

FIELD-BASED ASSESSMENT OF JUMP LANDING MECHANICS FOLLOWING
PARTICIPATION IN TRADITIONAL VERSUS PLYOMETRIC LOWER
EXTREMITY INJURY PREVENTION PROGRAMS

by

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LIST OF ABBREVIATIONS

Abbreviation	Description
ACL	Anterior Cruciate Ligament
LESS	Landing Error Scoring System

ABSTRACT

Context: Validated, field-based assessment tools for jump landing mechanics provide clinicians with portable, low cost methods of assessing an individual's risk of anterior cruciate ligament (ACL) injury. The Landing Error Scoring System (LESS) is one example of a field test that can be used for mass screenings. Little research has been done to quantify the influence of hip abductor strength on jump landing mechanics, particularly after fatigue has been induced in this muscle group. **Objective:** To investigate the effects of two 4-week lower extremity injury prevention programs (traditional hip abductor exercises versus lower extremity plyometric exercises) on field-based measurements of ACL injury risk before and after inducing neuromuscular fatigue. **Design:** Randomized controlled trial. **Setting:** Controlled laboratory setting. **Participants:** 33 women (age 20.97 ± 1.40 yrs; height, 1.63 ± 0.06 m; mass, 61.31 ± 8.59 kg); were randomly allocated into two groups: Traditional and Plyometric exercises. **Interventions:** Participation in one of two 4-week lower extremity injury prevention programs; hip abductor muscular fatigue was induced bilaterally using a concentric exercise protocol on an isokinetic dynamometer. **Main Outcome Measures:** Right and left limb concentric and eccentric hip abduction peak torque at $120^\circ/\text{s}$, closed kinetic chain single leg press peak force at $60^\circ/\text{s}$, and LESS test results. These measures were assessed pre- and post-fatigue at

baseline (Week 0), and pre- and post-fatigue at Week 4. **Results:** Of the 4 outcome measures that quantified hip abduction peak torque, statistically significant strength gains were observed in both groups for left hip abduction concentric peak torque ($p < 0.001$). Left hip abduction peak torque increased 28% in the Plyometric group and 20% in the Traditional group between Week 0 and Week 4 ($p < 0.001$, $\eta^2 = 0.362$), but no significant between group differences were observed ($p = 0.844$, $1-\beta = 0.054$). Closed kinetic chain, concentric right leg press peak force improved 21% in the Traditional group and 12% in the Plyometric group from Week 0 to Week 4 ($p < 0.001$, $\eta^2 = 0.465$), but there were no significant group differences present ($p = 0.370$, $1-\beta = 0.143$). The 4-week Plyometric lower extremity injury prevention program created significantly greater improvements in the LESS test scores on both the pre-fatigue and post-fatigue trials (16.7% and 11.6% improvements, respectively, between Week 0 and Week 4), than the Traditional exercise program, which demonstrated a 9.0% improvement on pre-fatigue and a 7.9% improvement on post-fatigue LESS test scores between Week 0 and Week 4. **Conclusions:** The lower extremity injury prevention programs that we employed were both effective in creating significant gains in lower extremity muscular strength of the participants over a 4-week period. Both interventions produced significant improvements (decreases) in LESS test scores within their groups. However, the Plyometric exercise group demonstrated significantly greater improvements in LESS test scores, a finding

that supports the premise that plyometric exercises should continue to be a required component in lower extremity injury prevention programs.

Key Words: anterior cruciate ligament, LESS test, plyometrics, hip abductors

CHAPTER 1

Introduction

Injury to the anterior cruciate ligament (ACL) is one of the most common musculoskeletal injuries occurring in sports today. These injuries are associated with significant financial and emotional costs due to well documented surgical and rehabilitation expenses, as well as decreased quality of life primarily due to an onset of early knee osteoarthritis.⁽¹⁻⁹⁾ Approximately 175,000 ACL injuries occur each year in the United States at an estimated cost of over \$2 billion dollars annually.⁽⁸⁾ Numerous authors have reported that females experience ACL injuries at rates of 2 to 10 times greater than their male counterparts and thus this injury disproportionately affects women much more than men.⁽¹⁰⁻¹⁸⁾

Over the years, various ACL injury prevention programs have been introduced to help combat high injury rates. These prevention programs have focused primarily on plyometric activities, balance/proprioception exercises, as well as core and hip musculature exercises.^(4, 9, 11, 13, 15, 16) However, little research has been done to demonstrate which of these ACL injury prevention programs have the greatest effect(s) on decreasing dynamic knee valgus positioning that is widely-recognized to be a causal factor in non-contact ACL injuries.^(4, 9, 13, 19)

In recent years, researchers from around the world have been successful in creating effective ACL prevention programs.^(4, 7, 20) In addition, many authors have developed clinical screening methods to identify individuals with lower extremity biomechanics that are known to put them at risk for ACL injury.

Specifically, poor jump landing mechanics have been linked to multiple lower extremity injuries, including non-contact ACL injuries ^(2, 5, 16, 19, 21-23).

In the United States, the vast majority of sports medicine clinicians work in relatively small clinical settings, e.g., colleges, high schools, outpatient clinics. In most cases, the clinicians employed by these institutions do not have access to the expensive high-speed infrared cameras and force plates needed to conduct the complex three-dimensional kinematic and kinetic analyses that are typically used to screen individuals for ACL injury risk in research laboratory settings.

This reality presents a problem for the sports medicine clinician who recognizes the benefit of pre-season screenings to identify specific groups of athletes who may be at risk of suffering an ACL injury. The challenge is that there are very few low-cost alternatives to high-tech, laboratory-based ACL injury screening, but some inexpensive, low-tech methods do exist.

The Landing Error Scoring System (LESS) test, a low-tech ACL injury risk pre-screening protocol, is one such test that has been shown to be both valid and reliable ⁽²⁴⁾. The LESS test is a relatively inexpensive screening tool that only requires the use of two basic video recorders, e.g., digital cameras, iPads, and a computer monitor for analysis of the images.

Based on a review of the current literature, there is a lack of evidence regarding the relationship between hip abduction strength and jump landing mechanics as evaluated by the Landing Error Scoring System (LESS) test. Hip abduction strength and fatigue have been studied in depth to help determine

these muscle group's effects on knee kinematics, possibly linking them to ACL injuries^(5, 12, 14, 22, 25-27). While the LESS test has been found to be a valid and reliable screening tool, no previous studies have been published that have examined the results of the LESS test after participants have completed prescribed exercise programs intended to increase hip musculature strength and endurance, or the influence of their contribution to jump landing mechanics.^(24, 28)

Padua et al.⁽²⁴⁾ recently evaluated the effectiveness of the LESS test on both males and females (n=50) during jump-landings. Each participant was required to jump from a 30 cm box to a marked distance of 50 percent of the participant's height, onto a force plate, and then perform a maximal vertical jump. These authors concluded that individual participants with higher LESS scores demonstrated different lower extremity kinematics and kinetics across multiple biomechanics factors and multiple planes of motion compared to individuals with lower LESS scores.⁽²⁴⁾ Individuals with higher LESS scores or poor jump-landing technique, demonstrate decreased hip and knee flexion, increased knee valgus and hip internal rotation, greater knee joint loading and vertical ground reaction forces.⁽²⁴⁾ These biomechanical abnormalities may place the individual at an increased risk of sustaining an ACL injury.^(24, 29-33)

There is a critical need to evaluate this research question with a randomized controlled trial because it will examine the effects of two 4-week interventions (a hip abduction program and a lower extremity plyometric strengthening program) among college-age women, and their subsequent (immediate) effects on drop landing mechanics measured by the LESS test. By

comparing these two methods of strengthening the hip abduction musculature, we may confirm and/or further establish the importance of hip abduction strength in ACL injury prevention. The results of this study may also provide additional insights related to the hypothesis that ACL injuries are more likely attributed to neuromuscular deficits that lead to biomechanical dysfunctions rather than the other known factors, e.g., hormonal, anatomical.⁽³³⁾

The hip abduction, hamstring, and quadriceps muscle groups are all involved with the control of the knee during athletic activities; this study will specifically examine the significance of hip abduction strength for ACL injury prevention programs. Closed kinetic chain frontal plane movement at the knee, specifically, dynamic valgus angulation, has been shown to be influenced by eccentric hip abduction strength.^(1, 6, 21, 22, 34, 35) If we are able to demonstrate that dynamic knee valgus angles during drop landing testing decrease in a manner proportional to increases in hip abduction strength, clinicians may change the focus of their ACL injury prevention protocols. If a significant gain in hip abduction strength is shown to have a positive effect on decreasing dynamic knee valgus, then athletic trainers, physical therapists, and strength and conditioning specialists, among others, can emphasize strengthening exercises for these muscles.

Current research also suggests that the hip abduction musculature may have more of an effect on controlling excessive knee valgus and transverse plane motions than does the quadriceps group.^(33, 36) These transverse plane motions (internal and external rotation) are important, primarily due to their

implications associated with ACL injuries.^(26, 34-36) Several studies have reported that decreased sagittal plane motions may also be implicated as being vital to the identification of individuals at risk of experiencing an ACL injury.^(8, 11, 18, 22, 37)

Decreases in sagittal plane motions, specifically knee flexion, have been implicated with causing increased ACL strain, due to quadriceps firing patterns causing an increase in anterior shear forces being applied across the ACL.^(8, 11, 18, 22, 37)

From a technology standpoint, the LESS test requires only that the clinician have access to two tripod-mounted digital video cameras that enable to the recording of motion at a reasonable rate, e.g., 30 frames per second, in both the frontal and sagittal planes of view. By using a low-tech approach to this ACL injury screening tool, we will be able to determine the extent to which participation in one of two intervention protocols (lower extremity plyometrics or traditional hip abduction strengthening) influences drop landing biomechanics. At the conclusion of this study we plan to have a greater understanding of the influence of lower extremity strength and endurance on dynamic knee stability.

The purpose of this study was to compare the effects of two 4-week lower extremity injury prevention protocols (traditional exercises versus lower extremity plyometrics) on frontal and sagittal plane landing mechanics after completing a hip abduction fatigue protocol. We will also quantify the effects of each prevention protocol, traditional and plyometric, on LESS test scores. These LESS test scores will provide us with information regarding the participants' ACL injury risk both before and after training.

Following the successful oral defense of this thesis, an abstract of these findings will be submitted in advance of the November 15, 2014 deadline for a peer-reviewed presentation at the 66th annual meeting of the National Athletic Trainers' Association, to be held in St. Louis to be held June 23-26, 2015. In the interim, the primary manuscript from this thesis will be submitted for publication to the *Journal of Athletic Training*.

CHAPTER 2

Manuscript

Field-Based Assessment of
Jump Landing Mechanics following Participation in
Traditional versus Plyometric Lower Extremity Injury Prevention Programs

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ABSTRACT

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concentric peak torque ($p < 0.001$). Left hip abduction peak torque increased 28% in the Plyometric group and 20% in the Traditional group between Week 0 and Week 4 ($p < 0.001$, $\eta^2 = 0.362$), but no significant between group differences were observed ($p = 0.844$, $1-\beta = 0.054$). Closed kinetic chain, concentric right leg press peak force improved 21% in the Traditional group and 12% in the Plyometric group from Week 0 to Week 4 ($p < 0.001$, $\eta^2 = 0.465$), but there were no significant group differences present ($p = 0.370$, $1-\beta = 0.143$). The 4-week Plyometric lower extremity injury prevention program created significantly greater improvements in the LESS test scores on both the pre-fatigue and post-fatigue trials (16.7% and 11.6% improvements, respectively, between Week 0 and Week 4), than the Traditional exercise program, which demonstrated a 9.0% improvement on pre-fatigue and a 7.9% improvement on post-fatigue LESS test scores between Week 0 and Week 4. **Conclusions:** The lower extremity injury prevention programs that we employed were both effective in creating significant gains in lower extremity muscular strength of the participants over a 4-week period. Both interventions produced significant improvements (decreases) in LESS test scores within their groups. However, the Plyometric exercise group demonstrated significantly greater improvements in LESS test scores, a finding that supports the premise that plyometric exercises should continue to be a required component in lower extremity injury prevention programs.

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INTRODUCTION

Injury to the anterior cruciate ligament (ACL) is one of the most common musculoskeletal injuries occurring in sports today. These injuries are associated with significant financial and emotional costs due to well documented surgical and rehabilitation expenses, as well as decreased quality of life primarily due to an onset of early knee osteoarthritis.⁽¹⁻⁹⁾ Approximately 175,000 ACL injuries occur each year in the United States at an estimated cost of over \$2 billion dollars.⁽⁸⁾ Numerous authors have reported that females experience ACL injuries at rates ranging from 2 to 10 times greater than their male counterparts.⁽¹⁰⁻¹⁸⁾

Recently, a variety of ACL injury prevention programs have been developed to help combat high injury rates. These prevention programs have focused primarily on plyometric activities, balance and proprioception, as well as core, knee and hip muscle strengthening exercises.^(4, 9, 11, 13, 15, 16) However, little research has been done to demonstrate which of these ACL injury prevention programs have the greatest effect(s) on decreasing dynamic knee valgus positioning that is widely-recognized to be a causal factor in non-contact ACL injuries.^(4, 9, 13, 19)

In recent years, researchers from around the world have been successful in creating effective ACL prevention programs.^(4, 7, 20) In addition, many authors have developed clinical screening methods to identify individuals with lower extremity biomechanics that are known to put them at risk for ACL injury. Specifically, poor jump landing mechanics have been linked to multiple lower extremity injuries, including non-contact ACL injuries^(2, 5, 16, 19, 21-23).

In the United States, the vast majority of sports medicine clinicians work in relatively small clinical settings, e.g., high schools, colleges, outpatient clinics. In most cases, clinicians employed by these institutions do not have access to the expensive high-speed infrared cameras and force plates needed to conduct the complex three-dimensional kinematic and kinetic analyses that are typically used to screen individuals for ACL injury risk in research laboratory settings.

This reality presents a problem for the sports medicine clinician who recognizes the benefit of pre-season screenings to identify specific athletes who may be at risk of suffering an ACL injury. The challenge is that there are very few low-cost alternatives to high-tech, laboratory-based ACL injury screening, but some inexpensive, low-tech methods do exist.

The Landing Error Scoring System (LESS) test, a low-tech ACL injury risk pre-screening protocol, is one such test that has been shown to be both valid and reliable ⁽²⁴⁻²⁶⁾. The LESS test is a relatively inexpensive screening tool that only requires the use of two basic video recorders, e.g., digital cameras, iPads, and a computer monitor for analysis of the images.

Based on our review of the current literature, there is a lack of evidence regarding the relationship between hip abduction strength and jump landing mechanics as evaluated by the Landing Error Scoring System (LESS) test. Hip abduction strength and fatigue have been studied in depth to help determine these muscle group's effects on knee kinematics, possibly linking them to ACL injuries ^(5, 12, 14, 22, 27-29). While the LESS test has been found to be a valid and reliable screening tool, no previous studies have been published that have

examined the results of the LESS test after participants have completed prescribed exercise programs intended to increase hip musculature strength, endurance and/or power, or the influence of their contribution to jump landing mechanics^(24, 30).

Current research suggests that the hip abduction musculature may have more of an effect on controlling excessive knee valgus and transverse plane motions than does the quadriceps muscle group^(31, 32). These transverse plane motions (internal and external rotation) are important, primarily due to their implications associated with ACL injuries^(28, 31, 33, 34). Several authors have reported that decreased sagittal plane motions may also be implicated as being vital to the identification of individuals at risk of experiencing an ACL injury.^(8, 11, 18, 22, 35) Decreases in sagittal plane motions, specifically knee flexion, have been implicated with increased ACL strain due to quadriceps firing patterns, causing an increase in anterior shear forces being applied across the ACL.^(8, 11, 18, 22, 35)

Research on the LESS test has been conducted to determine its effectiveness as a screening tool, but to our knowledge there has been no published research that has examined the LESS test after participants completed hip abduction strengthening and acute fatigue protocols. Therefore, the purpose of this study was to use a randomized controlled trial design to compare the effects of two different 4-week lower extremity injury prevention protocols on frontal and sagittal plane landing mechanics before and after completing an acute hip abductor fatigue protocol. We also sought to quantify the effects of

each lower extremity injury prevention protocol, Traditional and Plyometric, on the LESS test scores prior to and following the introduction of fatigue.

METHODS

Design

We employed a randomized controlled trial to compare the effects of two different 4-week lower extremity injury prevention protocols (plyometric exercises and traditional resistance band exercises) and evaluate the acute effects of fatigue on frontal and sagittal drop-landing mechanics using the LESS test to score the landings. We employed 2 independent variables for 6 of the 7 outcome measures in this study: Group, consisting of a Traditional and a Plyometric exercise group, and Time, comprised of pre-test (Week 0) and post-test (Week 4) measurements. Those 6 outcome measures were right and left concentric hip abduction peak torque at 120°/s, right and left eccentric hip abduction peak torque at 120°/s, and right limb closed kinetic chain concentric and eccentric leg press peak force at 60°/s.

To evaluate the LESS test scores, we employed 3 independent variables: Group, consisting of a Traditional and a Plyometric exercise group, Time, comprised of pre-test (Week 0) and post-test (Week 4), and Fatigue Status (pre-fatigue or post-fatigue).

Participants

A total of 35 recreationally-active female volunteers between the ages of 18 and 24 were initially screened for eligibility to participate in this study; 33 of those individuals (age, 20.97 ± 1.4 yrs; height, 1.63 ± 0.06 m; mass, 61.31 ± 8.59 kg) met all of the inclusion criteria and subsequently completed all aspects of the study. We operationally defined a “recreationally active” individual as one who engages in moderate-intensity physical activity for at least 30 minutes on at least three days of the week.⁽³⁶⁾ According to the American College of Sports Medicine, to achieve their basic recommendation for cardiorespiratory exercise one must engage in the following: moderate-intensity aerobic physical activity for a minimum of 30 minutes on five days each week or vigorous-intensity aerobic physical activity for a minimum of 20 minutes on three days each week.⁽³⁷⁾ Participants who volunteered for this study were screened to ensure that they were not currently participating in any lower body resistance training as part of their regular physical activity for the previous 4 weeks.

All data collection sessions were conducted in the Biomechanics and Sports Medicine Laboratory at Texas State University. All lower extremity injury prevention exercise sessions ranged from 15 to 30 minutes in duration and were held at either the Jowers Center Athletic Training Rehabilitation Room or the Bobcat Stadium End Zone Complex, and were supervised by a certified and licensed athletic trainer (NJR). The possible risks and benefits associated with participation in this study were explained to the volunteers. Volunteers who satisfied the inclusion/exclusion criteria were required to provide informed

consent prior to participation in any aspect of this study which was approved by the Institutional Review Board at Texas State University (IRB #2014E4204).

The women who completed all aspects of the study received a \$30 gift card, a \$15 gift card if the volunteer only participated in half of the study, and a \$10 gift card if she withdrew from the study after performing only the baseline measurements. All 33 women who met all the inclusion criteria completed all of the supervised and home exercise sessions as scheduled. One participant sprained her ankle during an activity outside of the study after completing the 4-week exercise program and was unable to perform the laboratory-based post-test activities; her data were subsequently excluded from our analysis.

Instrumentation

Strength testing of the hip abduction muscle group was performed using an isokinetic dynamometer (Biodex System 4 Pro™, Biodex Medical Systems, Shirley, NY). The isokinetic dynamometer was used initially to obtain hip abduction peak torque and closed kinetic chain leg press peak force values, and later used to administer the lower extremity fatigue protocol. A commercially-available wooden box (30.5 cm H x 42.5 cm L x 45.5 cm W) was used for administration of the Landing Error Scoring System (LESS) test.^(24, 26) Two digital tablets (iPad 3, Apple, Inc., Cupertino, CA) were used to collect digital video recordings of the LESS test. Each iPad was placed exactly 3 meters away from the individual's landing zone; one iPad was placed perpendicular to the frontal plane and the other perpendicular to the sagittal plane of motion.

Table 1. Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
<ul style="list-style-type: none"> • Must be free from any current lower extremity pain that has limited their activity in the past 6 months 	<ul style="list-style-type: none"> • Currently or within 6 months have been diagnosed with a lower extremity injury
<ul style="list-style-type: none"> • Must be free from any current injury that has limited their activity in the past 6 months 	<ul style="list-style-type: none"> • Lower extremity pain that has limited participants activity within the last 6 months
<ul style="list-style-type: none"> • No history of lower extremity injuries requiring surgery 	<ul style="list-style-type: none"> • History of anterior cruciate ligament injury
<ul style="list-style-type: none"> • No previous history of anterior cruciate ligament injury 	<ul style="list-style-type: none"> • Previously participated in an anterior cruciate ligament injury prevention program
<ul style="list-style-type: none"> • No previous participation in an anterior cruciate ligament injury prevention program 	<ul style="list-style-type: none"> • No participation in resistance training or the 4 weeks prior to the start of the study
	<ul style="list-style-type: none"> • Genu valgum tibiofemoral alignment (Q angle) greater than 20 degrees
	<ul style="list-style-type: none"> • Current participation in university-sponsored athletics or club sports

The Landing Error Scoring System (LESS) test was employed as a standardized scoring rubric to evaluate the biomechanical aspects of drop landings performed by each participant.^(24, 25) The LESS test is public information and can be used free of charge. All LESS Test video recordings were scored by the primary researcher (NJR). To establish intra-rater (test-retest) reliability, the primary author analyzed the LESS test performances of 10 pilot subjects who

were not participants in our intervention study. Using intraclass correlation ($ICC_{2,1}$) statistics, we calculated intra-rater reliability at 0.77.

