in female athletes more so than males is quadriceps dominance. This imbalance refers to the tendency of an athlete to stabilize forces about the knee using predominantly the quadriceps muscle. Females show a tendency to have less knee flexion during functional landing movements

resulting in a more dominant response to knee stability and stiffness within the quadriceps muscle.<sup>3</sup> The third imbalance is leg dominance. Leg dominance refers to asymmetry in terms of strength and relative recruitment differences. Females have been shown to favor one leg compared to the other, and Hewett et al. pinpointed this as a pre-cursor to ACL injury. The fourth imbalance is trunk dominance. Trunk dominance is the inability to precisely control the trunk in three dimensional spaces. Deficits in trunk proprioception and motion were shown to be a measure, for predicting future knee ligament injuries in females by a study.<sup>31,42</sup>

## **C.2 Anatomical Considerations**

The knee joint is a complex structure made up of multiple contributing parts with various responsibilities. The major muscles acting on the knee are the quadriceps and the hamstrings. The roles of the hamstrings and quadriceps in stabilizing the knee joint with regard to ACL injury will be discussed further in this section. The quadriceps forms the motor unit for extension at the knee joint. There are seven heads to the quadriceps and all but one insert into the patellar tendon.<sup>16</sup> The vastus intermedius (VI) originates on the anterior surface of the femoral shaft, its distal tendon inserts directly into the superior pole of the patella. The rectus femoris (RF) parallels the vastus intermedius. It originates on the anteroinferior iliac spine of the pelvis and blends into the central tendon of the quadriceps. The rectus femoris tendon is discretely separated from the deeper vastus intermedius until it reaches the distal end. The rectus femoris, vastus medialis obliques (VMO), vastus medialis (VM), vastus lateralis (VL) and vastus lateralis obliques (VLO) all terminate and merge distally in the superficial portion of the patellar tendon ultimately becoming



contiguous with the tibial periosteum.<sup>16</sup> The quadriceps' role in stabilizing the knee joint will be discussed with regard to the ACL.

The hamstrings muscle group is comprised of the semimembranosus (SM), semitendinosus (ST) and the biceps femoris (BF); with the biceps femoris including the long head (LH) and short head (SH). The hamstrings cross and act upon the two joints of the hips and knee.<sup>33</sup> The semitendinosus, semimembranosus and biceps femoris long head all originate at the ischial tuberosity.<sup>33</sup> The semitendinosus inserts at the medial surface of the tibia, the semimembranosus inserts at the medial tibial condyle and the long head inserts on the lateral side of the head of the fibular.<sup>33</sup> The short head of the biceps femoris originates at the linea aspera and lateral supracondylar line of femur while inserting at a shared tendon with the long head on the lateral side of the head of the fibular.<sup>33</sup> The hamstrings' role in stabilizing the knee joint will be discussed in regards to the ACL.

Dynamic of knee joint stability includes an agonist-antagonist relationship between the quadriceps and hamstring muscles. It has been reported that an increased co-contraction force by the hamstring and quadriceps serves to increase knee stability and decrease the risk of ligament damage.<sup>35</sup> As athletes contract their quadriceps they extend their knee. The quadriceps serves to stiffen or compress the tibiofemoral joint. The common quadriceps tendon attaches at the superior patella, and then attaches via the infrapatellar tendon to the tibial tubercle on the anterior tibia. As the quadriceps contract they pull the tibia anterior relative to the femur. The resultant biomechanical problem is that the ACL serves to maintain the posterior nature of the tibia (or check anterior movement), and when an athlete uses their quadriceps to stabilize the joint it causes an anterior shear stress to the tibia thus putting additional

stress on the ACL.<sup>17</sup> This anterior shear stress is reduced by the co-contraction of the hamstring muscles to hold the quadriceps' forces in check.

### **C.3 Eccentric Training**

The experimental group of this study will undergo an alternative strength and conditioning protocol in an attempt to impart or alter the quad dominance phenomenon described above. The strength and conditioning protocols will involve a traditional program with balanced concentric-eccentric training, while the experimental program will include additional eccentrically emphasized exercises. Muscles contract, flex, and shorten when in the concentric phase and elongate, stretch, and lengthen when in the eccentric phase.

The eccentric action of a muscle refers to a resisted lengthening of that muscle. In short, the muscle is exerting force while it's being lengthened. This type of action has also been called the yielding action (opposed to the overcoming action which refers to the actual lifting of the resistance) as well as negative action. Eccentric action is present in most free weight and machine exercises; however, since concentric strength potential is lower than the eccentric strength potential, the eccentric portion of a movement is rarely fully stimulated; the relative weakness of the concentric portion prevents a complete overload during the eccentric portion of the exercise. This weakness has never been defined, however it has been speculated that the increased strength potential of eccentric actions in comparison to concentric actions is due to the fact that it takes increased forces to break the actin-myosin cross-bridges once they are formed.<sup>2,7</sup> It's the eccentric portion of an exercise which provides the most gains physiologically and from a performance standpoint because they help to elicit the most muscle adaptation.