Experimental Procedures

Individuals who volunteered for this study were also screened to determine that they had not recently participated or were not currently participating in any university- sanctioned or club sports in order to control for a ceiling effect. All volunteers had bilateral Q-angle measurements taken by the principal researcher (NJR), a certified and licensed athletic trainer, as part of the screening process. During the initial meeting the principal researcher established each volunteer's dominant manipulation leg. This was accomplished by asking the volunteer a simple question, "Which leg do you prefer to use to kick a ball?"⁽²⁴⁾

Participants were randomized to one of two groups, a "Plyometric" lower extremity injury prevention program group (n=16) and a "Traditional" lower extremity injury prevention group (n=17). To qualify, volunteers needed to be free from any current lower extremity pain or injury that had limited their activity in the past 6 months and any past injuries requiring surgery to the lower extremity (Table 1). Randomization to groups took place using an envelope containing 10 slips of paper with the numbers 1 and 2 written on the slips of paper; 5 labeled with the number 1 (Traditional group) and 5 labeled with the number 2 (Plyometric group). After 10 participants selected their tabs and were assigned to their respective groups, all 10 slips of paper were placed back into the envelope.

This method was chosen to ensure complete randomization for the second, third, and fourth groups of 10 participants.

Each participant's height was measured and then used to establish their landing zone distance for the LESS test. Prior to each of the laboratory data collection sessions, study volunteers were encouraged to avoid caffeinated beverages and/or dietary supplements to avoid any potential performance enhancement during the isokinetic dynamometer strength and fatigue testing. Volunteers who qualified for participation were then randomly assigned to one of two groups: Plyometric or Traditional lower extremity injury prevention exercise intervention. Next, a 5-minute bout of stationary biking (60 to 90 rpm) was used as a warm-up prior to testing and training activities associated with the study. Following the warm-up period, participants began the initial data collection session by performing 3 trials of the LESS test to generate baseline as well as pre-fatigue drop landing measurements.

After imposing a mandatory 1-minute rest period after completion of the LESS test trials, participants were permitted 10 practice trials of submaximal concentric and eccentric closed kinetic chain (CKC) leg press to familiarize themselves with the testing procedures. We tested only the right limb of all participants because the manufacturer produces only a right limb CKC leg press attachment for their dynamometer. Participants performed the CKC leg press isokinetic strength tests in both concentric and eccentric modes. To obtain a participant's peak force value, 5 maximum concentric and eccentric repetitions of the CKC leg press through the participant's full available range of motion were

performed at 60°/s (Figure 1).

After completing the concentric and eccentric CKC leg press testing, hip abduction strength measures were performed in a standing position, based on the protocol used by Brent et al. (Figure 2).⁽¹⁰⁾ The movement arm of the dynamometer was positioned just superior to the lateral epicondyle, and participants were instructed to hold onto the dynamometer head for increased stability during the hip abduction concentric/eccentric strength testing trials. The dynamometer locking knob, or axis of the dynamometer, was aligned at the level of the hip joint.

Participants were permitted a maximum of 10 practice trials of submaximal standing hip abduction concentric and eccentric movements to familiarize themselves with the testing procedures. After the practice trials were completed, maximal concentric and eccentric hip abduction peak torque measurements at 120°/s through the participant's full available range of motion were obtained. Hip abduction peak torque values were obtained using the highest of the 5 maximal concentric and eccentric repetitions. Participants received scripted verbal encouragement from the principal researcher (NJR) during hip abduction and closed kinetic chain leg press strength testing. The verbal motivation was scripted and read in a similar manner to each individual participant in effort to ensure that each participant received the same type and amount of encouragement (Appendix G).

Figure 1. Closed Kinetic Chain Leg Press Testing Position.



Figure 2. Standing Hip Abduction Testing Position.



Muscle Fatigue Protocol

We used the participants' initial 5 maximum voluntary concentric repetitions of hip abduction at 120°/s to individualize each person's fatigue protocol, The testing velocity of 120°/s was chosen based on previous research by Brent et al., who demonstrated that 120°/s was a velocity that could be

comfortably performed in the upright position and represented hip abduction/adductor velocities during high-risk cutting activities.⁽¹⁰⁾ The standing position (Figure 2) was also used as the testing position for this study because it places the individual in a more functional position than the previously-researched side lying position. Our participants performed the maximum voluntary concentric repetitions bilaterally to obtain the peak hip abduction torque values for both lower limbs.

Based on previous research by Garcia et al., the fatigue criterion was set at a 50% decrease from the concentric peak torque value.⁽²¹⁾ Upon completion of the 5 maximum voluntary concentric repetitions for each limb, the principal researcher (NJR) individually calculated each participant's fatigue value percentage using that participant's known peak torque value. Participants were given 1 minute of rest after the 5 peak abduction torque trials before initiating the hip abduction fatigue protocol. Participants were instructed to perform a series of successive maximal voluntary concentric standing hip abduction repetitions until 3 consecutive trials fell below the established fatigue criterion (torque output below 50% of maximal torque). The total number of repetitions, total work and total time for these trials were recorded by the dynamometer's software for analysis at a later date. In keeping with the Thomas et al.^(17, 38) fatigue protocol, participants then were given a 20 sec rest period before resuming the fatigue protocol activities until 3 consecutive repetitions again fell below the predetermined 50% fatigue value. This fatigue protocol was repeated until the participant reached a fatigued state, operationally-defined as the point where the

first 5 consecutive maximal voluntary concentric repetitions are below the established 50% of initial peak torque value, after Thomas et al.^(17, 38) After fatigue has been established in the first extremity, the fatigue protocol was repeated with the contralateral limb.

While performing the fatigue protocol, the participant received scripted encouragement from the principal researcher (NJR). This motivational tactic was scripted and read to each individual participant to ensure that each participant received the same type and degree of verbal encouragement during the fatigue exercise bout (Appendix G).

Landing Error Scoring System (LESS)

Both before and after muscular fatigue was induced in both legs, the participant moved to the area within the research lab where 3 trials of the LESS tests were performed. The LESS tests performances were recorded using 2 high-definition (1080 p) digital tablets (Apple iPad 3) with imaging rates of 30 fields per second (fps) and were mounted on tripods 3 meters away from the anticipated landing zone. One digital tablet was placed so as to capture the participant's sagittal plane motion at the trunk, hip, knee, ankle and foot, while the second digital tablet was placed to record joint motion in the frontal plane for later analysis.

The LESS test requires that the participant stand on a box (30.5 cm H x 42.5 cm L x 45.5 cm W) and then jump forward to a line marked on the floor that equals half of the participant's height, and then jump straight up and land from a

maximum vertical jump height.⁽²⁴⁾ (Figures 3a, 3b and 3c). These LESS test procedures were read aloud to the participant prior to performing the first jump-landing trial. Participants were required to complete 3 successful tests. If a participant fell during a trial or did not perform the LESS test correctly, they completed additional jumps until 3 trials that met the requirements were obtained. Participants were not provided with any feedback during jump-landings, unless the jump task was performed incorrectly.⁽²⁴⁾ If a participant asked a question regarding the LESS test procedures, the principal researcher read the LESS test directions again, but did not provide any further instruction.

The recorded video data from the LESS tests were stored and analyzed at a later date when the participant was not present. The trained assessor utilized the video recordings to score each LESS test with its standardized 17-point scoring system. When examining the video recordings, the assessor focused on the designated “test leg”, which was defined as the participant’s dominant leg⁽²⁴⁾ (Table 2). The 3 trials of each participant’s pre-fatigue and post-fatigue LESS tests were averaged to obtain overall 3-trial average LESS test scores that were used for statistical analysis.⁽³⁰⁾ The LESS test scores are categorized into following ranges: LESS scores of less than or equal to 4 points are considered “excellent” landing technique, LESS test scores of 5 or 6 points are defined as “moderate”, while scores greater than 6 points are considered “poor” landing technique.⁽³⁰⁾ The higher the LESS test score, the greater the number of landing errors that were committed by the participant, signifying a greater risk of ACL injury. The LESS test scores provide objective information regarding the

participants' ACL injury risk both before and after training, with decreased LESS test scores indicative of reduced ACL injury risk. A free Kinovea kinematic analysis shareware program (Kinovea.org, accessed April 18, 2014) was used by the trained assessor to assist in the analyses of the LESS test videos.

Figure 3. The Landing Error Scoring System (LESS) test. (a) Preparatory phase; (b) Landing phase; (c) Jump phase.

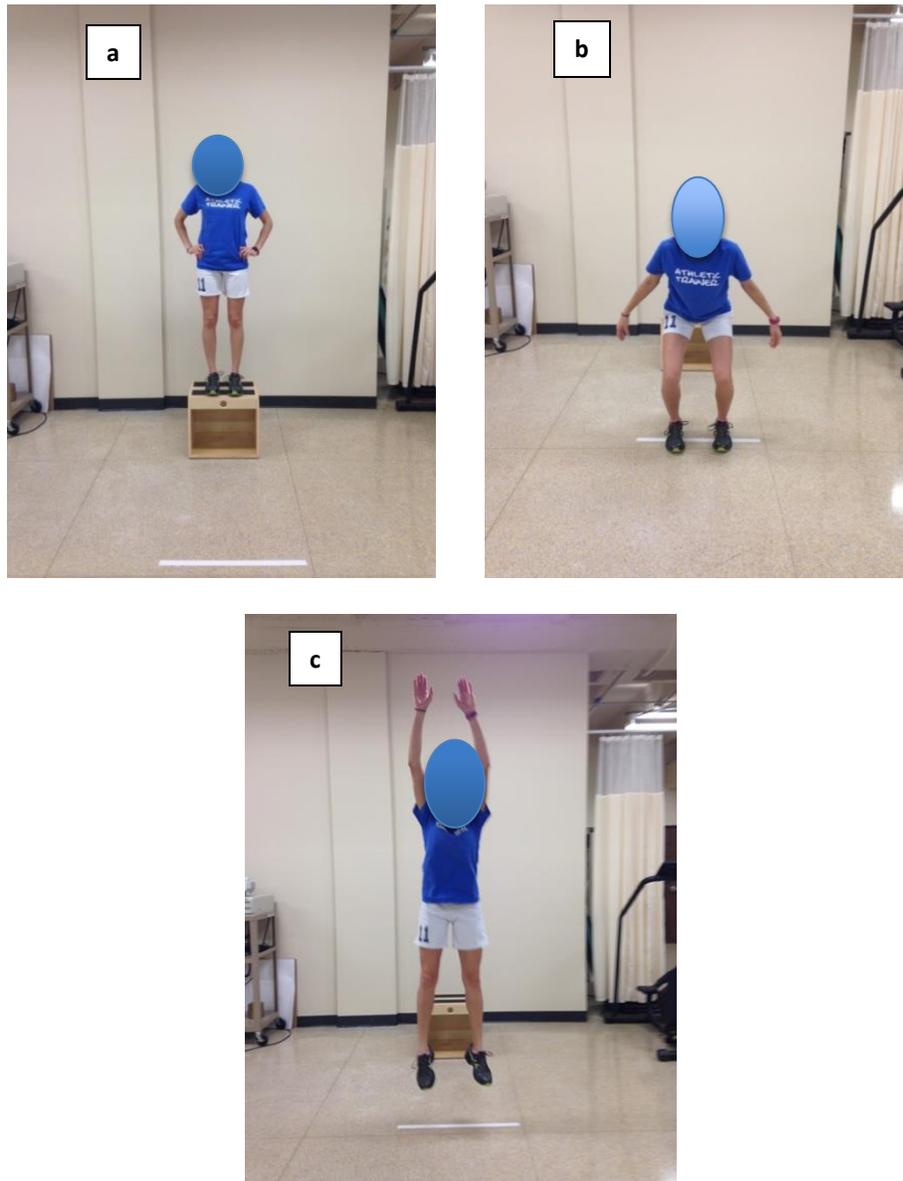


Table 2. LESS Test Scoring Rubric⁽²⁵⁾

Knee flexion angle at initial contact	At the time point of initial contact, if the knee of the test leg is flexed more than 30 degrees, score NO	0 = yes	1 = no
Hip flexion angle at initial contact	At the time point of initial contact, if the thigh of the test leg is in line with the trunk then the hips are not flexed and score NO. If the thigh of the test leg is flexed on the trunk, score YES	0 = yes	1 = no
Trunk flexion angle at initial contact	At the time point of initial contact, if the trunk is vertical or extended on the hips, score NO. If the trunk is flexed on the hips, score YES.	0 = yes	1 = no
Ankle plantar flexion at initial contact	If the foot of the test leg lands toe to heel, score YES. If the foot of the test leg lands heel to toe or with a flat foot, score NO.	0 = yes	1 = no
Knee valgus at initial contact	At the time point of initial contact, draw a line straight down from the center of the patella. If the line goes through the midfoot, score NO. If the line is medial to the midfoot, score YES.	0 = no	1 = yes
Lateral trunk flexion angle at initial contact	At the time point of initial contact, if the midline of the trunk is flexed to the left or the right side of the body, score YES. If the trunk is not flexed to the left or right side of the body, score NO.	0 = no	1 = yes
Stance width - wide	Once the entire foot is in contact with the ground, draw a line down from the tip of the shoulders. If the line on the side of the test leg is inside the foot of the test leg the score greater than shoulder width (wide), and score YES. If the test foot is internally or externally rotated, grade the stance width based on heel placement.	0 = no	1 = yes
Stance width – narrow	Once the entire foot is in contact with the ground, draw a line down from the tip of the shoulders. If the line on the side of the test leg is outside the foot of the test leg the score greater than shoulder width (narrow), and score YES. If the test foot is internally or externally rotated, grade the stance width based on heel placement.	0 = no	1 = yes
Foot position – toe in	If the foot of the test leg is internally rotated more than 30 degrees between the time period of initial contact and max knee flexion, the score YES. If the foot is not internally rotated more than 30 degrees between the time period of initial contact to max knee flexion, score NO.	0 = no	1 = yes

Table 2, Continued

Foot position – toe out	If the foot of the test leg is externally rotated more than 30 degrees between the time period of initial contact and max knee flexion, the score YES. If the foot is not externally rotated more than 30 degrees between the time period of initial contact to max knee flexion, score NO.	0 = n o	1 = yes
Symmetrical initial foot contact	If one foot lands before the other or if one foot lands heel to toe and the other lands toe to heel, score NO. If the feet land symmetrically, score YES.	0 = yes	1 = no
Knee flexion displacement	If the knee of the test leg flexes 45 degrees more than the angle at the position of initial contact to the max knee flexion score YES. If the knee of the test leg does not flex more than 45 degrees, score NO.	0 = yes	1 = no
Hip flexion displacement at max knee flexion	If the thigh of the test leg flexes more on the trunk from initial contact to max knee flexion angle, score YES. If the thigh does not flex more on the trunk, score NO.	0 = yes	1 = no
Trunk flexion at max knee flexion	If the trunk flexes more from the point of initial contact to the max knee flexion, score YES. If the trunk does not flex more, score NO.	0 = yes	1 = no
Knee valgus displacement	At the point of max knee valgus on the test leg, draw a line straight down from the center of the patella. If the line runs through the great toe or is medial to the great toe, score YES. If the line is lateral to the great toe, score NO.	0 = no	1 = yes
Joint displacement	Watch the sagittal plane motion at the hips and knees from initial contact to max knee flexion angle. If the participant goes through large displacement of the trunk, hips, and knees then score SOFT. If the subject goes through some trunk, hip, and knee displacement, but not a large amount, score AVERAGE. If the participant goes through very little, if any trunk, hip, and knee displacement, score STIFF.	0 = soft	1 = average 2 = stiff
Overall impression	Score EXCELLENT if the participant displays a soft landing and no frontal plane motion at the knee. Score POOR if the participant displays a stiff landing and a large frontal plane motion at the knee. All other landings, score AVERAGE.	0 = excellent	1 = average 2 = poor
Total points (maximum = 17 points)			

Lower Extremity Injury Prevention Exercise Protocols

Our 4-week injury prevention protocols were selected based on previous research demonstrating that a 4-week plyometrics program resulted in significant kinematic changes at the knee joint.⁽¹⁶⁾

Our Plyometric exercise group performed lower extremity plyometric exercises and progressions adapted from Pfile et al. (Table 3).⁽¹⁶⁾ The Traditional exercise group performed a standard hip abduction therapeutic exercise protocol that was based on previous research and EMG studies (Table 4).^(36, 39-41) Commercially-available resistance bands (Thera-Band[®], The Hygenic Corp, Akron, Ohio) were provided for the participants to use during this exercise regimen. The length of each participant's resistance band matched the length of their respective lower limb, specifically, the distance from the superior aspect of the greater trochanter to the apex of the lateral malleolus.

Following a 48-hour rest period following the pre-training strength and fatigue testing, participants were asked to report to the Jowers Center Athletic Training Rehabilitation Room or Bobcat Stadium to begin their respective lower extremity exercise protocols.

Participants were given a printed handout with detailed directions and pictures and were taught how to perform each exercise correctly by the principal researcher (Appendix E).

Participants were instructed to complete their assigned lower extremity injury prevention exercises on 4 days of the week for 4 weeks; the principal researcher supervised 2 exercise sessions per week while 2 exercise sessions

were performed at home without supervision. The scheduling of the 2 supervised exercise sessions per week was individualized to each participant's weekly academic and/or work schedules, e.g., Tuesday and Thursday, Wednesday and Friday groupings.

In addition, all participants kept a daily exercise log in order to document the amount of physical activity performed daily throughout the 4-week intervention. During the supervised training sessions (2 sessions per week), participants were organized into small groups that were in the same exercise program. At these supervised training sessions, the principal researcher (NJR) read aloud the directions on how to correctly performing each exercise. Participants only received feedback to correct improper exercise form; no other feedback was provided.

When completing their randomly-assigned lower extremity injury prevention protocol, all participants used the rate of perceived exertion (RPE) scale.⁽⁴²⁾ The principal researcher instructed participants in the Traditional group to work at a range between 12 to 14 or levels defined as "Somewhat Hard" on the RPE scale. Participants were provided with a RPE scale to take home for use during their unsupervised exercise days (Appendix F).

Participants assigned to the Traditional exercise group (Table 4) were instructed to make the eccentric phases of each exercise longer than the concentric phase. This method was intended to encourage both eccentric and concentric strength gains during the 4-week study. These instructions were

chosen based on previous research that demonstrated hip abduction eccentric strength deficits as a potential risk factor of ACL injuries.^(2, 10, 14, 22, 27, 36)

After 2 weeks, participants returned to the lab for progression of exercises and to verify subject compliance. Traditional exercise programs were progressed to the next stiffest resistance band (Thera-Band®) at the mid-point (2-week) of the study.

The exercises chosen for the Traditional lower extremity injury prevention exercise group were selected using an evidence-based approach. That is to say that we included exercises that have been shown to significantly activate the hip abductor musculature and as a result, improve hip abduction strength.^(36, 39-41)

Participants discontinued their assigned lower extremity injury prevention protocol at the end of 4 weeks and returned to the Biomechanics and Sports Medicine Laboratory within 48 to 72 hours for 3 trials of pre-fatigue LESS testing, final hip abduction and closed kinetic chain leg press concentric/eccentric strength testing, administration of the fatigue protocol, and 3 trials of post-fatigue LESS testing performance. Video records obtained at both at pre-test (Week 0) and post-test (Week 4) sessions were analyzed using the point values based on associated with the LESS Test scoring rubric (Table 2). One evaluator (NJR) analyzed all pre- and post-fatigue trials in order to avoid the introduction of interrater variability as a source of error. Three-trial average LESS scores were calculated for each participant for each condition^(24, 25) and these values were used for statistical analysis.

Table 3. Plyometric Exercise Group Progression

Phase 1 (Weeks 1 and 2)

Exercise	Sets x Repetitions
Forward/backward single-legged line jumps	1 x 30
Side-to-side single legged line jumps	1 x 30
High skips	1 x (28.65 meters)
Distance skips	1 x (28.65 meters)
Broad jumps	2 x 10
Tuck Jumps	2 x 10
Alternating single-legged lateral jumps	2 x 10

Phase 2 (Weeks 3 and 4)

Exercise	Sets x Repetitions
Forward single leg hop, hop, hop and stick	1 x 10
Squat jumps	2 x 10
Single-legged maximal vertical jump	1 x 10
Single-legged jump for distance	1 x 10
Broad jump, jump, jump, vertical jump	1 x 5
180° jumps	1 x 10
Single-legged lateral jumps	1 x 10

Table 4. Traditional Exercise Group Protocol

Exercise	Sets x Repetitions
Standing hip abduction with Thera-Band®	3 x 15
Standing hip abduction 45° with Thera-Band®	3 x 15
Monster walks with Thera-Band®	3 x 15
Clam shells with Thera-Band®	3 x 15
Single-legged bridges	3 x 15
Single-legged deadlifts	3 x 15
Single-legged squats	3 x 15

STATISTICAL ANALYSIS

A series of 6 mixed (between/within) Group (2) x Time (2) ANOVAs allowed us to determine the presence of any statistical differences between the two experimental groups at pre-test and post-test for the 6 outcome measures obtained with an isokinetic dynamometer. A single 3-way mixed ANOVA [Group (2) x Time (2) x Fatigue Status (2)] enabled us to determine the presence of any statistically significant differences between the LESS tests performed by the two experiment groups at Week 0 and at Week 4, while also evaluating the influence of non-fatigued and fatigued states on the LESS test results. An *a priori* alpha level of 0.05 was employed for all statistical tests. IBM SPSS software version 22 was used to perform all statistical analyses.

RESULTS

To determine whether the two experimental groups were statistically different at the outset of the study, we performed 1-way ANOVA testing and Levene's Test for Equality of Error Variances on all 6 pre-test (Week 0) isokinetic measures. The results of these analyses indicated that our randomization process was successful in distributing the variability homogeneously between the two experimental groups, as no statistically significant differences were observed for any of the 6 lower extremity strength measures between the Plyometric and Traditional exercise groups at the beginning of the study ($p > 0.05$) (Table 5).

For 1 of the 6 outcome measures, right hip abduction peak eccentric torque, Levene's Test was significant ($p = 0.02$) and required that we use the Greenhouse-Geisser correction for this variable with our subsequent analysis of the 2-way mixed ANOVA results.

In terms of participant compliance with the 4-week exercise programs, overall attendance at the 2 required supervised training sessions per week was 82%. Twenty-seven of the 33 participants (82%) had a 100% attendance rate, with the remaining 6 participants (18%) had attendance rates that ranged from 86% overall compliance rate (1 absence) to 75% (2 absences). No participant was dropped from the study for exceeding the limit of 2 missed sessions over the 4-week time period. All 33 participants reported 100% compliance with their 2 required home exercise sessions per week.

Table 5. Group Means \pm Standard Deviations, Univariate 1-Way ANOVA and Levene Test Results for Pre-Test Isokinetic Measures

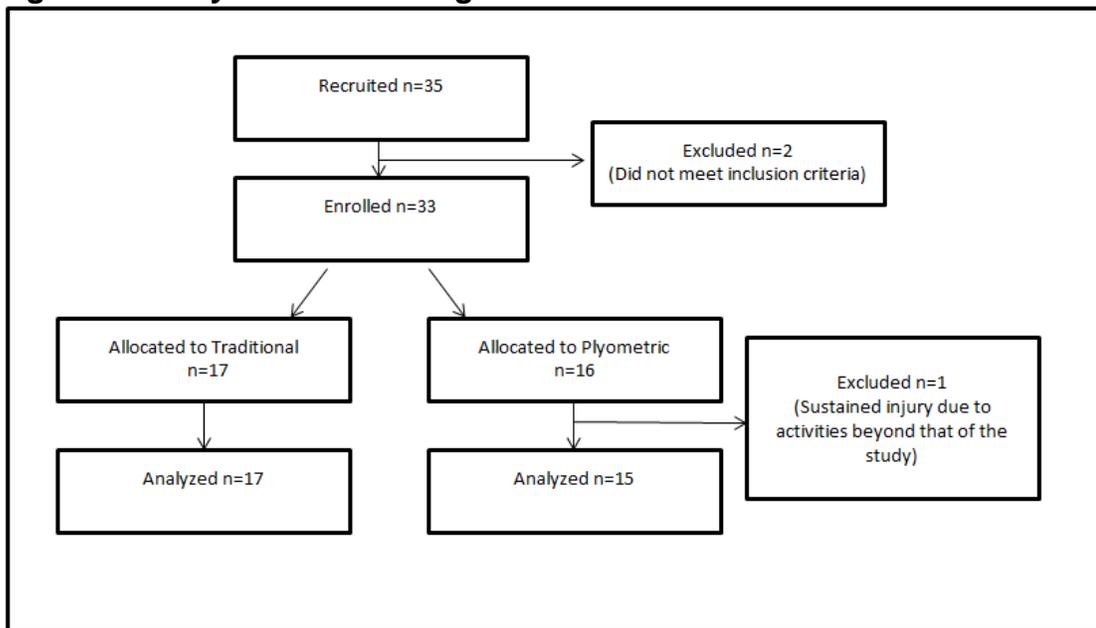
Outcome Measure	Plyometric Group (N = 16) (mean \pm SD)	Traditional Group (N = 17) (mean \pm SD)	p value	Levene's Test
R hip Abduction CON peak torque @ 120°/sec (Nm)	66.6 \pm 32.2	74.2 \pm 16.2	0.397	0.076
L hip Abduction CON peak torque @ 120°/sec (Nm)	61.1 \pm 28.2	63.7 \pm 19.2	0.785	0.129
R hip Abduction ECC peak torque @ 120°/sec (Nm)	90.1 \pm 18.0	92.8 \pm 4.4	0.547	0.022*
L hip Abduction ECC peak torque @ 120°/sec (Nm)	90.1 \pm 18.5	89.8 \pm 10.8	0.960	0.086
R leg press CON peak force @ 60°/sec (N)	1109.3 \pm 232.9	1018.9 \pm 231.0	0.272	0.829
R leg press ECC peak force @ 60°/sec (N)	1193.4 \pm 203.4	1242.1 \pm 159.6	0.449	0.584

* = $p \leq 0.05$; the Greenhouse-Geisser correction was used with this parameter on all subsequent ANOVA tests to correct for heterogeneity of error variance.

More specifically, those assigned to the Plyometric group averaged 100% attendance at the 16 sessions over the 4-week study period (16 ± 0.0 sessions), while the Traditional group who performed Thera-Band® exercises attended an average of 15.5 ± 0.7 of the 16 sessions. These high adherence rates may be attributed to the relatively short workout times required to complete each session,

as the supervised Traditional group sessions averaged 33.6 ± 6.6 minutes in length, while the supervised Plyometric group sessions lasted an average of 15.2 ± 3.5 minutes. The longer workout times for the Traditional group was due to a greater emphasis placed on performing the eccentric phase of the exercises, in addition to the lower intensity of the exercise program, requiring more sets and repetitions than the Plyometric group.

Figure 4. Study CONSORT Diagram



Hip Abduction Strength Measures

Of the 4 outcome measures that quantified hip abduction peak torque, statistically significant strength gains were observed for left hip abduction concentric peak torque. Left hip abduction concentric peak torque values increased 27.9% in the Plyometric group and 19.9% in the Traditional group between Week 0 and Week 4 ($p < 0.001$, $\eta^2 = 0.362$), but no significant between

group differences were observed ($p = 0.844$, $1-\beta = 0.054$) (Table 6). There were no significant Group x Time interaction effects observed for any of the 4 hip abduction strength measures ($p > 0.05$).

Closed Kinetic Chain (CKC) Leg Press

Closed kinetic chain, concentric right leg press peak force improved 21.3% in the Traditional group and 12.4% in the Plyometric group from Week 1 to Week 4 ($p < 0.001$, $\eta^2 = 0.465$), but there were no significant Group differences present for this outcome measure ($p = 0.370$, $1-\beta = 0.143$) (Table 7). No significant Group x Time interaction effects were observed for either of the two CKC leg press variables ($p > 0.05$).

LESS Test Scores

The results of the 3-way mixed ANOVA [Group (2) x Time (2) x Fatigue Condition (2)] revealed significant main effects for Group ($p < 0.026$, $\eta^2 = 0.184$), and for Time ($p < 0.001$, $\eta^2 = 0.658$) [Table 8]. The 4-week Plyometric lower extremity injury prevention exercise program created significantly greater improvements in the LESS test scores on both the pre-fatigue and post-fatigue trials (16.7% and 11.6% improvements, respectively, between Week 0 and Week 4, compared to the Traditional exercise program, which demonstrated a 9.0% improvement on pre-fatigue and a 7.9% improvement on post-fatigue LESS test scores between Week 0 and Week 4 (Table 9).

However, these findings must be interpreted with caution due to the presence of a statistically significant Group x Time interaction ($p < 0.003$, $\eta^2 = 0.307$).

Additionally, a main effect for Fatigue ($p < 0.001$, $\eta^2 = 0.963$) was also observed. Collapsing across experimental groups, the results of our paired t-test analyses indicated that at baseline (Week 0), the average pre-fatigue condition LESS test score was significantly better (7.56 ± 1.99) compared to post-fatigue condition LESS test score (7.98 ± 1.98) that same day ($p < 0.001$). Similarly, the grand mean for the pre-fatigue LESS test score following participation in the intervention protocols (Week 4) was significantly better (6.62 ± 1.84) than the average LESS test score after acute fatigue was induced that same day (7.41 ± 1.94 , $p < 0.001$).

Table 6. Summary of Hip Abduction Strength ANOVA Results (Mean \pm SD, p values and Effect Sizes)

OUTCOME MEASURES	Group Means \pm Standard Deviations				Main Effects (p value)		Effect Size for Time (Eta squared)
	PLYOMETRIC (N = 15)		TRADITIONAL (N = 17)		Group	Time	
	Pre-Test (Week 0)	Post-Test (Week 4)	Pre-Test (Week 0)	Post-Test (Week 4)			
Right hip ABduction CON peak torque (Nm) at 120 deg/sec	67.4 \pm 33.1	74.4 \pm 18.4	74.2 \pm 16.2	80.7 \pm 14.3	0.339	0.069	0.106 (medium)
Left hip ABduction CON peak torque (Nm) at 120 deg/sec	60.3 \pm 29.0	77.1 \pm 13.8	63.7 \pm 19.2	77.1 \pm 13.8	0.884	0.001*	0.362 (large)
Right hip ABduction ECC peak torque (Nm) at 120 deg/sec	90.1 \pm 18.6	86.3 \pm 16.1	92.8 \pm 4.4	92.2 \pm 7.2	0.318	0.156	0.066 (medium)
Left hip ABduction ECC peak torque (Nm) at 120 deg/sec	88.5 \pm 18.1	85.1 \pm 12.9	89.8 \pm 10.8	88.1 \pm 11.6	0.602	0.349	0.029 (small)

* = $p \leq 0.05$

Table 7. Closed Kinetic Chain (CKC) Leg Press ANOVA Results (Mean \pm SD, p values and Effect Sizes)

OUTCOME MEASURES	Group Means \pm Standard Deviations				Main Effects (p value)		Effect Size for Time (Eta squared)
	PLYOMETRIC (N = 15)		TRADITIONAL (N = 17)		Group	Time	
	Pre-Test (Week 0)	Post-Test (Week 4)	Pre-Test (Week 0)	Post-Test (Week 4)			
Right CKC leg press CON peak force (N) at 60 deg/sec	1123.9 \pm 233.4	1263.3 \pm 267.8	1018.9 \pm 231.0	1236.4 \pm 172.3	0.370	0.001*	0.465 (large)
Right CKC leg press ECC peak force (N) at 60 deg/sec	1214.7 \pm 191.2	1243.5 \pm 145.4	1242.1 \pm 159.6	1314.9 \pm 44.2	0.222	0.126	0.076 (medium)

* = $p \leq 0.05$

Table 8. Three-Way Mixed ANOVA Summary Table of LESS Test Results

Source	F Ratio	Significance	Observed Power	Partial Eta Squared
Group	5.6	0.026*	0.626	0.184
Time	48.1	0.001**	1.00	0.658
Group x Time	11.1	0.003*	0.893	0.307
Fatigue	15.2	0.001**	0.963	0.378
Group x Fatigue	3.1	0.090	0.396	0.111
Time x Fatigue	1.6	0.220	0.227	0.059
Group x Time x Fatigue	< 1	0.990	0.050	0.000

* = $p \leq 0.05$

** = $p \leq 0.001$

Table 9. LESS Test Score Results for Fatigue Status (Mean \pm Standard Deviation, $p \leq 0.05$)

Group	Week 0		Week 4	
	Pre-Fatigue	Post-Fatigue	Pre-Fatigue	Post-Fatigue
Plyometric Lower Extremity Injury Prevention Exercises (n = 15)	8.40 \pm 1.61	9.06 \pm 1.49	7.00 \pm 1.81	8.02 \pm 1.84
Lower Extremity Injury Prevention Exercises (n = 12)	6.75 \pm 2.00	6.89 \pm 1.69	6.14 \pm 1.85	6.63 \pm 1.86

DISCUSSION

The participants in our study demonstrated excellent compliance to each of the respective lower extremity injury prevention protocols. No study participants were excluded from the study due to excessive absences (greater than 2 sessions) from supervised workout sessions. However, these adherence rates should be interpreted with caution. While 2 of the 4 sessions each week were supervised, we cannot absolutely confirm whether or not the study participants were fully compliant with the home exercise sessions. Participants were required to complete a weekly workout log checklist, which was returned to the investigators at the end of the 4-week study duration. The principal investigator examined each workout log to determine participant program compliance. According to the self-reported workout logs, no at home exercise sessions were missed.

Program adherence has been identified in previous studies as a positive influential factor for the effectiveness of the ACL injury prevention protocols.⁽⁴³⁻⁴⁵⁾ Both Steffan et al. and Hägglund et al. demonstrated increased effectiveness of their respective ACL injury prevention programs in the high-adherence groups.^(44, 45) Steffan et al. found a 72% overall injury risk reduction for lower extremity injuries in the individuals completing the FIFA 11+ program who were placed in the high-adherence group compared to the medium-adherence group.⁽⁴⁵⁾ Hägglund et al. also found an 88% decrease in ACL injury rate in individuals classified as a high-adherence group compared to a low-adherence group.⁽⁴⁴⁾ This greater reduction of lower extremity injury risk among high-adherence groups demonstrates the importance of program compliance and its effect on injury risk reduction.^(44, 45) Therefore, it is extremely important that high levels of adherence be maintained when implementing an ACL injury prevention program at any level. Coaches, athletic trainers and other performance specialists may find these programs to be easily applied into the athletes' daily warm-up or workout sessions, due to the decreased time requirements, thus improving adherence rates.

There are similar time requirements needed to complete the exercise protocols in our study and in previous studies examining ACL injury prevention programs.^(44, 45) Both Hägglund et al.^(44, 45) and Steffan et al.^(44, 45) examined multifaceted injury prevention programs, where our study evaluated individual aspects of prevention programs. The injury prevention programs of these authors involved 15 to 20 minute intervention sessions that were used as a warm-up

activity by the coaches and players.^(44, 45) Their programs included a variety of exercises, including balance/proprioception, core strength, and jumping landing/plyometric technique training.^(44, 45) Our study did not use a multifaceted program as our purpose was to determine which aspect of these prevention protocols had a greater influence on overall risk reduction through improvements in drop landing mechanics.

We observed no significant differences in eccentric hip or knee muscle strength gains between the experimental groups at the conclusion of their respective 4-week interventions. However, significant concentric strength gains were found for both left hip abduction peak torque and right leg press peak force between measurements obtained at Week 0 and Week 4. These results are encouraging additions to the current body of knowledge because they demonstrate that both of these components of ACL prevention programs are important for improving hip and knee muscular strength in females. Since no significant differences were found between the experimental groups after the 4-week intervention period, we concluded that each of the interventions, Plyometric and Traditional, are important strategies for improving lower extremity strength. These results may advance training strategies implemented by coaches, athletic trainers and strength and conditioning specialists for improving hip strength and jump landing mechanics, thus decreasing an individual's ACL injury risk.

Our results differ from previous authors in that we did not find a significant group difference in hip abduction peak torque or leg press peak force.^(29, 36) Myer et al. found that after completing a 10-week neuromuscular strengthening

program participants demonstrated improved hip abduction strength.⁽²⁹⁾ The neuromuscular strengthening program employed by Myer et al. was designed to improve the participants' "core stability."⁽²⁹⁾ Neuromuscular training consisted of trunk and hip focused exercises consisting of plyometric, balance and strengthening activities.⁽²⁹⁾ Their group that underwent the neuromuscular training improved their isokinetic hip abduction strength values by 13.5% on their dominant limb.⁽²⁹⁾ The fact that Myer et al. employed an exercise program that was of 2.5 times greater duration than ours, i.e., 10 weeks vs. 4 weeks, may explain the differences in our respective outcomes.

Ferber et al. examined the effects of a 3-week hip abduction strengthening protocol that consisted of two exercises.⁽³⁶⁾ The results of their study reported a 32.7% improvement in hip abduction strength after completing the 3-week intervention period.⁽³⁶⁾ However, the Ferber et al. study enrolled participants with the diagnosis of patellofemoral pain syndrome and presented, at baseline, with a 28.7% deficit in hip abduction strength compared to the control group.⁽³⁶⁾ This large deficit in baseline strength values between the intervention and control group may be a reason why Ferber et al. were able to demonstrate significant improvements in hip abduction strength values using such a short intervention duration.

Chimera et al. found significant improvements in hip adductor and abduction co-activation after completing a 6-week plyometric intervention.⁽⁴⁶⁾ These investigators determined that the individuals involved in their plyometric

group were able to improve their motor control strategies after completing the selected intervention protocol.⁽⁴⁶⁾ These improved motor control strategies may place the knee joint in a more biomechanically neutral position, making the knee more resistant to dynamic forces.⁽⁴⁶⁾ However, Chimera et al. did not measure hip muscle torque directly; rather, these researchers used EMG readings to quantify muscle activation levels.⁽⁴⁶⁾ These values are important for helping researchers determine when and if neural adaptations, i.e., changes in muscle activation, occur within a muscle or muscle group, but they do not provide direct measures of muscular force or torque.

In addition to measuring hip abduction strength values, our study sought to determine the effects our selected interventions had on other important lower extremity musculature. We selected the closed kinetic chain leg press using a Biodex dynamometer to measure lower extremity peak force. This measurement is important to our study because it allowed us to analyze and report any strength changes that occurred due to the two selected interventions, and their effects on other important lower extremity musculature, i.e., quadriceps, gluteals and hamstrings.

Our results indicated that after completing the 4-week intervention, participants demonstrated increased concentric closed kinetic chain leg press maximal peak force irrespective of the lower extremity exercise program that they were following. Both interventions included training aspects for these large muscle groups (hip and knee extensors, ankle plantar flexors); however, we viewed these as improvements secondary to the study's primary focus on

increasing hip abduction strength. There is a lack of research measuring the effects of ACL injury prevention protocols on other larger lower extremity musculature using the closed kinetic chain leg press. To our knowledge no other ACL injury prevention study has explored leg press measurements obtained with the Biodex dynamometer's CKC leg press attachment. The lack of published research on this topic makes it challenging to compare the results of our study. Due to the improvements seen in our study, the CKC leg press measurement may be important in determining the effects of ACL injury prevention protocols on other larger lower extremity musculature. Although we cannot distinguish which lower extremity muscle or muscle group(s) demonstrated the greatest improvement through our prescribed interventions, CKC leg press may still be an important variable for ACL injury prevention programs and should be investigated further in future research.

Our study is not without its limitations. We acknowledge that the use of a college-level, recreationally-active female population may well limit the generalizability of our findings. However, with women sustaining ACL injuries at rates 2 to 10 times greater than men participating in the same activities, e.g., basketball, soccer, military basic training, the choice to delimit this study to only women can be readily defended.

Future studies should recruit participants from various age groups, as well as use both sexes to determine if there are significant differences between the sexes for plyometric or hip abduction injury prevention protocols. While we recruited more participants than was projected to provide a statistical power of

0.80 or higher, the variability present within our study population resulted in low observed statistical power on the 4 non-statistically significant isokinetic strength measures. Specifically, the observed power ranged from a low of 5% chance ($1 - \beta = 0.050$) to a high of 45% probability of finding statistical significance if present ($1 - \beta = 0.448$). In contrast, the observed statistical power for the two outcome measures with significant differences for Time (Week 0 to Week 4) had $1 - \beta$ values of 0.979 (98% chance to find statistical significance if present) and 0.999, respectively. Thus, future researchers are encouraged to recruit a larger study population (> 35 participants) in order to increase the statistical power and the chances of detecting group differences if they should exist, and reduce the risk of making a Type II error.

Another possibly limitation of the study was the 4 week duration selected for the interventions. Although this study was long enough in duration to see changes in the neural component of strength gains, i.e., muscle activation, we did not specifically quantify this component as part of this study. Future studies could collect surface electromyographic data before, during and after participation in the assigned lower extremity injury prevention program in order to better determine if muscle activation or rate of activation changed with the training programs in the muscle as well as improved neural recruitment/motor drive to the involved muscles.

It appears that the intervention period in the present study was not long enough, or the exercises were not of sufficient intensity to produce significant improvements in eccentric hip abduction strength. Future studies should

investigate the effects of the same lower extremity injury prevention protocols over a greater duration of time (6 to 8 weeks). By increasing the duration of the study, researchers should see an improvement in eccentric hip abduction peak torques.

An additional possible limitation was our use of unsupervised “at home” workout sessions, accounting for half of the total number of exercise sessions. Future investigators should consider an experimental protocol that requires participants to have 100% of their workout sessions supervised by a certified/licensed athletic trainer or other health professional. This change will provide the researcher with absolute confidence in the program adherence data in contrast to the uncertainty associated with self-reported exercise program compliance.

One of the greatest problems encountered with the present study was with the fatigue protocol that was administered to the hip abduction musculature using the Biodex System 4 dynamometer. The fatigue protocol that we used was adapted from previously-published hip abduction fatigue protocols for the Biodex dynamometer. ^(17, 21, 38) A maximum time frame of 40 minutes was placed on each single-legged hip abduction fatigue protocol with the dynamometer. While this protocol was successfully administered to several recreationally-active women and men during pilot testing in our laboratory, 3 participants in the actual study exceeded the maximum time allowed time — 40 minutes — for the hip abduction fatigue protocol. Said differently, 3 participants were still abducting their hips at a velocity of 120°/s with greater than 50% of their concentric peak

torque values after 40 minutes of continuous resistance exercise, exceeding the dynamometer's data storage capacity. After questioning each of these individuals, we determined that our inclusion/exclusion requirements were not sufficiently strict, e.g., ACSM's definition of "recreationally-active", to eliminate highly-trained persons who did not participate in club- or university-sanctioned sporting activities. As it turned out, all 3 of these participants were high-mileage distance runners who continued their regular training throughout the study. However, we did not exclude their data from our analysis.

Since our Biodex dynamometer has a fixed time frame for the fatigue protocol used in this study, future studies should modify our inclusion/exclusion criteria to eliminate competitive or highly-trained individuals who are not participating in club or university sports. Researchers should instead focus their recruitment efforts on more moderately-active individuals. By eliminating the ceiling effect associated with highly- trained recreational athlete, researchers may increase their chances of finding significant changes in hip abduction peak torque values.