The eccentric (yielding/negative) portion of an exercise is responsible for more strength gains than the concentric (overcoming) portion.<sup>7-8</sup> For example, studies by Hortobagyi et al. established that the total maximal strength improvement from eccentric-only training brought more strength gains than a concentric-only program followed for six weeks. In regards to total maximal strength, researchers were referring to the sum of maximum concentric, isometric, and eccentric strength.<sup>25-26</sup> In that parameter, eccentric training gave a mean improvement of 85% while concentric training led to an improvement of 78%. Furthermore, this study used sub-maximal eccentric actions and maximal concentric actions.<sup>25-26</sup> This points to the potential of yielding or eccentric strength training, at least when maximum strength gains are concerned. <sup>25-26</sup> These results concur with the body of scientific literature on the subject. For example, a study by Higbie et al. found a combined strength increase (concentric strength improvement plus eccentric strength improvement) of 43% with an eccentric-only regimen compared to one of 31.2% with a concentric-only regimen.<sup>23</sup> A study by Hilliard-Robertson et al. should also be noted, which concluded: "A resistance training protocol which includes eccentric as well as concentric exercise, particularly when the eccentric is emphasized, appears to result in greater strength gains than concentric exercise alone." <sup>24</sup> Additional evidence to lend support to the earlier work was done by Komi and Buskirk, who recorded greater strength increases after an eccentric training regimen than after a concentric-only regimen.<sup>26</sup> Colliander also noted that omitting eccentric stress in a training program severely compromises the potential strength gains.<sup>7-8</sup> Additionally a study by Friedmann-Bette reported that eccentric-only training led to an average muscle size gain of 6.6% over ten weeks while a concentric-only program led to gains of 5%.<sup>18</sup>

These results are backed by another study by Farthing and Chilibeck, which concluded that eccentric training resulted in greater hypertrophy than concentric training.<sup>14</sup> One study by LaStayo et al. even found accentuated, or emphasized, eccentric training to cause 19% more muscle growth than traditional strength training over eleven weeks.<sup>30</sup>

The studies above reported eccentric training allows one to stimulate greater strength and size gains versus concentric training alone. There are three major reasons why; a greater neural adaptation to eccentric training than to concentric training;<sup>25-26</sup> a more important force output produced during a maximal eccentric action (greater overload) because you can use a higher external load;<sup>7-8</sup> and a higher level of stress per motor unit during eccentric work.<sup>18,23</sup> Less motor units are recruited during the eccentric portion of a movement, thus each of the recruited motor units receives much more stimulation.<sup>18,23</sup> Furthermore, since the nervous system seems to recruit less motor units during a maximal eccentric action, the potential for improvement could be greater than with maximal concentric actions.<sup>23</sup> The recruitment of less motor units during maximal eccentric actions exhibits the greater neural efficiency by way of the decreased motor activation triggering the increased muscular activation. The resultant is then a more focused and active neural response to similar muscular demands.<sup>23</sup> Simply put, less motor neurons are recruited to create a greater force output in the eccentric phases of movement.

#### **C.4 Muscle Physiology**

The way a muscle contracts and the corresponding results of this phenomenon are paramount to this study. Skeletal muscles contract according to the sliding-filament model. An action potential originating in the central nervous system reaches

an alpha motor neuron, which then transmits an action potential down its own axon.<sup>2</sup> The action potential propagates by activating voltage-gated sodium channels along the axon toward the chemical synapse. This potential reaches the motor neuron terminal and causes a calcium ion influx through the voltage-gated calcium channels. The  $\text{Ca}^{2+}$  influx causes vesicles containing the neurotransmitter acetylcholine to fuse with the plasma membrane, releasing acetylcholine out into the extracellular space between the motor neuron terminal and the motor end plate of the skeletal muscle fiber.<sup>2</sup> The muscle fiber membrane becomes more positively charged, triggering an action potential.<sup>2</sup>

The action potential spreads through the muscle fiber's network of T-tubules, depolarizing the inner portion of the muscle fiber. The depolarization activates L-type voltage-dependent calcium channels (dihydropyridine receptors) in the T tubule membrane, which are in close proximity to calcium-release channels in the adjacent sarcoplasmic reticulum.<sup>2</sup> Myosin (which has ADP and inorganic phosphate bound to its nucleotide binding pocket and is in a ready state) binds to the newly uncovered binding sites on the thin filament (binding to the thin filament is very tightly coupled to the release of inorganic phosphate).<sup>2</sup>

Myosin is now bound to actin in the strong binding state. The release of ADP and inorganic phosphate are tightly coupled to the power stroke (actin acts as a cofactor in the release of inorganic phosphate, expediting the release).<sup>2</sup> This will pull the Z-bands of the sarcomere towards each other, thus shortening the sarcomere and the I-band. ATP binds myosin, allowing it to release actin and be in the weak binding state. The myosin then hydrolyzes the ATP and uses the energy to move into the "cocked back" conformation. This continues until ATP is no longer available. <sup>2</sup>