The results of this study confirmed our supposition that the Plyometric exercise group would demonstrate greater improvements, or decreases, in the LESS test scores than the Traditional exercise group after 4 weeks. We believed that the Plyometric group would have better LESS test scores because the plyometrics place a strong emphasis on landing mechanics during the 4-week injury prevention protocol. These results are similar to previous findings that have

demonstrated plyometric exercises to be an important aspect of lower extremity injury prevention protocols for improving biomechanical landings.^(3, 11, 13, 16, 47) The plyometric exercises used in this study were effective at decreasing errors seen on the LESS test scoring rubric. These observed improvements biomechanics during a drop-landing task are similar to previous studies examining the effects of prevention programs with a plyometric component.⁽¹³⁾

Myer et al. recently reported that both plyometric and balance experimental groups had improved frontal plane landings and decreased valgus knee angles ($p=0.38$).⁽¹³⁾ These results are significant to the literature, because they demonstrate the importance of plyometric training for improving both frontal and sagittal plane biomechanics that are previously cited as potential injury risk factors.^(13, 16, 48) One important factor to note is that only one study examined implemented only a plyometrics group, all other studies examined producing significant drop-landing improvements, were multifaceted intervention programs.^(3, 11, 13, 16, 47) Therefore, we cannot directly state if the plyometric exercises were the only reason for the improved drop landings. This decrease in LESS test errors in our study are directly linked to the improved landing mechanics we observed in participants who underwent plyometric training. Decreased LESS test scores have been shown to be positively correlated with improved drop-landing mechanics, as well as decreased lower extremity injury risk.⁽²⁴⁾ This decreased lower extremity injury risk is especially important to individuals who are looking to implement an injury prevention program into their team's training regimen.

Previous research that has examined drop-landing biomechanics and how improved landings decrease overall lower extremity injury risk, specifically ACL injury risk reduction.^(3, 13, 48) By decreasing the LESS test score, participants effectively improved their landings and placed their lower extremity in a more biomechanically-efficient position. This more efficient landing position may decrease the individual's risk of suffering an ACL injury, by appropriately distributing forces acting on the tibiofemoral joint. Improved knee flexion angles and decreased knee valgus have been demonstrated to decrease ACL injury risk.^(3, 13, 48)

Previous studies have demonstrated that both decreased knee flexion angles and increased knee valgus angles at initial contact place an individual at an increased risk of ACL injury.⁽¹³⁾ Hewett et al. recently analyzed drop-landings and found that knee abduction angles were significantly different between the individuals that suffered an ACL injury and the uninjured group both at initial contact and maximum displacement.⁽¹²⁾ Their results demonstrated an 8.4° greater knee valgus angle at initial contact and 7.6° greater knee valgus angle at maximum displacement in the individuals who sustained an ACL injury compared to the uninjured group.⁽¹²⁾ The same study also demonstrated a 10.5° difference between groups for maximal knee flexion.⁽¹²⁾ The results show that individuals who sustain an ACL injury demonstrate faulty landing mechanics that may place them at an increased injury risk. Therefore, researchers and clinicians should look at ways to decrease these faulty landing mechanics.

As stated earlier, adding a plyometric intervention may improve drop landing mechanics. Myer et al. found that plyometric training alone was able to decrease dynamic knee valgus angles and improve knee flexion angles.⁽¹³⁾ To date, only one study has reported results that contradict those of the Myer et al plyometric training study. Pfile et al. observed that individuals who underwent plyometric training actually decreased their knee flexion angles during drop-landings.⁽¹⁶⁾ The authors attributed their opposing results to the fact that injury prevention protocols were led by a member of the coaching staff rather than a more qualified health care clinician.⁽¹⁶⁾

Our findings demonstrated that acute fatigue negatively influenced the LESS test scores. Both treatment groups involved in our study demonstrated significant increases in LESS test scores, meaning worse drop-landing mechanics, after the fatigue protocol was administered. When individuals participate in long durations of physical activity, the muscle starts to develop and accumulate a muscle metabolism byproduct called lactic acid. This lactic acid decreases a muscle's ability to produce a force⁽²¹⁾ This decreased muscle force then can lead to impaired biomechanics during activity, since the muscle will become unable to produce the forces required of the body to maintain a safe body position. The impaired mechanics due to increased fatigue may contribute to an increased risk of musculoskeletal injury during activity participation.⁽²¹⁾ These neuromuscular fatigue effects have been suggested as a possible contributor to ACL injuries, since more injuries occur near the end or during the second half of a match.⁽¹⁷⁾

Previous studies that have examined the effects of fatigue on drop landings have generally observed increased faulty landing positions after individuals have undergone a fatigue protocol.^(2, 21) Specifically, both Geiser et al. and Garcia et al. found increased knee abduction angles when individuals performed drop-landings in a fatigued state.^(2, 21) To our knowledge, no previous studies have investigated the effects of effects on LESS test scores. Thus, the results of our study add to the body of knowledge and advance our understanding of the effects of hip abductor fatigue and its influence on drop landing mechanics as evaluated with a low-cost injury risk screening tool.

We believe that further investigation with a larger sample size is required prior to being able to identify which aspect of the current prevention protocols is responsible for the improvements seen in drop-landing mechanics. Both of the injury prevention protocols used in this study caused significant lower extremity strength gains after just 4 weeks. Therefore, in terms of improving hip abductor and general lower extremity strength, either intervention could be implemented as an ACL-injury prevention protocol.

Our findings showed that both groups demonstrated improved LESS test scores after their respective 4-week training programs. However, in terms of LESS test score improvements, plyometric exercises resulted in improved landing mechanics even when acute fatigue was introduced. Determining which aspect of currently practiced prevention protocols is primarily responsible for decreasing injury risk is vital to decreasing the high injury rate seen in the female population. As previously discussed, existing research suggests that improving

biomechanical drop-landings is key at reducing lower extremity injuries. Additional research must be performed to determine the best method of exercise and intervention duration.⁽¹⁶⁾ Once this is accomplished, medical professionals should have the tools and knowledge to design a more comprehensive and more successful lower extremity prevention protocol in order to reduce the disproportional incidence of ACL injuries among women.

CONCLUSIONS

The exercise programs used in this study were both effective in creating significant gains in lower extremity muscular strength of the participants over a 4-week period, with both protocols producing near equivocal improvements. This finding is of particular interest to researchers who have ongoing studies investigating the root cause(s) of success of ACL-injury prevention programs.^(3, 7, 9, 13, 19, 29, 47-49)

To date, plyometric exercise has been identified as the one common component of successful ACL-injury prevention programs worldwide.^(3, 11, 13, 16, 47) If more traditional resistance band exercises produce similar strength gains in hip and knee musculature, the differences in both the temporal and neuromuscular patterns of loading and response (stretch-shortening cycle) associated with plyometrics may be the cause of the prophylactic effect(s) of these ACL injury prevention programs.

Both interventions produced significant improvements (decreases) in LESS test scores after completing their respective lower extremity injury

prevention program. However, the plyometric exercise group demonstrated larger improvements in LESS test scores. These larger decreases in LESS test scores demonstrate a decreased lower extremity injury risk in females. Our findings support the work of others who have concluded that plyometric exercises should continue to a required component in lower injury prevention programs.

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CHAPTER 3

Summary And Recommendations For Future Research

The central research question addressed in this thesis was the quantification of the effects of two lower extremity injury prevention (muscular strengthening) programs on drop landing mechanics and assessments before and after acute neuromuscular fatigue had been induced. We investigated which particular component of an ACL injury prevention program had the most influence on hip abduction strength values and drop landing mechanics.

This study's protocol involved the measurement each participant's hip abduction peak torque and closed kinetic chain (CKC) leg press peak force values using an isokinetic dynamometer. Each participant's drop landing mechanics were also analyzed using the Landing Error Scoring System (LESS) Test in both a non-fatigued and fatigued state. The fatigue protocol used in this study involved a standing hip abduction movement that was monitored by the dynamometer. The participants performed standing hip abduction repetitions until their peak torque values dropped below 50% of their maximum concentric hip abduction peak torque value, after Carcia et al.⁽²¹⁾ at which point they were considered to be fatigued.

We did observe significant strength gains over time for two of the hip abduction variables. Left hip abduction concentric peak torque and right CKC leg press concentric peak force both increased significantly from Week 0 (baseline) and when measured at the conclusion of the study (Week 4). There were no differences observed between the strength gains achieved by the Plyometric and

Traditional exercise groups. These results demonstrate that both groups had the capacity to produce significant strength gains over the 4-week period.

Interestingly, none of the 3 eccentric measures of hip and knee muscular strength improved from baseline to the end of the study, regardless of experimental group.

Our study is not without its limitations. We acknowledge that the use of a college-level, recreationally-active female population may well limit the generalizability of our findings. However, with women sustaining ACL injuries at rates 2 to 10 times greater than men participating in the same activities, the choice to delimit this study to only women can be readily defended.

Future studies should recruit participants from various age groups, as well as use both sexes to determine if there are significant differences between the sexes for plyometric or hip abduction strengthening protocols. While we recruited more participants than was projected to provide a statistical power of 0.80 or higher, the variability present within our study population resulted in low observed statistical power on 4 of the 6 non-significant isokinetic strength measures from a low of 5% ($1 - \beta = 0.05$) to a high of 46% ($1 - \beta = 0.448$). In contrast, the observed statistical power for the two variables with significant differences for Time (Week 0 to Week 4) had $1 - \beta$ values of 0.979 (98% chance to find statistical significance if present) and 0.999, respectively. Thus, future researchers are encouraged to recruit a larger study population (> 35 participants) in order to increase the statistical power and the chance of detecting

group differences should they exist, and reduce the chances of making a Type II error.

Another possibly limitation of the study was the 4 week duration selected for the interventions. Although this study was long enough in duration to see changes in neural component of strength gains, we did not specifically quantify this component of strength as part of this study. Future studies could collect surface electromyographic data before, during and after participation in the assigned lower extremity injury prevention program in order to determine if any improvements were made as well as identify any changes in neural recruitment/motor drive to the involved muscles.

The intervention period in the present study was not long enough to produce significant improvements in eccentric hip abduction strength. Future studies should investigate the effects of the same lower extremity strengthening protocols over a greater duration of time (6 to 8 weeks). By lengthening the duration of the study, researchers should see significant increases in both concentric and eccentric hip abduction peak torques.

An additional possible limitation is the use of unsupervised “at home” workout sessions. Future investigators should consider an experimental protocol that requires participants to have 100% of their workout sessions supervised by a certified/licensed athletic trainer or other health professional. This change will provide the researcher with absolute confidence in their program adherence data, in contrast to the uncertainty associated with self-reported exercise program compliance.

One of the largest problems encountered with the present study was with the fatigue protocol that was administered to the hip abduction musculature using the Biodex System 4 dynamometer. The fatigue protocol that we used was adapted from previously-researched hip abduction fatigue protocols for the Biodex dynamometer. ^(17, 21, 41) We set a maximum time limit of 40 minutes to complete each single-legged hip abduction fatigue protocol. While this protocol was successfully administered to several recreationally-active women and men during pilot testing in our laboratory, 3 participants in the actual study exceeded the maximally-allowed time limit of 40 minutes for the hip abduction fatigue protocol. Said differently, these participants were still abducting their hips at a velocity of 120°/s with greater than 50% of their concentric peak torque values after 40 minutes of continuous resistance exercise, and exceeded the dynamometer's data storage capacity. From our questioning each of these individuals after the fact, we now believe that our inclusion/exclusion requirements were not sufficiently stringent e.g., ACSM's definition of "recreationally-active", to eliminate highly-trained persons who did not participate in club- or university-sanctioned sporting activities. As it turned out, all 3 of these participants were high-mileage distance runners who continued their regular training throughout the study.

Since our Biodex dynamometer has a fixed time frame for the fatigue protocol used in this study, future studies should modify our inclusion/exclusion criteria to eliminate competitive or highly-trained individuals who are not participating in club or university sports. Researchers should instead focus their

recruitment efforts on more moderately-active individuals. By eliminating the ceiling effect associated with highly-trained recreational athlete, researchers may increase their chances of finding significant changes in hip abduction peak torque values.

Recommendations for Future Research

- Increase the study duration from 4 weeks to 6 to 8 weeks to improve strength gains observed in the participants.
- Define and add “competitive recreational athlete”, e.g., marathon runner, road cyclist, to the study’s exclusion criteria.
- Compare the same protocols using both male and female participants.
- Increase the amount of total study participants to increase the statistical power of the study.
- Add a familiarization period or training session to introduce participants to expectations on drop landings and correct standing hip abduction form.
- Have two examiners watch the participant perform the drop jump landings required with the LESS test. We recommend have one investigator observe the sagittal plane and one observe the landing from the frontal plane. This change will improve the detection of unsatisfactory trials during the LESS tests.
- Paradoxically, the eccentric hip abduction peak torque values decreased in both the left (-2.8%) and right (-2.3%) limbs of our study participants in both treatment groups between Week 0 and Week 4. Therefore, we

recommend adding a true control group of recreationally-active individuals to the study design in order to better explain any unanticipated outcome(s).

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APPENDIX A

INSTITUTIONAL REVIEW BOARD SYNOPSIS IRB SYNOPSIS

1. *Identify the sources of the potential subjects, derived materials or data. Describe the characteristics of the subject population, such as their anticipated number, age, sex, ethnic background, and state of health. Identify the criteria for inclusion or exclusion. Explain the rationale for the use of special classes of subjects, such as fetuses, pregnant women, children, institutionalized mentally disabled, prisoners, or others, especially those whose ability to give voluntary informed consent may be in question.*

The potential participants for this study will be recruited from general student population at Texas State University. Our goal is to recruit 30 physically-active female participants between the ages of 18 and 24 years. For the purposes of this study, a “physically-active person” has been operationally defined as an individual who participates in moderate intensity physical activity for 30 minutes per day on 3 or more days of the week (American College of Sports Medicine, 2013).

As proposed, this study will involve two groups of participants who will be randomly assigned to either a “traditional exercise” lower extremity injury prevention group or a “plyometric exercise” lower extremity injury prevention group. The seven Traditional exercises will be performed with a piece of elastic material (Thera-band®) to provide additional resistance to the movement. The seven Plyometric exercises involve quick powerful movements that rapidly stretch a muscle or a group of muscles in order to activate the stretch reflex (myotatic reflex), and subsequently produce a stronger, more powerful muscle contraction (Prentice, 2011).

Volunteers will be screened to determine whether they meet the following inclusion/exclusion criteria for participation in the study:

Criteria for Inclusion

- Females between the ages of 18-24 who are physically active
- No previous history of injury to the anterior cruciate ligament of the knee
- No previous participation in an anterior cruciate ligament injury prevention program

Criteria of Exclusion

- Current diagnosis of a lower extremity injury within the last 6 months
- Currently experiencing any lower extremity pain
- A medical history of lower extremity injury that required surgical intervention
- History of anterior cruciate ligament injury
- Previous participation in anterior cruciate ligament injury prevention program
- Current participation in a resistance exercise (“weight training”) program
- More than 20 degrees of genu valgum (“knock-knee”) alignment

We will not recruit any of the special classes of subjects to this study.

- 2. Describe the procedures for recruitment of subjects and the consent procedures to be followed. Include the circumstances under which consent will be solicited and obtained, who will seek it, the nature of information to be provided to prospective subjects, and the methods of documenting consent. (Include applicable **Consent Form** (s) for review.) If written consent is not to be obtained, this should be clearly stated and justified.*

Procedures for recruitment of subjects

Volunteers will be recruited through the use of flyers and oral announcements in Texas State University classes and labs. After obtaining the necessary permission from Campus Activities and Student Organizations, flyers will be posted on bulletin boards around fitness facilities and classrooms at Texas State University. Similarly, after obtaining permission from individual instructors, verbal recruiting announcements will be made in classes. Both recruiting methods will provide potential volunteers with the essential information about the research project, including the purpose of the study, study procedures, time commitment, and investigator contact information. Individuals who are interested in study participation will be responsible for contacting the principal investigator.

Procedures for obtaining consent

Potential subjects will contact the study’s principal investigator to arrange an initial meeting in the Biomechanics/Sports Medicine Laboratory in

Jowers Center at Texas State University. At this meeting, the volunteer will be given a written **Consent Form** that will be used as a guide for the conversation. The study's purpose and all procedures will be verbally explained, and then the volunteer will have as much time as she needs to read the form. Each volunteer's level of understanding about the study will be assessed before being asked to sign the IRB-approved **Consent Form**. In cases in which English is not the volunteer's first language, additional time will be provided for questions to ensure that the potential participant fully understands all of the elements of the study. Participation in the study will not begin until a signed **Consent Form** is returned to the principal investigator.

- 3. If your planned recruitment process involves emailing Texas State students, staff, faculty or other individuals using their active Texas State email address, provide details in the **Synopsis**. (In addition, the IRB will require a draft of your recruitment email, using the enclosed template and formatted as illustrated in the example in this document, submitted in addition to other required documents.*

The recruitment process for this study will not involve the use of e-mails to any Texas State University student, staff, faculty or other member of our academic community.

- 4. If you plan to distribute a survey to collect information directly from individuals who comprise a significant proportion of one or more Texas State affiliation groups, as defined in Section 04 of [UPPS No. 04.01.02, Information Resources Identity and Access Management](#), you must follow the review and approval procedures outlined in [UPPS No. 01.03.05, Administrative Surveys](#), and provide information in your **Synopsis** [regarding review and approval](#).*

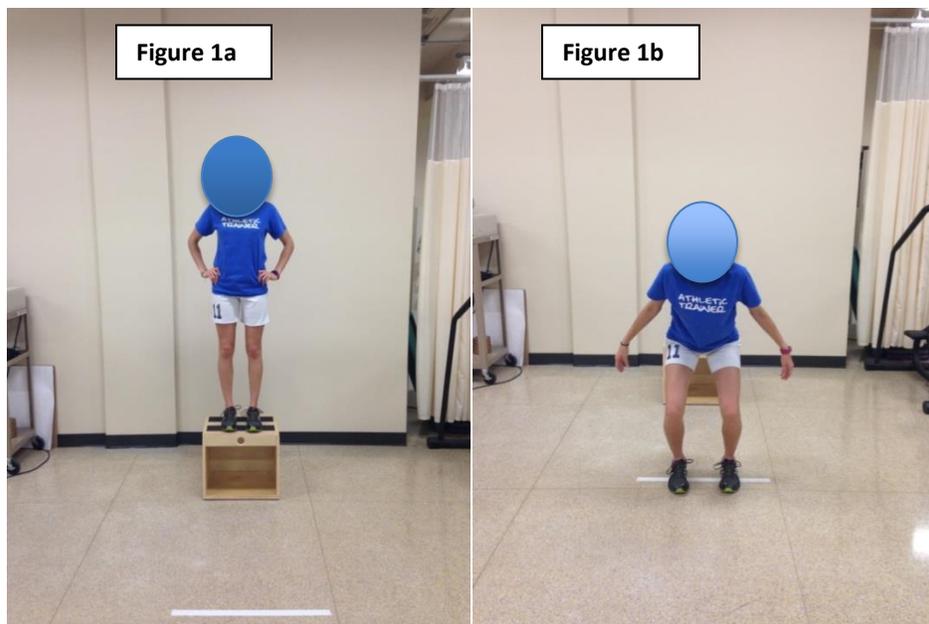
The proposed study does not include a survey research component.

- 5. Describe the project's methodology in detail. If applicable, detail the data collection procedures, the testing instruments, the intervention(s), etc. If using a survey, questionnaire, or interview, please provide a copy of the items or questions.*

Study Overview

The proposed study will be a randomized controlled trial (RCT) in which the participants will be randomly assigned to one of two lower extremity injury prevention exercise groups. The total length of participation in this study will be five calendar weeks. After obtaining written consent from the participant, the study will begin with a “pre-test” that will take place in Texas State University’s Biomechanics/Sports Medicine Laboratory in Jowers Center. This initial session will take approximately 1 hour to complete, and involves lower extremity muscular strength testing, and a series of drop landings evaluated with the Landing Error Scoring System (LESS) test (see **Figures 1a and 1b**), both before and after being fatigued (Padua et al., 2009).

Figures 1a and 1b. The Landing Error Scoring System (LESS) test. 1a. Preparatory phase; 1b. Landing phase.



Once the participant is found to be eligible for participation, she will engage in a 5 minute warm-up period and then be asked to perform the LESS test—a series of three two-footed landings from a 12” high box (**Figures 1a and 1b**). Two iPad cameras mounted on tripods will be used to record the landings for later analysis. The zoom lens feature on the iPad cameras will be adjusted so as to capture lower extremity motion at the hips, knees and ankles, as the outcome measures of interest in this study are all related to landing mechanics. With different landing

strategies, e.g., landing in an extremely flexed-knee position, it is possible that a participant's facial features may be captured on the recording. If this occurs, and that participant's landing is used as an example in a public forum, e.g., thesis defense, medical meeting presentation, peer-reviewed manuscript, that participant's facial features will be covered using a computer-generated opaque oval (see Figures 1a, 1b, 2 and 3 for examples). Further, all participants will be assigned code numbers, with all data captured on the recording devices stored using these codes. All personal identifying information will be removed. These coding procedures will help protect the identities of each participant.

Next, the participant will be given time to practice and learn the techniques used for lower extremity strength tests to be performed using a computerized strength testing device known as a dynamometer. There will be two different strength tests administered using this device, standing hip abduction (moving the whole lower limb away from the midline of the body against the resistance offered by the dynamometer, while standing on the other leg, see **Figure 2**) and a seated leg press (pushing the hip and knee joints into full extension against the resistance offered by the dynamometer, see **Figure 3**). After completing the strength tests, the participant will undergo a hip abductor fatigue protocol on each leg that is administered using the dynamometer. After completing the hip abductor fatigue protocol, the participant will again be asked to perform the LESS test—three two-footed drop landing tests from a 12" high box. As before, two iPad cameras mounted on tripods will be used to record the landings for later analysis.

Figure 2. Standing hip abduction strength testing with a computerized dynamometer.

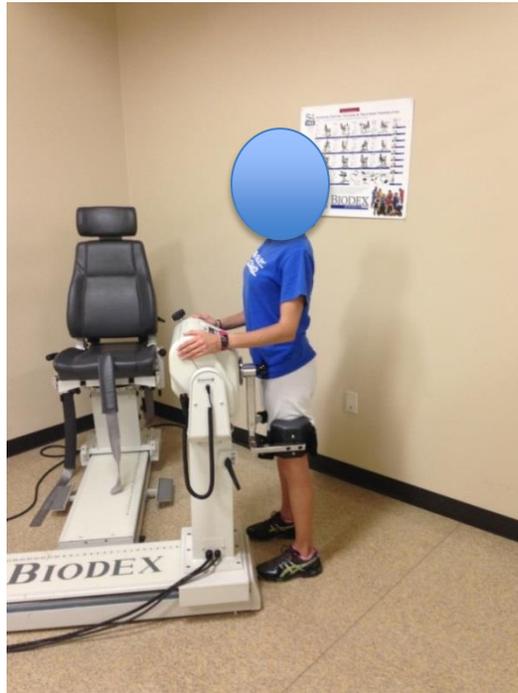
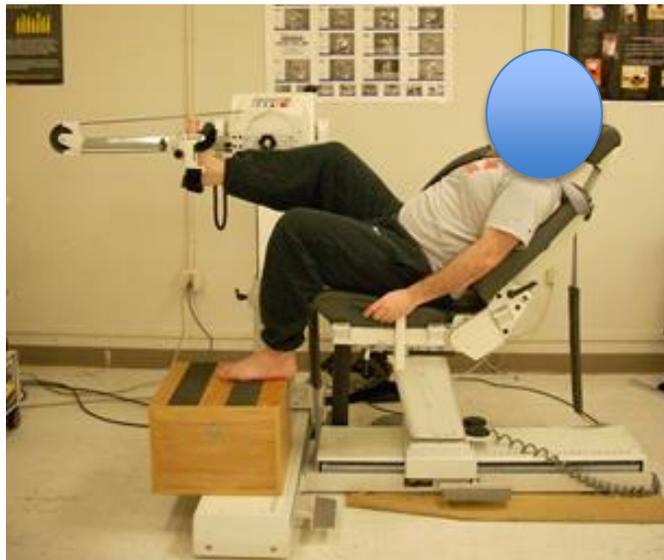


Figure 3. Leg press strength testing with a computerized dynamometer.



After successful completion of this pre-test session, the participant will be randomly assigned to one of the two 4-week exercise programs—“traditional” or “plyometric”. Both exercise programs consist of seven exercises that are performed throughout the intervention period. Each participant will be asked to complete four 15 to 20 minute exercise sessions per week for 4 weeks. Two of the 4 weekly exercise sessions will be supervised in Jowers Center or at Bobcat Stadium by the principal researcher, while the two other sessions may be performed unsupervised at home or at a location of the participant’s choosing. During the 4-week intervention, each participant will also be asked to maintain a daily physical activity journal, recording the number of minutes and type of physical activity performed in addition to the lower extremity injury program exercises.

At the conclusion of the 4-week exercise program, the participant will be asked to return to the Biomechanics/Sports Medicine Laboratory for a “post-test” that will involve completion of the same lower extremity muscular strength testing and drop landing measures that were taken at the beginning of the study. This post-test session should last approximately 1 hour.

6. *Describe any potential risks — physical, psychological, social, legal or other — and state their likelihood and seriousness. Describe alternative methods, if any, that were considered and why they will not be used.*

The potential risks for this study are minimal, but may include muscle or joint soreness upon the completion of hip and knee muscular strength assessments performed with a computerized strength measuring device known as a dynamometer. It is possible that participants may slip and fall while landing with on both feet from a 12” high box, a requirement of the Landing Error Scoring System (LESS) testing. The principal investigator, a licensed athletic trainer skilled in sports injury prevention and emergency care, will be present to provide the participants with any medical care needed. To further reduce the already low risk of falling, the LESS testing will be completed in a controlled laboratory environment with minimal noise and distractions. Both the dynamometer strength testing and LESS testing have been employed and validated in many other published studies and thus no alternative test will be considered. Specific exclusion criteria have been created to avoid adding potential risks and/or discomforts to the volunteers participating in the study.

- 7. Describe the procedures for protecting against or minimizing any potential risks and include an assessment of the likely effectiveness of those procedures. Include a discussion of confidentiality safeguards, where relevant, and arrangements for providing mental health or medical treatment, if needed.*

Procedures for Participants Safety

At all times, the principal investigator will be responsible for the safety of the study participants during their use the dynamometer and while performing the three trials of the Landing Error Scoring System (LESS) test. The principal investigator will ensure the participant is properly seated on the dynamometer and have accessory movements eliminated through the use of appropriate restraining harnesses in accordance with the manufacturer's instructions. For example, a strap will be placed just proximal to the knee joint to help control unnecessary motion of the thigh. Participants will be instructed to hold the head of the dynamometer to decrease the risk of falling. For additional safety the principal investigator will stand near the participant while testing procedures take place. All of these procedures are designed to decrease participant injury risk. Also, all steps have been taken in the creation of the exclusion criteria to minimize the potential for any pain or injury to the participants.

Confidentiality Safeguards

Each participant will be assigned a code number that will insure the confidentiality of the information that they provide to this study. All study documents will be kept secure in a file cabinet in a locked room within the Biomechanics/Sports Medicine Laboratory at Texas State University. Only the investigators for the study will have access to the study materials. A document with individually-identifiable data such as a **Consent Form** will be kept separately from others that do not have identifying information. All electronic data will be stored on a computer that requires a unique log-in ID and password to gain access to the data, which will be kept confidential by the study investigators. All electronic data obtained through this study will be kept for no more than three years before being destroyed. For permanent destruction, the electronic data files will be moved to the "Recycle Bin" on the PC computer's desktop, and then the Recycle Bin will

be emptied to ensure complete removal from the system. A password will also be required in order to gain access to any electronic (video) data recorded by the iPad devices, and this password will be known only to the investigators. Once the video recordings of the LESS tests have been transferred to a log-in ID and password-protected PC computer, the original files will be deleted from the iPad recording devices.

8. *Describe and assess the potential benefits to be gained by the subjects, as well as the benefits that may accrue to society in general as a result of the proposed study.*

By participating in this study, volunteers may experience the benefit of increased lower extremity muscular strength and endurance, and a decreased risk of experiencing an anterior cruciate ligament (ACL) injury. Another potential benefit to be gained by participation in this study is a contribution to the orthopedic injury research body of knowledge regarding the relationship between hip muscular strength, muscular fatigue, and performance on the Landing Error Scoring System test, a validated measure of the ACL injury risk.

9. *Clearly describe any compensation to be offered/provided to the participants. If extra credit is provided as an incentive, include the percentage of extra credit in relation to the total points offered in the class. Also, if extra credit is provided, describe alternatives to participation in your research for earning extra credit.*

Participants who complete all aspects of the four-week study will be compensated with a \$30 HEB gift card. For completion of half of the study participants will receive a \$15 HEB gift card. Participants who only complete baseline testing will receive a \$10 HEB gift card. Beyond the above-mentioned financial compensation plan, at the conclusion of the study all participants will be provided with a Theraband® elastic tubing exercise protocol.

- 10. Discuss the risks in relation to the anticipated benefits to the subjects and society.*

There are minimal risks and benefits associated with participation in this study. There is a potential benefit to research and identification/prevention of anterior cruciate ligament injury risk. There are potential risks including fall risk and potential onset of delayed muscle soreness. We believe the risk-benefit ratio is acceptable.

- 11. Identify the specific sites/agencies to be used as well as approval status. Include copies of approval letters from agencies to be used (note: these are required for final approval). If they are not available at the time of IRB review, approval of the proposal will be contingent upon their receipt.*

All data collection sessions will take place in the Texas State University's Biomechanics/Sports Medicine Laboratory. All supervised exercise participation will take place in the Jowers Center Athletic Training Rehabilitation Room or at the End Zone Complex at Bobcat Stadium. No agencies or sites outside of Texas State University will be used for subject recruitment, data collection, or exercise session supervision.

- 12. If you are a student, indicate the relationship of the proposal to your program of work and identify your supervising/sponsor faculty member.*

Dr. Rod Harter is a Professor of Athletic Training, and director of the nationally-accredited Athletic Training Program at Texas State University, where I am currently a graduate student in the major of Athletic Training.

- 13. In the case of student projects, pilot studies, theses, or dissertations, evidence of approval of Supervising Professor or Faculty Sponsor should be included. Thesis and dissertation proposals must be approved by the student's committee before proceeding to the IRB for review.*

The committee for this thesis consists of Dr. Rod Harter (chair), Dr. Luzita Vela, and Dr. Joni Mettler — all are faculty members in the Department of Health and Human Performance at Texas State University.

14. If the proposed study has been approved by another IRB, attach a copy of the letter verifying approval/disapproval and any related correspondence. If the proposed study has not been reviewed/approved by another IRB, please state this explicitly.

The proposed study protocol has not been reviewed by any other IRB.

15. Identify all individuals who will have access, during or after completion, to the results of this study, whether they be published or unpublished.

No persons, except the principal investigators, will have access to the raw data or personal identifying information. All interested individuals or groups may contact the principal investigators for the results of this study.

16. Provide date of completion of the required CITI training on the protection of human subjects. Applicants must provide training dates for themselves and for supervising faculty member. All training must be current and not expired.

Dr. Rod Harter, Faculty, completed the CITI refresher course training on 2/11/2014;
(Reference ID #7054667)

Nathan Robey, Graduate Student, completed the CITI training on 8/25/2013;
(Reference ID #11060662)

APPENDIX B

TEXAS STATE INFORMED CONSENT FORM
(Consent Form to Be in a Research Study)

(In this form “you” means a person 18 years of age or older who is being asked to volunteer to participate in this study. In this form “we” means the researchers and staff involved in running this study at Texas State University.)

Principal Investigator:

Nathan Robey, ATC, LAT, CES
Graduate Teaching Assistant
Dept. of Health and Human
Performance
113A End Zone Complex
San Marcos, TX 78666
njr29@txstate.edu
507-990-4764

Rod Harter, PhD, ATC, LAT, FNATA
Professor of Athletic Training
Dept. of Health and Human
Performance
A132 Jowers Building
San Marcos, TX 78666
rod.harter@txstate.edu
512-245-2972

What is the purpose of this form?

This form will help you decide if you want to participate in the research study. You need to be informed about the study, before you can decide if you want to be involved. You do not have to be in the study if you do not want to. You should have all your questions answered before you give your permission to be involved in the study.

Please read this form carefully. If you choose to participate in the study, you will need to sign this form. You will receive a copy of this signed form.

Why is this research being done?

The primary purpose of this study will be to compare the effects of your participation in one of two different 4-week lower extremity injury prevention programs on hip, knee and ankle joint muscular strength development and the way in which you land from a jump from a 12" high box.

As a secondary purpose, we will also quantify the effects of participating in a lower extremity injury prevention program on Landing Error Scoring System (LESS) test scores, both before and after a laboratory-based fatigue protocol that simulates the muscular fatigue experienced after moderate levels of physical activity.

(NOTE: The LESS test results have been shown to be a good measure of a person's risk for an injury to the anterior cruciate ligament (ACL) of the knee, an important ligament that is injured at a rate 2 to 10 times more often among women participating in the same sports/physical activities as men.)

How long will this study take?

Your participation in this study will require approximately five calendar weeks to complete. After you have read and signed this **Consent Form**, your participation in the study will begin with a "pre-test" that will occur at Texas State University's Biomechanics/Sports Medicine Laboratory, taking approximately 1 hour to complete lower extremity muscular strength testing, and drop landing measures associated with the LESS test, both before and after being fatigued.

At that point, you will be randomly assigned to one of two lower extremity injury prevention exercise programs and asked to complete four 15-20 minute exercise sessions per week for 4 weeks. Two of the 4 weekly exercise sessions will be supervised in Jowers Center or at Bobcat Stadium by the principal researcher, while the two other sessions may be performed unsupervised at home or a

location of your choosing. During the 4-week program, you will also be asked to maintain a daily physical activity journal, recording the number of minutes and type of physical activity performed in addition to the lower extremity injury program exercises.

At the conclusion of your 4-week exercise program, you will be asked to return to the Biomechanics/Sports Medicine Laboratory for a “post-test” that involves completion of the same lower extremity strength testing and drop landing measures (both pre- and post-fatigue) that were taken at the beginning of the study. The post-test session should last approximately 1 hour.

What will happen if you are in the study?

If you agree to participate in this study, you will sign this **Consent Form** before any study procedures take place. You will be screened for any past or current musculoskeletal injuries to determine whether you qualify for participation in this study. The screening involves answering several questions about your sports injury medical history and an orthopedic evaluation of your lower extremity joints (hips, knees and ankles) performed by a licensed athletic trainer. You may choose not to answer any of the questions for any reason, or allow the orthopedic examination to occur.

If you are found to be eligible for participation, the study will begin with a “pre-test” session that will take place in Texas State University’s Biomechanics/Sports Medicine Laboratory in Jowers Center. After a 5-minute warm-up riding on a stationary bicycle at 60 to 90 rpm, you will be asked to perform the LESS test—a series of 3 two-footed drop landing tests from a 12” high box. Two iPod cameras mounted on tripods will be used to record your landings for later analysis. Next, you will be given time to practice and learn the techniques used for lower extremity strength measurement tests to be performed using a computerized strength testing device known as a dynamometer. There will be two different strength tests administered using this device: (1) standing hip abduction (moving your whole lower limb away from the midline of your body against the resistance offered by the dynamometer, while standing on the other leg) and (2) a seated leg press (pushing your hip and knee joints into full extension against the resistance offered by the dynamometer).

After completing the strength tests, you will undergo a hip abductor fatigue protocol on each leg administered with the dynamometer. After completing the hip abductor fatigue protocol, you will be asked to perform the LESS test again—three drop landing tests from a 12” high box. As before, two iPod cameras will be used to record your landings for later analysis.

Experimental protocol for hip abduction strength testing: The following procedures will be performed in order:

1. You will be instructed how to hold onto the head of the isokinetic dynamometer with both hands for greater postural stability during the testing. We will place a strap around the testing extremity, just above (superior to) your knee joint near the lateral femoral epicondyle.
2. You will be given the opportunity to perform 5 to 10 practice trials of concentric muscle contractions (pushing outward/upward against the machine’s resistance, away from the body) and eccentric muscle contractions (resisting the device’s inward/downward pushing against your thigh) of the hip abductor muscles.
3. You will be asked to perform 5 maximal concentric and 5 maximal eccentric contractions of the hip abductor muscles on the right and left sides.

Experimental protocol for single leg press strength testing: The following procedures will be performed in order:

1. You will be asked to sit in the dynamometer chair and be strapped in with a harness that resembles a seat belt in a car. These procedures follow the dynamometer manufacturer’s instructions in order to ensure your safety, as well as obtain proper stabilization for the single leg press strength test.
2. You will be given the opportunity to perform 5 to 10 practice trials of concentric muscle contractions (pushing away from your body against the machine’s resistance, into knee and hip extension) and eccentric muscle contractions (resisting the device’s upward pushing against your knee and hip joints into flexion) for the single leg press strength test.
3. You will be asked to perform 5 maximal concentric and 5 eccentric contractions of the single leg press on your right and left legs.

Experimental protocol to induce muscular fatigue: These exercises are designed to rapidly fatigue your hip abductor muscle groups. The following procedures will be performed in order after you have performed each of the strength measurements;

1. You will be asked to assume a standing position, and the dynamometer's thigh attachment will be strapped to your lower extremity just above your knee.
2. You will be asked to perform a series of maximal concentric contractions of hip abduction until you feel fatigued.
3. You will then receive a 20-second rest period before starting the second set of maximal concentric contractions of hip abduction.
4. You will continue to perform maximal concentric contractions of hip abduction until you reach a fully fatigued state.

*****You should not experience any pain or discomfort during the testing session. However, if you do experience any pain or discomfort the lead researcher will be near by to immediately stop the fatigue protocol session.*****

Experimental protocol for Landing Error Scoring System (LESS) testing:

You will be asked to perform a series of 3 drop landings before and after you have completed the fatigue protocol:

1. You will be asked to stand on the top of a 12" (30 cm) high wooden box;
2. You will then jump out to the marked line on the floor and attempt to land with both feet on that line.
3. Upon landing, you will jump straight up as high as you can and land on both feet from that maximum vertical jump.
4. You will be asked to repeat this three times while two iPad cameras mounted on tripods record your performances.

Lower Extremity Injury Prevention Exercise Programs: You will be given a series of lower extremity exercises and instructed on how to perform each of them correctly.

1. You will be asked to complete the assigned exercise program 4 days a week for 4 weeks.
2. On two days per week, you will perform your exercises under the direct supervision of a licensed athletic trainer, either in Jowers Center or at Bobcat Stadium.
3. Two days of training will be completed on your own at another location of your own choosing.
4. You will be asked to maintain a daily physical activity journal, recording the number of minutes and type of physical activity performed in addition to the lower extremity injury program exercises.

5. At the end of the 4-week study, you will return to the Texas State University's Biomechanics/Sports Medicine Laboratory for your final testing session ("post-test").

What are the risks of being in this study?

There are a few minor risks or possible discomforts that may be associated with participation in this study. There is a small chance that you may experience mild symptoms related to delayed onset of muscle soreness approximately 24 to 48 hours after completing the strength and fatigue testing. There is also a small chance of experiencing a lower extremity injury during the drop landing testing. However, the researchers will take every precaution to minimize these risks. If at any time you are uncomfortable with participating in the study you may withdraw from the study with no fear of repercussions.

What if you are hurt in this study?

Please be advised that medical treatment is available upon the event of physical injury resulting from the study. Medical treatment will be limited to first aid and ice. In the event that you sustain an injury needing medical treatment beyond that of first aid and ice, you will need to seek appropriate medical attention. Texas State University students may choose to go to the Student Health Center free of charge. Please call 512-245-2161 to schedule an appointment or speak to a health care provider at the Student Health Center. We will report any adverse events per institutional policy. In the event that you believe you have suffered injury not apparent immediately after testing, please contact the IRB chairperson Dr. Jon Lasser at 512-245-3413, who will review the matter with you and identify any other resources that may be available to you.

Will you be compensated/helped for being in this study?

You will receive a \$30 HEB gift card if you complete all aspects of this study. You will receive a \$15 HEB gift card if you complete the pre-test and at least 2 weeks of the 4-week exercise program associated with this study. You will receive a \$10 HEB gift card if you withdraw from the study after performing only the baseline ("pre-test") measurements.

In addition to being compensated for your time in the study, your participation will contribute to expanding the body of knowledge regarding the Landing Error Scoring System (LESS test) and ACL injury prevention programs. This information may prove useful in the design and implementation of low-tech, large group screenings for anterior cruciate ligament injury risk.

Beyond financial compensation, at the conclusion of the study, all participants will be provided with a Theraband® elastic resistance band and a lower extremity exercise program. At the conclusion of the study, upon request, participants will be shown the video records of their LESS test landings, and provided with the results of their lower extremity strength tests.

Who funds the study?

The study will be funded by a small grant from Texas State University's College of Education Graduate Student Research Grant program.

Who will see your information?

Your participation in this study is confidential. Only the investigators will have access to your personal identifiers and to any information that may be linked with your identity. All information that you complete will have an identification number rather than your name to ensure your confidentiality. All electronic data will be stored in a locked cabinet in Texas State University's Biomechanics/Sports Medicine Laboratory for up to three years following the conclusion of this study before being destroyed. Access to any electronic data recorded by the iPad devices will require a password in order to gain access, and this password will be known only to the investigators. Once the original iPad video recordings have been transferred to the log-in ID and password-protected computer, they will be deleted from the recording devices. In the event that the results of this study are published or publicly disseminated at scientific meetings, none of your personal identifying information will be disclosed.

If you want to know about the results before the study is done:

We cannot disclose any information to you until the end of the duration of the study and the results have been analyzed. At this time you will be provided with information regarding your potential ACL injury risk. You may also ask any questions you may have regarding the results of the study.

Right to ask questions:

You may ask questions about the research procedures at any time and will receive immediate responses. If you have any further questions, please direct these to Nathan Robey at njr29@txstate.edu or 507-990-4764 or Dr. Rod Harter at rod.harter@txstate.edu or 512-245-2972.

Voluntary Participation

Your participation in this study is completely voluntary. You may withdraw from this study at any time without any negative consequences from anyone associated with they study.

What if you have concerns about a study?

This project #2014E4204 was approved by the Texas State IRB on February 27th 2014. Pertinent questions or concerns about the research, research participants' rights, and/or research-related injuries to participants should be directed to the IRB chair, Dr. Jon Lasser (512-245-3413 - lasser@txstate.edu) and to Becky Northcut, Director, Research Integrity & Compliance (512-245-2314 - bnorthcut@txstate.edu).

What does your signature mean?

Before you sign this form, please ask questions about any part of this study that is not clear to you. Your signature below means that you understand the information given to you about the study and in this form. If you sign the form, it means that you agree to participate in the study.

You have been given an opportunity to ask any questions that you may have and all have been answered to your satisfaction.

You must be 18 years of age or older to consent to this study. If you consent to participate in this study and to the above state terms, please sign your name and date below.

You will be given a copy of this consent form for your records.

Participant Name (please print in all caps)

Participant Signature

Date

I, the undersigned, verify that the above informed consent procedure has been followed.

Investigator Signature

Date

APPENDIX C
PRE-SCREENING QUESTIONNAIRE

1. Demographic Information

Name: _____ Code number: _____
DOB: _____ Today's date: _____
Height (ft): _____ Weight (lbs): _____
Q-angle measurements (in degrees): R knee _____
L knee _____
Dominant Leg: Right Left

2. Are you currently physically active for at least 30 minutes a day on 3 or more days of the week?

Yes No

3. Have you had any lower extremity injury/pain that has limited your physical activity during the past 6 months?

Yes _____ No

4. If you answered "yes" to Question #3, are you currently free from the lower extremity injury/pain that has limited your activities in the past 6 months?