### **C.5 Electromyography – Quadriceps and Hamstrings Activation**

EMG is a tool used to analyze the amount of muscle activation during contraction. Muscles create an electrical output when they contract caused by physiological processes.<sup>29</sup> The excitability of muscle fibers through neural control represents a major factor in muscle physiology. This phenomenon can be explained by a model of a semi-permeable membrane describing the electrical properties of the sarcolemma.<sup>3</sup> An ionic equilibrium between the inner and outer spaces of a muscle cell forms a resting potential at the muscle fiber membrane. This difference in potential which is maintained by physiological processes (ion pump) results in a negative intracellular charge compared to the external surface.<sup>2</sup> As the central nervous system calls for muscle contraction, the activation of an alpha-motor anterior horn cell (induced by the central nervous system or reflex) results in the conduction of the excitation along the motor nerve.<sup>2,3,15</sup> After the release of transmitter substances at the motor endplates, an endplate potential is formed at the muscle fiber innervated by this motor unit.<sup>12,15</sup> The diffusion characteristics of the muscle fiber membrane are briefly modified and Na<sup>+</sup> ions flow in. This causes a membrane depolarization which is immediately restored by backward exchange of ions within the active ion pump mechanism.<sup>29</sup>

If a certain threshold level is exceeded, a depolarization of the muscle membrane causes an action potential to quickly change.<sup>2,29</sup> It is a mono-polar electrical burst that is immediately restored by the re-polarization phase and followed by an hyper-polarization period of the membrane.<sup>29</sup> Starting from the motor end plates, the action potential spreads along the muscle fiber in both directions and inside the muscle fiber.<sup>3,15</sup> This excitation leads to the release of calcium ions in the intracellular space. Linked chemical processes (electro-mechanical coupling) finally

produce a shortening of the muscle cell. 2,3,29 This model linking excitation and contraction represents a highly correlated relationship.<sup>15</sup> From a practical point of view, one can assume that in a healthy muscle any form of muscle contraction is accompanied by the described mechanisms.

The EMG signal is based upon action potentials at the muscle fiber membrane resulting from depolarization and re-polarization processes as described above.<sup>2,29</sup> After initial excitation the electrical current travels along the muscle fiber at a velocity of 2-6m/s and passes over the EMG electrode which transmits it for analysis. 2,3,29 The action potential in muscles is a direct result of messages from the nervous system to contract and perform tasks. The co-contraction (simultaneous contraction) of the quadriceps and hamstrings during functional tasks serves to stabilize the knee.<sup>16-17</sup> Several studies report that females show a discrepancy when compared to males with regard to hamstring activation.<sup>3,12,21,38,41</sup> Hewett et al. categorize this discrepancy as “quadriceps dominance.”<sup>22</sup>

The quadriceps dominance imbalance during functional tasks in females has been demonstrated by several studies using EMG analysis of muscle activation.<sup>2,9,23,37</sup> Studies have looked at the muscle activation and respective ratios of hamstring-quadriceps activation during functional tasks ( jump-landing, cutting, and vertical stop-jumps).<sup>2,9</sup> With jump and drop landings being highlighted as effective tasks to analyze the ratios of hamstring-quadriceps activation in functional tasks, this study aims to use similar tasks to those used in previous studies<sup>2,6,9</sup> to analyze the average time-to-peak EMG activation of the hamstring muscle groups and how it is impacted by two different strength and conditioning training protocols.

Time-to-peak EMG is a measure of how fast the muscle being analyzed activates during a task. Cohen et al. reported that time-to-peak EMG results correlated significantly with increased muscle function and force production.<sup>6</sup> The above study also reported the timing of time to peak beginning at the onset of EMG activity. Falk et al. calculated the onset of EMG activity as when the signal increased five standard deviations above the mean of the baseline activation levels and remained at or above that level for over twenty milliseconds.<sup>13</sup> For the purpose of this study the force plates that the athletes are landing on are being used to trigger the timing of the EMG data. The time-to-peak measures for each athlete will be averaged across the ten trials of each test day (pre and post). The athletes landing on the plate will be marked on the EMG data output. To account for muscle EMG pre-activation there will be three windows of time recorded for EMG output. The three windows of time recording EMG data are as follow; a pre-landing phase of 250 milliseconds before plate strike, a reactionary phase of 250ms immediately after plate strike and then a voluntary phase of 250ms after the reactionary phase. These three phases will allow for analysis of multiple EMG outputs in terms of pre-activation, synched activation or delayed activation. The above windows were also designated at 250ms each because in the study conducted by Cohen et al. a window of 250ms was found to be appropriate for calculating time-to-peak EMG activation measures.<sup>6</sup>

## **C.6 Summary**

Females have demonstrated a discrepancy in ratios of hamstring-quadriceps activation, in comparisons to males, during functional movement tasks. This discrepancy in activation is thought to be a significant cause of the high ACL injury rates in female athletes. Eccentrically emphasized training has been shown to increase



strength gains and muscle growth more effectively than traditional practices. The eccentric portion of functional movements such as jump-landings and cutting tasks have been analyzed and reported to be implicated in ACL injury. These findings when considered together suggest that females lack eccentric functionality and would benefit from strength and conditioning training protocols that emphasize eccentric muscle actions. However, the effect of eccentric training on muscle activation in comparison with traditional training practices has not been studied.