Yes No

5. Have you ever had any lower extremity injuries that have required surgery?

Yes _____ No

6. Do you have any previous history of anterior cruciate ligament injury?

Yes No

7. Have you ever participated in an anterior cruciate ligament injury prevention program?

Yes No

8. Are you currently participating in any resistance training program, i.e., weight training?

Yes No

9. Are you currently involved in a university-sponsored NCAA sport or a club sports team?

Yes No

APPENDIX D

REVIEW OF LITERATURE

Anterior cruciate ligament (ACL) injuries are among the most common musculoskeletal injuries occurring in sports today. These debilitating injuries are associated with both short and long-term rehabilitation costs and a predictable decrease in overall health-related quality of life. This is especially true with female athletes, who are at a reported 2 to 10 times greater risk of suffering a non-contact ACL injury as their male counterparts in basketball and soccer.⁽¹⁻²⁹⁾ With youth sports participation continuing to rise by approximately 20% each year in the United States, it is important to find a way to reduce the risks of athletes suffering ACL injuries.⁽³⁰⁾

Approximately 175,000 ACL injuries occur in the United States each year with the associated direct and indirect costs estimated at over \$2 billion dollars a year.⁽²⁶⁾ Injuries to the ACL not only cost the athlete and/or parents money for surgery and rehabilitation, but also may cost the athlete in lost competition time, scholarships and future health care costs specifically associated with knee osteoarthritis.^(8, 16, 19) As a result, this controversial injury has spawned a great number of research studies that have sought to identify ACL injury risk factors as well as effective ACL injury prevention strategies. Researchers generally agree that the cause of ACL injury may not be attributed to one lone risk factor, but more likely a combination of risk factors.^(5, 31, 32) Current ACL injury prevention programs have been introduced, but have shown little effect on reducing injury rates.⁽¹⁵⁾

The scope of this review of anterior cruciate ligament (ACL) literature will encompass the following topics: (a) ACL injury risk factors, (b) the role of hip abductor musculature in ACL injury, (c) ACL injury prevention programs, (d) the influence of fatigue on lower extremity biomechanics, (e) laboratory versus field-based ACL injury screening tools, and (f) the Landing Error Scoring System (LESS) Test. A thorough and rigorous search process for related articles began with a large database search and a review of previously referenced articles. Databases used were CINAHL, Medline, PubMed, and SPORT Discus. Research articles were searched from the period from January 1991 to November 2013.

ACL Injury Risk Factors

Today's research is focused on trying to understand why ACL injuries are occurring and what can be done to help prevent them. In order to successfully prevent this debilitating injury from occurring during sports participation, researchers must fully understand the nature of the injury mechanism and the risk factors commonly associated with ACL injuries. As previously stated, there are a multitude of injury risk factors that may have an influence on determining an individual's likelihood of suffering an ACL injury. The ACL injury risk factors that will be discussed during this review will be; anatomical, hormonal, biomechanical, and neuromuscular.

Anatomical Risk Factors. One of the ACL risk factors that has been identified is based on an individual's morphology and anatomical characteristics.

Most of the anatomical risk factors being examined are attributed to female athletes and determining why they specifically are at an increased risk of experiencing an ACL injury.⁽³¹⁾ When compared to their male counterparts, females have ACLs of shorter length, smaller cross-sectional area, and less overall volume— all of which may contribute to a decreased resistance to ligament failure.^(31, 33, 34)

Decreased femoral condylar depth has been cited throughout the literature as a possible structural alignment that may predispose an individual to ACL injuries.⁽³⁵⁻³⁷⁾ Hashemi et al. reported that individuals who had sustained an ACL injury had a decreased femoral condylar depth compared to uninjured “control” individuals.⁽³⁷⁾ Researchers found a 0.9 mm difference in femoral condylar depth between injured and uninjured males.⁽³⁷⁾ Medial tibial depth was found to cause the highest increase in ACL injury risk.⁽³⁷⁾ However, researchers were only able to relate these findings to ACL injury risk and not to explain the possible gender disparity.⁽³⁷⁾

Mclean et al. demonstrated that individuals who had a greater difference between medial and lateral tibial plateau posterior slopes experience greater peak knee-abduction and internal rotation angles than those with decreased tibial slopes.⁽³⁸⁾ These increased knee abduction and internal rotation moments (Internal moment forces) occurring at the knee joint may increase the strain placed on the ACL during sport specific activities, potentially leading to an ACL tear.^(18, 24)

Females in general, when compared to their male counterparts, experience increased sagittal, frontal and transverse plane knee laxity which can be correlated to their higher-risk landing strategies.⁽³¹⁾ There are still many questions that must be answered regarding the underlying anatomy of the knee and knee joint in order to determine how much of an effect individuals anatomical predispositions may have on ACL injury risk.

Hormonal Risk Factors. Hormonal fluctuations have been studied as another potential risk factor leading to higher ACL injury rates. During each month female's experience large fluctuations of hormone concentrations, specifically estrogen and progesterone levels.⁽³⁵⁾ During the ACL Researcher Retreat VI held in Greensboro, NC, researchers have determined that a females risk of ACL injury increases during the pre-ovulatory phase of the menstrual cycle, more so than during the postovulatory phase.⁽³⁵⁾ Researchers have discovered sex hormone receptors on the ACL itself, which may attribute to the increase in ACL injury rates. It is unclear whether this increased risk is primarily due to the influence of a single hormone or multiple hormones.⁽³⁵⁾ Research in this area of study requires significantly more investigation in order to determine what exactly the underlying influence of hormones is for the increased ACL injury rate and if the use of contraceptives should be advocated as a prevention strategy.

Biomechanical Risk Factors. The biomechanics of ACL injury have been extensively studied in effort to determine how lower extremity landing mechanics effect ACL loading. One of the most cited lower extremity body

positions thought to place the ACL under high amounts of strain is increased knee abduction.^(2, 5, 11, 12, 28, 35, 39-43) When examining high-risk body positions occurring during dynamic sport postures, high ACL strain occurs with tibial valgus, tibial internal rotation, or a combination of the two.^(18, 24, 27) Knee abduction, or medial knee collapse, movements increase during dynamic sports tasks such as landing, cutting and sidestepping.^(2, 5, 11, 12, 27, 28, 35, 39-44) Research performed by Quatman et al. supports the theory of knee abduction (knee valgus) as a biomechanical component of ACL injuries.⁽²⁷⁾ The results of the study demonstrated similar bone bruising patterns on individuals who experienced an ACL injury through a combined abduction and anterior tibial translation, as well as abduction and external rotation.⁽²⁷⁾ These findings indicate knee abduction as an integral part of the landing mechanics typically associated with ACL injuries.⁽²⁷⁾ Larger knee valgus angles upon landing from a jump occur more frequently in females than males.^(11, 16, 41, 42) These landing style differences occurring between the sexes have been attributed to the slow neuromuscular development observed in pubescent female athletes.^(8, 16) Females also demonstrate a lack of adequate neuromuscular adaptations during their pubertal development phase.⁽⁸⁾

Non-contact ACL injuries have been shown to occur during the early phase of landing, when the deceleration demands are the greatest.^(28, 31, 35) When individuals land in a more erect posture (less knee flexion), the demands on the quadriceps muscle increase, causing the tibia to translate forward and thus increase strain placed on the ACL ligament.^(5, 16, 31, 35) This type of landing is considered to be part of a neuromuscular imbalance known as “quadriceps dominance” and will be addressed in a later portion in this literature review.^(5, 16)

Fatigue also has been well documented as a potential component of risky positions associated with ACL injuries.^(35, 39, 40, 45, 46) As the level of fatigue of lower extremity muscles increases, biomechanical changes increase as well, causing higher amounts of hip adduction to occur.⁽³⁹⁾ These higher amounts of hip adduction cause the knee to present in an exaggerated valgus position.⁽³⁹⁾ Carcia et al. found that participants (college-age students, male=10 and female=10) landed in a more valgus knee position when in a fatigued state than in the non-fatigued state.⁽³⁹⁾ The Carcia et al. study suggests that fatigued hip abductor muscles allowed the tibiofemoral joint to move into an increasingly-adducted position (knee abduction) during drop-landings.⁽³⁹⁾ This finding demonstrates the importance of hip abductor musculature in providing dynamic stability to the lower extremity during dynamic landing positions, thereby reducing ACL injury risk.⁽³⁹⁾

In a similar study, Geiser et al. observed that fatigue-induced hip weakness increased motion occurring at the knee and shifted the moments occurring at the knee in the frontal plane.⁽⁴⁰⁾ Their findings are quite similar of

those of Carcia et al., in that both demonstrated that when fatigued, hip abductor muscles are unable to properly control lower extremity movements and allow the knee to be displaced more medially (into genu valgus) during sport specific tasks.^(39, 40) Geiser et al. found that the internal moments experienced at the knee in the frontal plane were increased during cutting and jumping tasks and decreased during running.⁽⁴⁰⁾ These cutting and jumping tasks are representative of the movements seen during non-contact ACL injuries. This knowledge may help further elucidate injury mechanisms as well as possible risk factors of non-contact ACL injuries.⁽⁴⁰⁾

Homan et al. found that even when individuals (82 healthy and physically active males = 41 and females = 41) differed significantly in hip abduction and external rotation strength, they displayed relatively the same motions in the frontal and sagittal planes.⁽⁴⁷⁾ The results of this EMG study suggest that weaker individuals employ greater neural drive to the hip abductor muscles during landings to accomplish the same landing position as the stronger individuals.⁽⁴⁷⁾ Weaker individuals were established as individuals who demonstrated greater gluteus medius EMG amplitudes compared to the high hip abductor strength group who demonstrated decreased EMG amplitudes ($p=0.036$).⁽⁴⁷⁾ This increase in neural drive is required by weaker individuals to compensate for their lack of strength and attempt to protect the individuals from risky positions associated with ACL injuries.⁽⁴⁷⁾ These authors concluded that hip abductor musculature strength may influence improper biomechanics and increase the risk of ACL injury.⁽⁴⁷⁾

Neuromuscular Risk Factors. Neuromuscular control is defined as the unconscious activation of dynamic restraints occurring in preparation for and in response to joint motion and loading for the purpose of maintaining and restoring functional joint stability.⁽⁴⁸⁾ Proper neuromuscular control is required to ensure correct biomechanics of the body when performing dynamic activities.

Collectively, the existing clinical research has demonstrated that individuals require high amounts of neuromuscular control in order to generate enough support to maintain dynamic knee stability.⁽¹⁶⁾ It is well documented that young girls do not experience the same neuromuscular development during puberty as their male counterparts, making them more susceptible to injury.^(6, 16) Lower extremity neuromuscular imbalances affecting the muscular control system responsible for dynamic knee stability may increase the risk of sustaining and ACL injury.^(5, 16) Understanding and identifying these neuromuscular imbalances may aid in the development of appropriate neuromuscular intervention programs aimed at decreasing ACL injury risk. Three neuromuscular imbalances have been identified in individuals demonstrating increased ACL risk factors: ligament dominance, quadriceps dominance, and leg dominance.^(5, 16)

According to Myer et al., “ligament dominance” occurs when an athlete employs the use of their knee ligaments, rather than the appropriate lower extremity musculature, to absorb the forces experienced during sporting activities.⁽¹⁶⁾ A ligament dominance compensation that commonly occurs during vigorous physical activity is medial knee motion, which results in increased knee valgus positioning.^(5, 16) If an athlete continues to rely on these ligament

dominant compensations, they may increase their risk of sustaining an ACL injury due to the increased stresses placed on the ligament itself. Once the athlete sustains a high load or force that exceeds that of the ACL's maximum load, then the ligament may tear partially or completely.

Researchers have found that female athletes are more likely to experience ligament dominant knee valgus positions than compared to male athletes of the same age.⁽¹⁶⁾ Ford et al. recently examined the differences in knee valgus motions between male and female high school basketball players. These authors found female participants (n = 40) manifested ligament dominance during drop landings, which meant that the female athletes' lower extremity musculature was unable to control the torques applied through the knee joint.⁽⁴⁾

A second ACL injury risk factor, "quadriceps dominance" is defined as the imbalance between the quadriceps and hamstring recruitment patterns during athletic activity.^(5, 16) During sporting activities, female athletes have a tendency to over-activate their quadriceps muscles instead of recruiting their hamstring muscles.^(5, 16) This increased quadriceps activation generates greater lower extremity joint torques, which may lead to injury, due to increased stress placed on joint structures.^(12, 40) When observing quadriceps dominance in elite female collegiate athletes, they react to forward tibial translation by activating their quadriceps muscles.^(5, 10, 16) In comparison, male athletes tend to rely on their hamstring muscles to respond to the unanticipated anterior tibial translation.^(10, 16) These findings are important because they demonstrate that females employ an inappropriate compensation pattern to assist with force absorption during

dynamic sporting activities.^(5, 10, 16) Increased quadriceps activation actually places increased stress on the ACL ligament itself, which may lead to injury.⁽²⁴⁾

During sport-specific activities, female athletes use less knee flexion during landings, demonstrating increased quadriceps musculature activation, and decreased hamstring activation.^(10, 16, 27) Increased ACL strain has been noted to occur during sport-specific tasks that occur with decreased knee flexion angles.⁽²⁷⁾ The increased strain is primarily due to the increased activation of the quadriceps muscle which actually creates an anterior tibial translation force.^(5, 10, 16, 31) If the individual's hamstring musculature is not activated properly to counteract these anterior translation forces, then increased stress will be placed on the ACL ligament itself until the ultimate failure point is reached, causing injury. According to Myer et al., only when the knee flexion angles reach beyond 45 degrees will the quadriceps muscle switch from its antagonistic role, to a more agonist effect on the ACL ligament.⁽¹⁶⁾ Thus, instructing female athletes to land with increased knee flexion may decrease injury risk. Increased hamstring activation during jump landings is desirable due to its function of pulling the tibia posteriorly, thus decreasing anterior shear forces at the knee.⁽⁵⁾

The third ACL injury risk component identified by Myer et al., "leg dominance" occurs when there is a significant difference between the muscular strength and joint kinematics in contralateral extremity measurements.⁽¹⁶⁾ When individuals rely on their dominant limb, an imbalance is created, placing increased stress on the dominant leg potentially leading to injury.⁽¹⁶⁾ This imbalance also increases injury risk on the non-dominant leg due to the lack of

muscular strength and control.⁽¹⁶⁾ Significant leg dominance has been reported in female athletes.⁽⁴⁾ Ford et al., observed significantly greater side-to-side maximum knee-valgus angles among female athletes when compared to their male counterparts.⁽⁴⁾ These authors described the implications of the leg dominance theory as the weaker lower extremity having an increased risk of injury due to its decreased ability to manage increased amounts of force, while the stronger lower extremity is subjected to increasing higher loads and forces.⁽⁴⁾ Female's decreased ability to control excessive forces in the weaker extremity or correctly distribute the forces may be a potential cause for the increased risk of ACL injury in female athletes.⁽⁴⁾

Knapik et al. theorized that imbalances in side-to-side strength and flexibility were possible predictors of ACL injury, thus when imbalances occur, athletes are at an increased risk of experiencing an injury.⁽⁴⁹⁾ Knapik et al. demonstrated that among individuals (n=138 female student/athletes, ages 16-21) whose dominant leg was at least 15% stronger (knee extension and flexion musculature) than their non-dominant leg, were 2.6 times more likely to experience a lower extremity injury (muscle strains, knee sprains, ankle sprains, etc.) than individuals with a less than a 15% imbalance.⁽⁴⁹⁾

The Role of the Hip Abductor Musculature in ACL Injury

The primary muscles responsible for controlling dynamic knee valgus angles are the gluteus medius, the gluteus maximus and the tensor fascia latae—all key hip abductors.⁽²⁾ The gluteus medius and gluteus maximus musculature play a very important role in normal gait and landing mechanics.⁽⁴⁴⁾ During ambulation the gluteus medius is responsible for providing pelvic stability during the swing and stance phases of gait.^(23, 50-53) Insufficient strength to the gluteus medius can result in increased hip sway and a pelvic drop on the contralateral side.^(51, 54-56) During single-limb stance the weight-bearing limb is responsible for 84% of the individual's body weight.⁽⁵³⁾ These muscles are especially important during weight bearing, because they eccentrically control the proximal portion of the femur, effectively controlling internal rotation and abduction.⁽⁴⁴⁾

Deficits in hip abductor muscle strength have been shown to correlate with increased frontal plane movements of the knee, specifically knee abduction internal moments.^(2, 41, 46, 57, 58) Increased knee abduction angles occurring in the frontal plane have been shown to place an individual at an increased risk of suffering ACL injury.⁽⁴³⁾ Salavati et al. found that fatigue of the proximal hip musculature of male participants, was correlated with decreased overall postural stability in both the frontal and sagittal planes.⁽⁴⁶⁾ The study also demonstrated a greater overall reduction of postural control in the frontal (medial-lateral) plane compared to the sagittal (anterior-posterior) plane.⁽⁴⁶⁾

Currently, researchers are trying to understand how the hip abductor musculature affects frontal plane mechanics and how much fatigue influences frontal plane motions. Geiser et al. reported an increase in frontal plane motions after participants underwent a protocol to fatigue the proximal hip musculature.⁽⁴⁰⁾ Hip abductor fatigue has been linked to increases in knee valgus angles, otherwise known as medial knee collapse, occurring in the frontal plane.^(30, 39, 40, 46, 47, 59) It is known that females experience increased knee valgus angles compared to their male counterparts, which may attribute to their increased vulnerability of experiencing an ACL injury.⁽⁴⁾ However, research has demonstrated that by increasing hip abductor strength, knee valgus angles during sports specific tasks decrease, possibly decreasing ACL injury risk.^(23, 60) The goal of this area of research is to understand the impact hip abductor fatigue and its associated weakness has on sport specific tasks in order to determine if strengthening protocols decrease these dangerous knee valgus angles.

Hip musculature involved in femoral external rotation has become a topic of interest involving fatigue and potential lower extremity injury.^(45, 61) These femoral external rotator muscles are responsible for preventing the femur from experiencing excessive internal rotation, occurring in the transverse plane, during sport activities.^(21, 42, 47, 55, 57, 62) The gluteal muscles function eccentrically to control excessive hip internal rotation; strengthening of these muscles may have an effect on reducing potentially damaging moments occurring at the knee.^(42, 62) Strengthening of the proximal hip musculature may also be effective at reducing detrimental joint angles and positioning associated with mechanisms of non-

contact ACL injuries.⁽⁴⁷⁾ High quality evidence is lacking and future research should help determine which muscle groups and/or individual muscles have the most effect at reducing these detrimental lower extremity body positions. One goal of the current study will be to identify what lower extremity muscles sports medicine clinicians and researchers should focus on when developing ACL injury prevention protocols.

Anterior Cruciate Ligament Injury Prevention Programs

In an effort to decrease the number of debilitating and costly ACL injuries worldwide, researchers have attempted at implementing specific prevention programs, e.g., FIFA 11+™, Sportsmetrics™, PEP Program™. These ACL injury prevention programs vary greatly in their protocol focus (plyometric, strength training, balance training, and core strength) and time requirements. Current research suggests that increasing an athlete's neuromuscular control, specifically at the knee, may be effective at controlling for excessive torques and loads that may cause ACL injury.^(6, 8, 14, 18, 29, 63, 64) However, it is still unclear what aspect of these neuromuscular training protocols, e.g., combined plyometric and dynamic stabilization or plyometric alone, is responsible for the reduction of ACL injury rate.^(18, 64) By understanding exactly which part of these neuromuscular prevention programs is most effective at reducing injury risk and incidence, researchers and clinicians will be able to create and implement highly-effective neuromuscular programs aimed at reducing ACL injuries.

Plyometric training may be one of, if not the most effective means of decreasing ACL injuries.^(6-9, 14, 18, 19, 29, 60, 63) Research findings suggest that these training protocols may have a significant effect at reducing female injury patterns, specifically ACL injuries. Myer et al. examined the effectiveness of a plyometric program and a balance program at reducing poor biomechanics associated with ACL injuries.⁽¹⁸⁾ Their results demonstrated that participants in both experimental groups demonstrated a decreased initial contact ($p=0.02$) as well as hip adduction angles ($p=0.015$) after training.⁽¹⁸⁾ Their plyometric training group demonstrated increased knee flexion angles at initial contact ($p=.047$) and maximum angle ($p=0.031$). Whereas the balance training group had improved medial knee drop, or decreased knee valgus angles, during landings ($p=0.005$).⁽¹⁸⁾ These authors concluded that both their balance and plyometric groups achieved significantly lower knee valgus angles.⁽¹⁸⁾ However, a limitation of this study is that each group participated in a resistance training protocol, an activity that may have skewed the results. The generalizability of the findings is also diminished since we cannot directly know whether the resistance program did or did not affect the results.

Numerous researchers have investigated the contribution of plyometric activities to the prevention of ACL injuries.^(7, 10, 14, 29, 60) Hewett et al. found that after completing a six-week jump training protocol, participants experienced a decrease in the overall incidence of ACL injuries.⁽⁷⁾ This decreased injury rate was primarily attributed to a decrease in knee adduction internal moments and abduction external moments as well as improvements in hamstring-to-quadriceps

strength ratio.^(7, 60) Chimera et al. found similar results as Hewett et al.⁽⁷⁾ in that their results demonstrated a muscle activation pattern change after the completion of a plyometric program.⁽⁶⁰⁾ Specifically, after the completion of the 6-week plyometric program, individuals had increased pre-activation of the hip adductors and also hip adductor-abductor co-activation.⁽⁶⁰⁾ These neuromuscular adaptations led to an increase in dynamic restraint and overall functional stability at the tibiofemoral joint.⁽⁶⁰⁾ Proper muscular strength is important to maintain proper stability at the knee joint. Without the proper lower extremity musculature strength, the supporting ligaments would be unable to withstand the forces applied during sporting activities.⁽¹⁰⁾

Balance and isometric strengthening exercises have also been studied to determine their effectiveness at improving neuromuscular recruitment and decreasing ACL injury risk. Perhaps the most famous of studies involving balance training is one done by Myklebust et al..⁽¹⁹⁾ This research group incorporated balance training along their position-focused plyometric exercises in an attempt to decrease ACL injuries in female team handball players.⁽¹⁹⁾ Their results demonstrated a reduction in ACL injuries among elite female team handball players; however, these researchers concluded that further inquiry was needed to determine the effects of each component of their injury prevention program on ACL injury risk.⁽¹⁹⁾

Interestingly, a recent review performed by Hübscher et al. in 2010, found no statistical evidence that balance training alone reduced the incidence of knee ligament injuries.⁽⁶⁴⁾ However, the author's meta-analysis found that multi-intervention training programs were effective at reducing the risk of acute knee injuries by 50%.⁽⁶⁴⁾

A more recent study by Myer et al. measured the effectiveness of trunk and hip neuromuscular training on decreasing the incidence of ACL injuries.⁽¹³⁾ These investigators used a variety of exercises aimed at improving the athlete's ability to control the trunk as well as improve overall core stability.⁽¹³⁾ After completing a ten-week neuromuscular strengthening program, athletes experienced improved hip abductor strength.⁽¹³⁾ This increase in hip abductor strength may have an effect on the control of the lower extremity and reduce valgus knee positioning associated with ACL injuries during athletic activities.⁽¹³⁾

Over the years, numerous attempts have been made to try and find the best ACL prevention protocol, and so far with minimal success.⁽²²⁾ Pfeifer et al. were unable to demonstrate a significant reduction in non-contact ACL injuries among Idaho high school girls' sports teams over two competitive seasons using knee ligament injury prevention group and a control group.⁽²²⁾ The lack of a significant reduction of non-contact ACL injuries in their treatment group points to a need for more research to determine exactly which parts of the ACL injury prevention programs have the most effect of on decreasing injury risk. Future research should be aimed at determining the intervention with the greatest reduction in ACL injury risk and with the greatest compliance.

In addition to the determining the potential key to ACL prevention programs, researchers have attempted to determine the effectiveness of current neuromuscular training programs.⁽⁶⁵⁻⁶⁸⁾ Throughout the literature, neuromuscular programs have been shown to decrease risk of ACL injuries.⁽⁶⁵⁻⁶⁸⁾ However, recently researchers have begun to examine both player and coach compliance when implementing prevention protocols and discovered that compliance is a large determining factor in the effectiveness of an ACL prevention program.^(65, 67, 68) Myklebust 's research group has published several studies regarding the implementation and the effectiveness of their ACL injury prevention protocol on decreasing ACL injury rates among female Norwegian team handball players. Recently, these authors sought to examine whether or not the ACL prevention protocol has truly been successful in the long run.⁽⁶⁷⁾ While reviewing the literature on their selected protocol Myklebust et al. determined, their prevention protocol was successful at keeping the ACL injury rate low in handball players.⁽⁶⁷⁾ The relatively low ACL injury rate can be attributed to the coach as a partner during the prevention program. Having coaches involved in the implementation of the prevention protocol could increase the compliance rate among teams. If players and coaches can both buy into the prevention program and incorporate these into their warm-up routines, then ACL injury risk reduction may be greater than currently reported.⁽⁶⁷⁾

Adherence to ACL injury prevention programs has demonstrated decreases in ACL injury occurrence rate.^(65, 67, 68) Several studies have demonstrated decreases in overall injury risk between high program adherence

and low program adherence groups.^(65, 68) Steffan et al. found that individuals completing the FIFA 11+ in the high-adherence group demonstrated significant improvements in balance and reduction in injury risk.⁽⁶⁸⁾ The results of their study revealed an overall injury risk reduction of 72% in lower extremity injuries in the high adherence group, compared to the medium-adherence group.⁽⁶⁸⁾ No significant differences were found between their high and low-adherence group, which may be attributed to in low playing exposure of the low-adherence group.⁽⁶⁸⁾ Hägglund et al., demonstrated an effective prevention of acute knee injuries in individuals (n=4,556, females football players ages 12-17) placed in the high-adherence group.⁽⁶⁵⁾ These authors demonstrated an 88% decrease in ACL injury rate in the high-adherence group compared to those in the low-adherence group.⁽⁶⁵⁾ These results are significant in that they demonstrated a reduction in injury rates in high-adherence groups. If clinicians and coaches want to decrease the risk of injury in their athletes, then they must incorporate these neuromuscular training programs into their daily warm-up or workout routines. As the research demonstrates it is important to ensure patient compliance and adherence to the program in order to see a significant reduction in ACL injuries.^(65, 67, 68)

Influence of Fatigue on Lower Extremity Biomechanics

The influence of fatigue on lower extremity biomechanics has been associated as a potential factor for increased ACL injuries in female athletes.^(2, 21, 39, 40, 45, 46) Research has demonstrated that as proximal hip weakness increases,

moments occurring at the knee in the frontal plane increase as well.^(39, 40, 46) Increased knee valgus angles occurring in the frontal plane have been associated with increased ACL injury risk.^(15, 28, 32, 39, 40, 43, 69) Geiser et al. participants performed a series of sport specific tasks (jumping, cutting, and running) after completing a hip abductor fatigue protocol.⁽⁴⁰⁾ Researchers found that when in a fatigued state, study participants experienced increased knee adduction moments during the sport specific tasks.⁽⁴⁰⁾ These increased knee adduction moments have been associated with increased ACL injury risk in previous research.⁽²⁸⁾ Carcia et al. found similar results with participants who completed a hip abductor fatigue protocol. During drop jump landings, participants landed with their knees in a more valgus position than in their non-fatigue state.⁽³⁹⁾ This increase in knee valgus can be attributed to the hip abductors being unable to control the amount of hip adduction during landings when fatigued.⁽³⁹⁾

Salavati et al. found that proximal hip fatigue had a greater effect of postural stability than distal hip muscular fatigue did.⁽⁴⁶⁾ While this study did not evaluate drop-landings, rather postural stability, it is still important because of the implications discussed, relating postural instability as a possible risk factor for ACL injuries. Salavati et al. were able to demonstrate that proximal hip muscle fatigue had a significant effect on postural stability in both the frontal and sagittal planes.⁽⁴⁶⁾ However, Salavati et al. reported greater effects of instability occurred within the frontal plane rather than the sagittal plane.⁽⁴⁶⁾ As discussed within the article, frontal plane movers may be more important due to the significance these

muscles have on single-leg stance control.⁽⁴⁶⁾

McMullen et al. used surface electromyography (sEMG) to examine the effect of proximal hip musculature fatigue, specifically the gluteus medius, on postural control. These researchers found that study participants experienced impairments in postural control and quality of movements after completing an eccentric gluteus medius fatigue protocol.⁽⁴⁵⁾ This EMG study is important because it allows researchers to examine how prolonged bouts of exercise influence postural control in sports related activity, after fatigue occurs.⁽⁴⁵⁾ If the gluteus medius is put in a fatigued state, individuals may be placed at an increased risk of injury due to lack of femoral control.^(45, 47)

While many studies have demonstrated the effects of fatigue on hip abductors and its effects on controlling knee valgus angles, there are studies that have found non-significant changes in landing biomechanics after fatigue.^(21, 70) A study examining hip abductor fatigue during single leg landings found that even when researchers induced a 43% strength deficit after the fatigue protocol, no significant changes in hip or knee kinematic or kinetics were noted.⁽²¹⁾ Researchers were unable to detect any significant changes during the first 60 milliseconds of the single-leg landing, which is conventionally when ACL injuries occur.⁽²¹⁾ More importantly, Patrek et al. demonstrated that tasks involving more than just single-leg landings would be required to place significantly more force on the ACL for injury to occur.⁽²¹⁾ By introducing acceleration and deceleration tasks, along with single-leg landings, researchers may be able to detect increased changes in frontal plane landing mechanics, possibly leading to

increased ACL injury risk.⁽²¹⁾

Thomas et al. had participants perform dynamic landing tasks after completing a fatigue protocol, in an effort to determine the influence of isolated hip rotators and triceps surae fatigue on dynamic landing mechanics.⁽⁷⁰⁾ These authors found that fatigue did produce specific hip and knee kinematic changes during dynamic landings; however, they were not enough to place the ACL at an increased risk of injury.⁽⁷⁰⁾ Their findings demonstrate the need for further research on this topic to help researchers and clinicians understand the exact role of neuromuscular fatigue on ACL injuries.⁽⁷⁰⁾

Fatigue protocols for the hip abductors vary widely in the body of research examined for this literature review. Protocols varied in their resistance velocities, subject positioning and level of hip abduction torque needed to reach a fatigued state.^(2, 21, 39, 40, 70) Brent et al. used the isokinetic resistance velocity of 120°/s to induce isolated hip musculature fatigue protocols.⁽²⁾ Brent et al. determined after pilot testing that 120°/s could be accomplished more comfortably while in a standing position and represented velocities associated with functional cutting activities.⁽²⁾ The standing position was chosen due to its close representation of a functional position.⁽²⁾ On the other hand, Geiser et al. chose to use velocities of 60°/s for the concentric hip abduction muscle actions and 300°/s for eccentric muscle actions, to allow for minimal resistance during adduction movements.⁽⁴⁰⁾ However, when comparing the speeds between the two relevant studies, Geiser et al. performed the hip fatigue protocol in a side lying position, which may have attributed to the reduction in isokinetic velocity.⁽⁴⁰⁾

Throughout the literature examined, there were various levels of fatigue used. One study examining standing hip abduction used a fatigue state of 50% of the subject's ipsilateral baseline force values for two consecutive trials in order to establish a fatigued state.⁽³⁹⁾ This fatigue value of 50% has been used with success in multiple other fatigue protocols examining much larger muscle groups such as the quadriceps/hamstring group.^(71, 72) The study examining the hip abductors done by Geiser et al. used a fatigued state of a decrease in peak torque of only 20%.⁽⁴⁰⁾ This relatively small value was chosen by the researcher used previous studies that found a reduction in strength between injured and uninjured hip abductors to be about 20%.⁽⁴⁰⁾

Laboratory-Based versus Field-Based ACL Injury Screening Tools

ACL injuries occurring in athletic and recreational populations, lead to both short-term and long-term disabilities associated with loss of playing time and the possibility of development of early onset osteoarthritis.^(13, 17, 73) Due to these factors, prevention of ACL injuries is crucial to maintaining the quality of life in athletic and recreationally active individuals.⁽¹⁷⁾ The identification of individuals considered to be at a high risk of suffering an ACL injury may be beneficial in the reduction of ACL injury occurrence.^(17, 54) Through this identification process of high-risk individuals, clinicians and coaches may be able to effectively implement a neuromuscular training program that could potentially decrease the patients ACL injury risk.⁽¹⁷⁾ Currently, the gold standard for the assessment of ACL injury risk factors is an expensive 3-D motion analysis laboratory-based method that is

relatively inaccessible to most clinicians.^(17, 54) Therefore, attempts must be made to make a more inexpensive and clinician friendly field-based test. A lower cost option must be established and proven effective at identifying ACL risk factors. Several attempts at a more accessible field-based screening tool, drop-jump assessment have been made; however, few have been adopted for widespread use (LESS test and ACL injury risk prediction algorithm).^(17, 32, 74-76)

Several low cost alternatives have been made available to clinicians for field based testing.^(17, 32, 74-76) Researchers in the Myer et al. group found that the ACL injury risk prediction algorithm demonstrated the potential to increase the efficacy and efficiency of ACL prevention strategies.⁽¹⁷⁾ The groups ACL injury risk prediction model demonstrated increased ability to measure high knee abduction moments, and therefore may aide in the identification of patients at high risk of ACL injury.⁽¹⁷⁾ Most research for field-based screening tools has used a form of 2-D analysis either examining the frontal plane alone or both frontal and sagittal planes together.^(12, 32) McLean et al. examined the reliability of a 2-D video measurement compared to that of the gold standard 3-D motion analysis.⁽¹²⁾ They concluded that the 2-D camera method provides reliable descriptions of frontal knee plane movements, had similar potential for screening elite basketball players during dynamic valgus movements and may also be useful for evaluating the effectiveness of training programs aimed at decreasing knee valgus.⁽¹²⁾ Padua et al. examined the reliability of the LESS field test at detecting ACL risk factors and found the field test to be both valid and reliable.⁽³²⁾ The significance of the LESS test is that it examines both the frontal and sagittal

planes, allowing clinicians to determine both knee valgus and knee flexion movements during drop-landings.⁽³²⁾

Landing Error Scoring System (LESS) Test

The Landing Error Scoring System (LESS) test was developed by a group of researchers from the University of North Carolina in 2002 in order to give clinicians a field-based screening tool to aid in identification of individuals with increased risk of experiencing an ACL injury. The LESS test consists of 17 items used to assess the jump-landings performed by the volunteers. Each of these 17 items is placed into specific grouping based on the errors being assessed. The first set of items (LESS items 1 through 6) are used to analyze both the individual's lower extremity and trunk positioning at initial ground contact.⁽³²⁾ The second set of items (LESS items 7 through 11) are used to assess errors that occurred with the positioning of the individuals feet.⁽³²⁾ This set of items are analyzed at differing times during the landing, initial contact (LESS item 11), entire foot in contact (LESS items 7 & 8), and time between initial contact and maximum knee flexion (LESS items 9 & 10).⁽³²⁾ The third set of items examined, assess the lower extremity and trunk movements between initial contact with the ground and the moment of maximum knee flexion angle (LESS items 12 through 14), or the moment of maximum knee valgus angle (LESS item 15).⁽³²⁾ The fourth and final set of items examined during the LESS test are two "global" items. These global items are used to assess the individuals overall sagittal plane movement and the rater's general perception of landing quality (LESS items 16 & 17).⁽³²⁾

A recent study by Onate et al. demonstrated excellent expert-rater vs. novice rater reliability, as well as moderate to excellent validity when examining the drop-jump landing test.⁽⁷⁵⁾ When examining the subjective expert-rater scores and objective 3-dimensional instrumentation values, researchers found excellent agreement (84-100%).⁽⁷⁵⁾

The LESS test is an assessment tool that has been adopted by programs such as the National Academy of Sports Medicine's for use in their corrective exercise specialist-training program. An important aspect of the LESS test is that it can be performed at a relatively low cost to the clinician, only requiring two standard video recorders.^(32, 75, 76) This is important because most clinicians do not have access to sophisticated, expensive three-dimensional motion analysis systems for the screening of athletes during pre-participation exams. LESS test has been found to be both a valid and reliable clinical assessment tool.^(32, 75) Padua et al. found that the LESS test was able to successfully distinguish between groups on a range of jump-landing biomechanics.⁽³²⁾ Another important result is that researchers demonstrated significant differences in biomechanics and ground-reaction forces between individuals with poor (LESS score >6) and excellent (LESS score <4) jump-landing techniques.⁽³²⁾ These results are important to clinicians because the LESS test has the ability to provide them with a reliable field screening at a minimal cost. However, Smith et al. did not find the LESS test to be a valid predictor of ACL injuries.⁽⁷⁶⁾ These authors noted that more research must be done before adopting the LESS test as a potential field-based screening test.⁽⁷⁶⁾

LESS testing has been shown to have excellent interrater and intrarater reliability.^(32, 75) Onate et al. demonstrated that even novice raters were able to interpret the LESS test videos at the same level as expert raters.^(32, 75) Onate recommended the use of the LESS test to measure dynamic jump-landing motions due to its high interrater and intrarater reliability, and its minimal time and material requirements.⁽⁷⁵⁾ Padua et al. demonstrated excellent interrater and intrarater reliability with the LESS test; however, these authors used a modified version of the LESS test that did not require cameras.⁽⁶⁹⁾ These researchers chose to modify the LESS test in effort to make it more clinician-friendly by not having to purchase cameras.⁽⁶⁹⁾ One potential limitation to their study is that the examiners of the modified LESS test were considered experts in performing drop-landing assessments and therefore could perform the analysis without the use of camera feedback.⁽⁶⁹⁾ This presents with a problem with using the modified version, because most “young professionals” in the field of athletic training do not have extensive experience in the analysis of drop-landings. Due to this lack of experience, the clinician may not be able to observe all of the body positions in the four allowed drop-landing tasks.

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APPENDIX E
LOWER EXTREMITY INJURY PREVENTION PROTOCOLS

Exercises Descriptions

Hip Abductor

1. Single hip abduction (side-lying) with Thera-Band®: Start by positioning yourself in a side-lying position on the floor. Start with the exercising limb in full knee extension and keep a neutral hip position. Then slowly complete a hip abduction movement and then return slowly to the starting position. Make sure to keep both your leg and foot in a forward and neutral position. Place the resistance exercise band around each ankle, just superior to the malleolus of the moving both lower limbs. Perform 3 sets of 15 repetitions **(See photos below)**

Starting Position



End Position



2. Standing hip abduction (standing, 45 degrees) with Thera-Band®: Position yourself in a standing position, using a stable service to maintain your balance. Place a secured resistance exercise band around your ankle, just superior to the malleolus. Slowly complete a hip abduction movement at a 45 degree angle, and then slowly return to the starting position. Keep your knee in full extension and your leg slightly rotated outward. Perform 3 sets of 15 repetitions (**See photos below**)

Starting Position



End Position

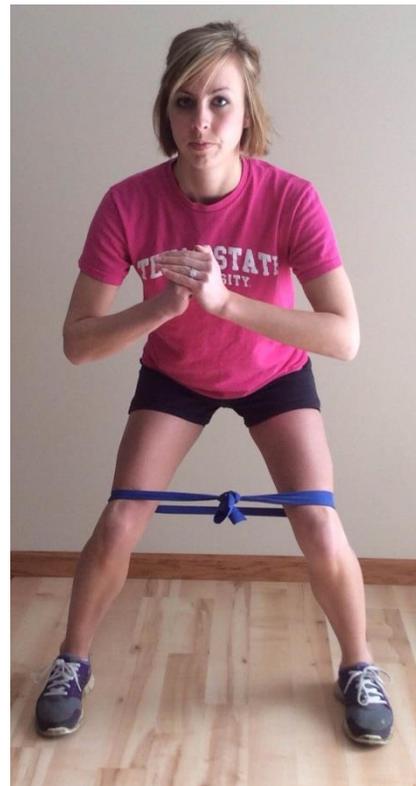


3. Monster band walks with Thera-Band®: In this exercise you will complete a resisted side stepping motion. Begin and maintain this exercise in 30 degrees of hip and knee flexion position. Keep your hands on your hips throughout the exercise. Place the resistance band around your knee, just superior to both femoral condyles. Start the exercises with your feet together. Next take a sidestep with your dominant limb. Make sure to keep your toes pointed forward and knees bent throughout the exercise. You will sidestep for a distance of 15 feet. Upon reaching the 15 foot marking you will face the same direction and side step back to their original starting position using your non-dominant leg. This counts as 1 repetition. Perform 3 sets of 15 repetitions **(See photos below)**

Starting Position



End Position



4. Clam shells with Thera-Band®: You will complete this exercise in a side-lying position. Start the exercise by laying in the hook-lying position (knees flexed to 90 degrees and hips flexed to 60 degrees), with the resistance band placed above lateral epicondyle of the femur. Next, abduct your movement or top knee off of the bottom knee, then slowly return to the starting resting position. This movement counts as 1 repetition. While performing the exercise, keep your hips facing forward. Ensure to keep your feet together and your back straight. Perform 3 sets of 15 repetitions **(See photos below)**

Starting Position



Ending Position



5. Unilateral Bridge: You will begin this exercise lying on your back with one knee bent and the other extended (**Starting position photo**). Start the exercise pushing the bent knees foot into the floor to raise your hips off of the ground. Continue to raise your hips off of the floor until your straight leg is aligned with the bent leg. Try to keep your pelvis as level as possible during the exercise. Each raise counts as 1 repetition. Perform 3 sets of 15 repetitions on each leg (**See photos below**)

Starting position



Ending position



6. Single Leg Deadlift: You will begin the exercise balancing on your dominant leg with your hip in a 30 degree flexed position. Slowly flex at the hip until your opposite upper extremities third digit touches the ground next to your balancing foot and then return to the starting position. Do not allow your knee to travel past your toes. After touching the floor with your opposite hand, return to the starting position by contracting your glute and hamstring musculature. This counts as 1 repetition. Perform 3 sets of 15 repetitions **(See photos below)**

Starting Position



Ending Position

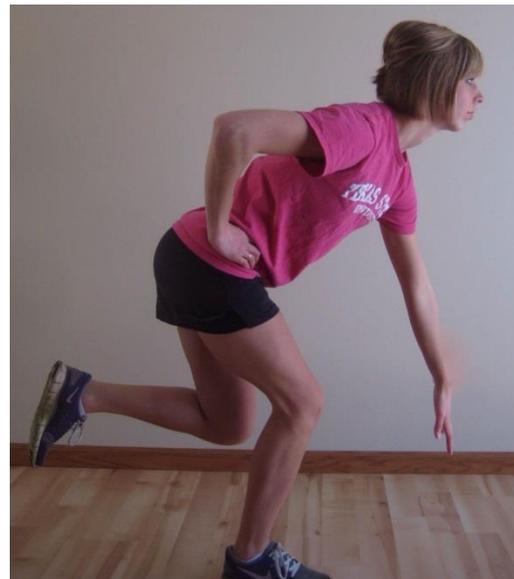


7. Single Leg Squats: Begin the exercise by balancing on your dominant leg, with your hip and knees flexed at 30 degrees. Then slowly lower your non-dominant hand towards your dominant foot. You may stop lowering yourself to the ground once your third digit touches your dominant foot. Once you have reached your dominant foot, you will return to the original starting position by contraction your glute and hamstring musculature. This counts as 1 repetition. You will then repeat the same exercises for your non-dominant leg. Make sure to maintain proper knee position during the exercise by not allowing your knee to travel past your toe. Perform 3 sets of 15 repetitions **(See photos below)**.

Starting Position



Ending Position



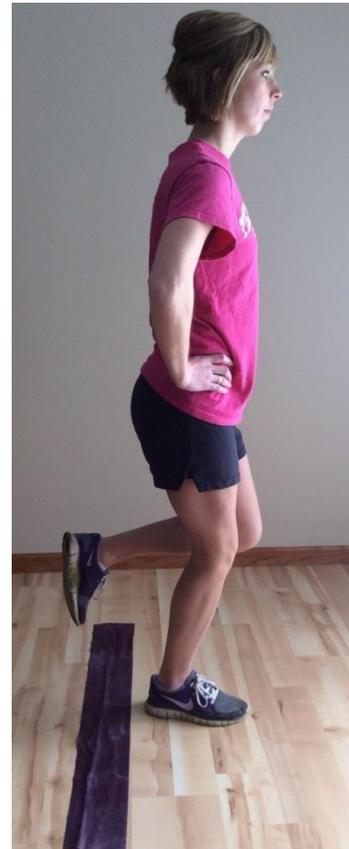
Plyometric Exercise Group (Weeks 1 and 2)

1. Forward/backward single-legged line jumps: Find a straight line or mark a straight line on a stable surface. Stand on your right foot and place your hands on your hips. Jump forwards and backwards over the marked line at a comfortable height. Focus on landing with your knee slightly bent and your trunk and upper extremity in line with your lower extremity (**see photos below**). Perform this exercise as fast as possible, but ensure you are under control and not losing your balance. Perform 30 repetitions, each forward and backward jump counts as 1 repetition. After completing 30 repetitions switch to the opposite foot and repeat the same procedures.

Starting Position



Ending Position



2. Side-to-side single legged line jumps: Find a straight line or mark a straight line on a stable surface. Stand on your right foot and place your hands on your hips. Jump side-to-side over the marked line at a comfortable height. Focus on landing with your knee slightly bent and your trunk and upper extremity in line with your lower extremity (**See photos below**). Perform this exercise as fast as possible, but ensure you are under control and not losing your balance. Perform 30 repetitions, each forward and backward jump counts as 1 repetition. After completing 30 repetitions switch to the opposite foot and repeat the same procedures.

Starting Position

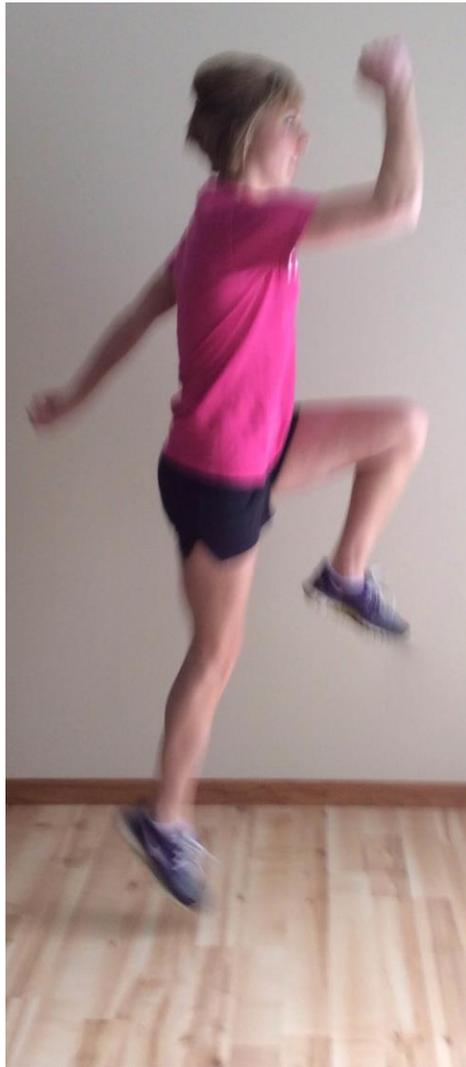


Ending Position



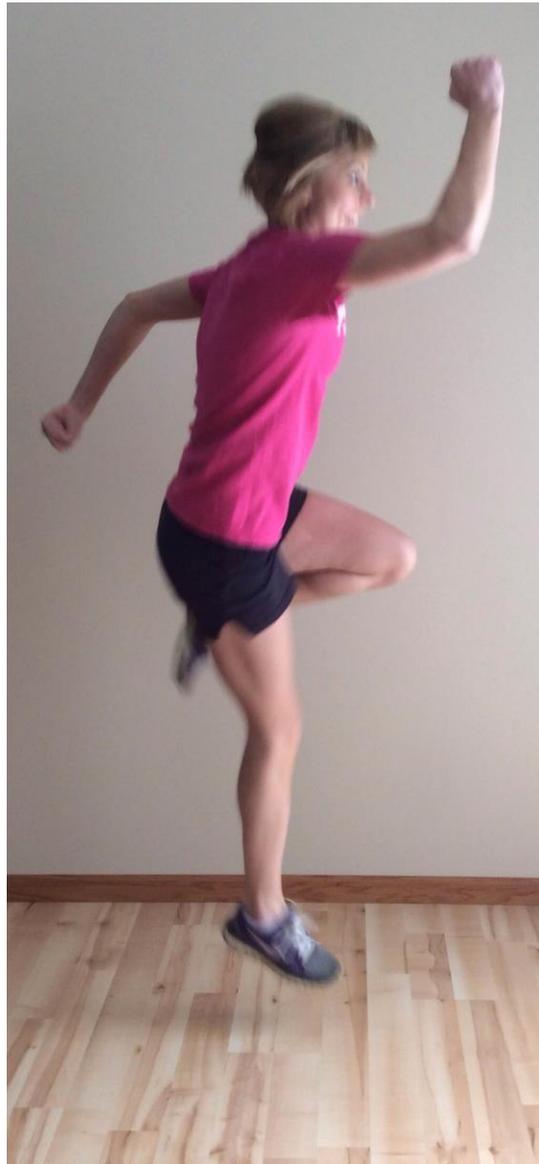
3. High Skips: Begin the exercise at a designated starting line. Next, skip as high as possible, swinging your upper extremity to propel yourself upward. Perform the skips down the designated area **(94 feet or 31 yards)**. Make sure you stay in a straight line and avoid any sideways movements. Make sure to land softly and bend at your knees and hips each time you land. Upon landing quickly perform another high skip using the opposite upper extremity to propel yourself upwards. Perform 1 repetition of this exercise **(See photo below)**.

Jumping Position



4. Distance Skips: Begin the exercise at a designated starting line. Next, skip as far as possible, swinging your upper extremity to propel yourself forwards. Perform the skips down the designated area (**94 feet or 31 yards**). Make sure you stay in a straight line and avoid any sideways movements. Try to land softly and bend at your knees and hips each time you land. Upon landing quickly perform another distance skip using the opposite upper extremity to propel yourself forwards. Perform 1 repetition of this exercise (**See photo below**).

Jumping Position



5. Broad Jumps: Begin the exercise with your feet set shoulder-width apart. Bend at your hips and knees and swing your upper extremity to maximally jump forward as far as possible. Take off and land with both feet equally. Focus on sticking the landing and landing softly on the ground with hips and knees bent. Make sure to land in an upright position, not bending too far forward, backward or to one side. Perform 2 sets of 10 jumps. **(See photos below).**

Starting Position



Landing Position

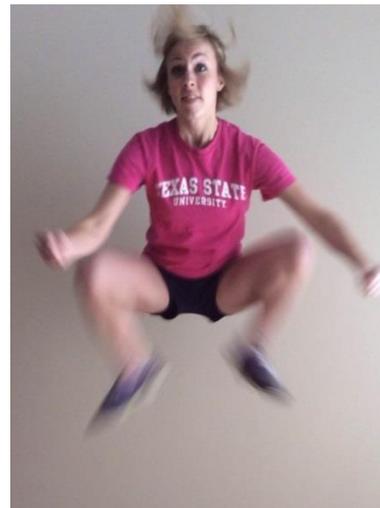


6. Tuck Jumps: Begin the exercise with your feet set shoulder-width apart. Bend at your hips and knees and swing your upper extremity to maximally jump vertically as high as possible. Take off and land with both feet equally. While in the air, tuck both of your knees to your chest. Focus on landing softly with your weight evenly distributed. Make sure to land in an upright position, not bending too far forward, backward or to one side. Upon landing, immediately perform another jump for maximal height. Perform 2 sets of 10 jumps as fast as possible. **(See photos below)**.

Starting Position



Jumping Position



Landing Position

7. Alternating Single-Leg Lateral Bounding: Begin the exercise with your feet set at shoulder-width apart. Bend at your hips and knees and jump to the side. You will begin by pushing off with one extremity and landing on the opposite extremity. Focus on landing softly, with your hips and knees bent, weight distributed evenly and trunk balanced over your hips. Once you have stuck the landing and are equally balanced you will jump back to the opposite side. This exercise will be repeated as fast as possible, while maintaining good form and balance. Perform 2 sets of 10 jumps. **(See photos below).**

Starting position



Ending Position



Plyometric Exercise Group (Weeks 3 and 4)

1. Forward single-leg hop, hop, hop and stick: Begin the exercise with your hands on your hips and balancing on your right lower extremity. Hop forward quickly 3 times in a row. Focus on bending at the hips and knees during jumping and landing, keeping your shoulders over your hips and maintaining balance. On the third hop, stick the landing and hold for a count of 5 seconds. Make sure you are balanced and that your knees are bent over your toes with your hips bent in line with your shoulders. Perform 10 repetitions of this exercise. **(See photos below).**

Starting Position



Ending Position



2. Squat jumps: Begin this exercise with your feet set shoulder width apart and with your hips and knees bent in a squat position. Focus on keeping your back straight and your chest up. Jump as high as you can and reach as if you were going for a rebound in basketball. Land softly, flexing at the hips and knees and keeping your balance central. Upon landing continue into another squat position and perform another jump. Perform 2 sets of 10 repetitions for maximal height and speed. **(See photos below)**.

Starting Position



Jumping Position



3. Landing Position

3. Single-leg maximal vertical jump: Begin the exercise by balancing on your right lower extremity. You will then bend at your hip and knee and explode upward as high as you can as if you were going for a basketball rebound. You may swing your upper extremities to gain more momentum. Upon landing, hold the landing for a count of 3. Perform 10 repetitions of single-leg maximal vertical jumps on each leg. **(See photos below)**.

Starting Position



Ending Position



4. Single-leg jump for distance: Begin the exercise on your right lower extremity with your hip and knee bent. You will then explode forward as far as you can, using your upper extremities to generate momentum. Focus on landing softly on the same extremity used to jump, by bending your hips and knees. Hold the land for a count of 3 before performing another max distance jump. Perform 10 repetitions on each lower extremity. **(See photo below).**

Starting Position



Ending Position (Landing Position)

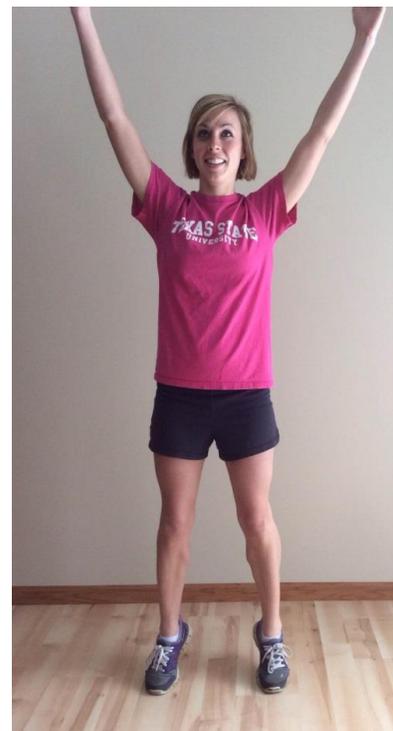


5. Broad jump, jump, jump, vertical jump: Begin this exercise with your feet set shoulder width apart and hips and knees bent. Use your upper extremity to perform a maximal forward jump, and then landing on the ground with both feet equally. Focus on landing with your hips and knees bent, weight evenly distributed between extremities, and sticking the landing. Make sure you are maintaining a balanced position during each landing. Perform 3 consecutive broad jumps, at the end of the third jump perform a maximal vertical jump off both feet as if trying to reach for a rebound and try to land in the same position from which you jumped from. Perform 5 repetitions of this type of jump sequence, all 3 broad jumps and 1 vertical jump equal 1 repetitions.

Starting Position



Ending Position

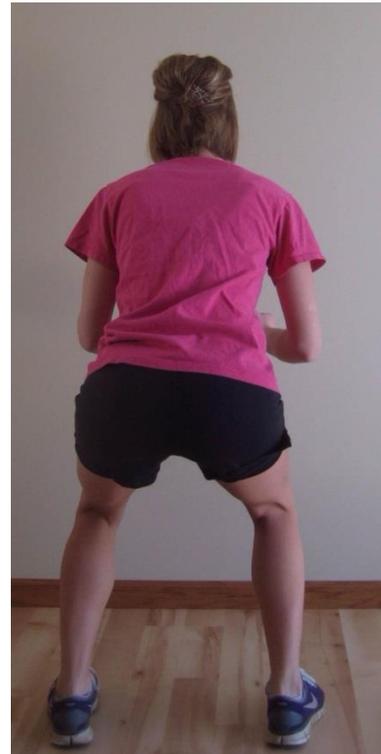


6. 180 degrees jumps: Begin this exercise with your feet set shoulder width apart and hips and knees bent. Start by jumping off both feet and rotating 180 degrees in the air so that when you land you are facing the opposite direction from which you started. Focus on landing softly with your hips and knees bent. When you land, make sure you are balanced position. Upon landing, you will immediately make another 180 degree jump in the opposite direction from which you just came. Perform 10 repetitions, 2 180 degree jumps equals 1 total repetition.

Starting Position



Ending Position



7. Single-leg lateral bounding: Begin the exercise by standing on your right lower extremity with your hands on your hips and begin to jump sideways. When landing focus on landing softly with your hips and knees bent. You should be in a balanced position upon landing. Once you have regained your original form, jump back to your original position. Perform 10 repetitions on both extremities. Each side to side jump only counts for 1 repetition.

Starting Position



Ending Position



APPENDIX F

RATE OF PERCEIVED EXERTION (RPE) SCALE

Rate of Perceived Exertion (RPE)

This scale is designed to measure your perceived exertion during your assigned exercises. When trying to determine your RPE, the number 6 represents “no exertion at all” or “complete rest”. However, the number 20 refers to a maximal effort given during the exercise, meaning you are working as hard as possible during the exercise. For this study you should always be performing your assigned exercises at a 12-14 or the numbers in bold.

6 – No Exertion at all

7- Extremely Light

8

9 – Very Light

10

11 – Light

12

13 Somewhat Hard

14

15 – Hard (Heavy)

16

19 – Extremely Hard

20 – Maximal Exertion

APPENDIX G

BIODEX TESTING SCRIPT

Below are the specific instructions that will be given to each individual during the hip abductor and closed kinetic chain strength testing, as well as the fatigue protocol. The instructions on this form will be the only directions given to each individual. No other motivation or special directions will be given to the individual by the researcher.

- 1) You will begin the testing session using a simple familiarization process on the Biodex 4 Pro. You will now complete the familiarization process by performing a set of 10 repetitions of the closed kinetic chain exercise. This phase will allow you to become familiar with the testing procedures. Once you are finished with the familiarization process, we will begin the strength testing. If you experience any pain or discomfort during the exercise please let me know so that we can correct it.

Verbal cues

- Drive your foot as far forward as you can and then slowly resist the machine as it pushes back against you.
 - Do not let your foot just fall backwards.
 - Drive your foot as hard as you can!
 - Keep Resisting!
- 2) You will now begin the closed kinetic chain leg press peak force testing. You will perform 5 maximal repetitions. You can start when I say go. Again, if you experience any pain or discomfort during the exercise please let me know so we can stop the test and correct it.

Verbal cues

- Drive your foot as hard and as far forward as you can!
 - Do not let your foot fall backwards; make sure you slowly resist the machine pushing your leg backwards.
 - Keep pushing!
 - Almost done! Keep it going
- 3) Next, you will be performing 10 practice repetitions of hip abduction to familiarize yourself with the testing procedures. These repetitions should be performed comfortably at your own pace. Once you have finished the familiarization phase we will begin the peak torque testing. If you

experience any pain or discomfort during the exercise please let me know so that I can stop the test and correct the issue.

4) **Verbal cues**

- Push your leg up away from your body and then maintain the pressure as the machine pushes back down toward your opposite heel.
- Keep your trunk straight and upright, no leaning!
- Keep resisting the machine!

5) You will now begin the hip abductor peak torque testing. You will perform 5 maximal repetitions. You may start when I say go. Again, if you experience any pain or discomfort during the exercise please let me know so that we can stop testing.

Verbal cues

- Push your leg up away from your body and then pull back down toward your opposite heel as hard as you can!
- Keep your body nice and straight, no leaning!
- Keep pushing!
- Almost finished keep it up!

6) You will now complete the fatigue part of this testing session. You will continue to perform the hip abduction movement until I instruct you to stop. You will then receive a small rest period before being asked to again complete a repeated bout of the hip abduction exercise, again until I instruct you to stop. This will be repeated until I say it is time to switch legs. The same protocol will be applied on your opposite leg, again until I inform you to stop. If you experience any pain or discomfort during the exercise please let me know so that we can correct it. Any questions before you get started?

Verbal cues

- Push your leg up away from your body and then pull back down toward your opposite heel as hard as you can!
- Keep your body nice and straight, no leaning!
- Keep pushing!
- Keep going don't give up!
- Almost finished keep it up!

APPENDIX H

LANDING ERROR SCORING SYSTEM

Volunteer Instruction Form

Instructions for the Volunteer (read by researcher)

- You will complete 3 jump-landing tasks from the wooden box to the designated area marked on the floor by the white tape.
- You will jump forward from the box, not vertically, down onto the marked white line. Once you have landed on the designated white line you will then immediately rebound for a maximal vertical jump.
 - ***As if you were going for a rebound in basketball or a header in soccer.***
- You want to focus on jumping as high as possible once you have landed from the box.

For Researcher (observations)

A successful jump consists of (Padua et al. 2009)

- 1) Jumping off with both feet from the box
- 2) Volunteer jumps forwards, but not vertically off box
- 3) Lands with feet entirely on the floor
- 4) Jump-landing task completed in a fluid motion

The study volunteer must complete 3 successful jumps before completing the testing session.

APPENDIX I

OVERVIEW OF THE STUDY

Purpose of Study: The purpose of this study will be to compare the effects of two 4-week lower extremity prevention protocols (traditional exercises versus lower extremity plyometrics) on frontal and sagittal plane landing mechanics after completing a hip abductor fatigue protocol. We will also quantify the effects of each prevention protocol, traditional and plyometric, on LESS test scores. These LESS test scores will provide us with information regarding the participants ACL injury risk both before and after training.

Experimental Hypotheses:

- The participants in both the Traditional and Plyometric exercise groups will demonstrate significant improvements in hip abductor and CKC single leg press strength measurements between Week 0 (pre-test) and Week 4 (post-test) ($p < 0.05$).
- The Plyometric protocol will show significantly greater improvements in LESS Test scores (decreased LESS Test scores), than Traditional exercise group at the end of the 4-week intervention ($p < 0.05$).
- The plyometric protocol will demonstrate a decrease in fatigable effects (increased LESS Test scores), when comparing the pre and post-LESS test at the end of the 4-week intervention ($p < 0.05$).

Assumptions:

- This study assumed that participants were healthy, recreationally-active individuals.
- This study assumed that participants fully complied with their assigned 4-week protocols.
- This study assumed that participants will give maximal effort when requested.
- This study assumed that all testing equipment used, were reliable and accurate.
- This study assumed that all participants followed the correct exercise techniques when performing exercises at home.

Delimitations:

- Recreationally-active, female volunteers, ages 18-24 (n=30)
- No current LE injury that has limited activity in the past 6 months
- No previous LE injury requiring surgical interventions (ACL)
- No previous participation in ACL prevention program
- Variable Resistance bands (Theraband)
- 4 exercise sessions per week x 4 weeks
- 2 sessions(supervised) + 2 sessions(unsupervised)

Limitations:

- Compliance of participants unsupervised exercise sessions.
- Instruction of correct exercise forms can only be performed during supervised sessions.
- The participant's level of activity during the 4-week study cannot be controlled for outside of the 40-60 minutes of weekly supervised exercise sessions.
- A learning affect is possible during the Landing Error Scoring System, however we are unable to control for any learning

Operational Definitions:

Drop Jump – the act of an individual dropping from a known height onto a pre-determined landing location. Upon landing the individual begins a jump for maximal height.

Fatigue – the temporary loss of power to respond induced in a sensory receptor or motor end organ by continue stimulation.

Fatigued State – Point at which 5 consecutive maximal voluntary concentric repetitions fall below the participants established 50% peak torque value.

Frontal Plane – anatomical plane that divides the body into anterior and posterior halves.

Genu Valgum – The Tibia is angled medially more than 5° relative to the femur at tibiofemoral joint.

Hip Abduction – movement of distal leg away from midline of the body.

Hip external rotation – rotational movement away from the midline of the body.

Neuromuscular Training – A combination of training protocols consisting of plyometric and movement training, core strengthening, balance training, resistance training and interval speed training designed to improve an individual's athletic performance.

Physically Active – an individual completing at least 30 minutes of moderate-intensity daily physical activity five days per week.

Recreationally Active – an individual who engages in moderate intensity physical activity for at least 30 minutes on three days per week.

Resistance Training – an individual who engages in regular resistance training activities (i.e., resistance bands, dumbbells, etc.) as part of their physical activity regimen.

Tibiofemoral joint – joint that lies between the femur bone of the upper part of the leg and the tibia bone of the lower part of the leg.

Valgus knee angle – inward angulation of the distal end of the femur and the proximal end of the tibia.

Significance of the study:

The outcomes of this study will provide significant contributions to the field of sports medicine by 1) comparing the effects of two 4-week lower extremity prevention protocols on frontal plane landing mechanics after fatigue, 2) providing information on the effects of each prevention protocol on Landing Error System Scoring (LESS) test scores. In the literature, hip abductor strength deficits have been reported to have an effect on movements at the knee joint, specifically, dynamic knee valgus. These improper landing angles have been linked to increases in ACL injury risk. These improper landings are especially important when examining female drop landings, since females are approximately 2 to 10 times more likely to suffer an ACL injury.