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The Effect of a Neuromuscular Training Program on Jump Landing Performance

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THE EFFECT OF A NEUROMUSCULAR TRAINING PROGRAM ON JUMP LANDING PERFORMANCE

by

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HUMAN PERFORMANCE

DECLARATION OF ORIGINALITY

I do hereby declare and attest to the fact that this is an original study based solely upon my scholarly work here at Lindenwood University and that I have not submitted it for any other college of university or degree here or elsewhere

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This thesis has been approved as partial fulfillment of the requirement of the degree of Master of Science in Human Performance at Lindenwood University

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ABSTRACT

Injury to the anterior cruciate ligament (ACL) is highly prevalent within competitive sports of all levels and types. Female athletes are at higher risk for sustaining an ACL injury, specifically those participating in field and court based sports involving large dynamic movements, such as soccer, basketball, lacrosse, and gymnastics. The use of neuromuscular training to promote proper mechanics during jumping and change of direction activities may decrease the risk of ACL injury. **PURPOSE:** The purpose of this study is to determine the effect of a neuromuscular training program on jump landing mechanics in female college athletes. **METHODS:** Forty-three female Division II college athletes (20.06±1.2yrs, 67.34±2.5in, 148.76±19.9lbs) were recruited from the rosters of four teams including, soccer (N=11), lacrosse (N=19), field hockey (N=6), and volleyball (N=7). Of the 43 participants that completed baseline testing, 34 completed post testing. Jump landing performance was assessed using the Landing Error Scoring System (LESS) Analysis of the jumps was assessed by three separate evaluators and the scores were averaged to obtain an overall LESS score. Participants were randomized into two groups; a neuromuscular training (TRAIN) and a control (CONT) group. TRAIN performed six weeks of neuromuscular jump training, twice per week for a total of 12 sessions. Data was analyzed using a 2 x 2 (group x time) ANOVA with repeated measures on time. All data are presented as means ± SD. **RESULTS:** There was no interaction effect observed for knee valgus at initial contact ($p=0.16$; $p>0.05$) or at maximum knee flexion angle ($p=0.64$; $p>0.05$). The amount of knee valgus observed at both initial contact and maximum knee flexion remained the same for TRAIN, whereas there was a statistical trend ($p=0.059$) towards an increase in knee valgus at initial contact over time in the CONT. Significance differences between groups and time were found for total LESS score ($p=0.049$; $p<0.05$). A significant difference was observed ($p = 0.019$) for total LESS score in the CONT as performance decreased from baseline (6.03±1.13 errors) to post testing (6.61±1.33 errors), whereas in the TRAIN performance remained the same from baseline (5.69±1.22 errors) to post testing (5.65±1.44 errors). **CONCLUSIONS:** Neuromuscular training appears to help maintain jump landing performance over a six-week period while a lack of training appears to result in a decrease in performance. Slight improvements in knee valgus were observed in the TRAIN group which may be further improved over a longer training period. These findings support the use of a neuromuscular jump training program over a

relatively short period of time to improve landing mechanics. Longer investigations are needed to better determine if reductions in injury potential can result.

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KEY TO ABBREVIATIONS

ACL-anterior cruciate ligament

ANOVA-analysis of variance

ATC-certified athletic trainer

BMI-body mass index

CMJ-counter movement jump

CONT-control group

DL-double leg

DVRT-differential variable reluctance transducer

EMG-electromyography

FPPA-frontal plane projection angle

KLIP-knee ligament injury prevention

LESS-landing error scoring system

MRI-magnetic resonance imaging

NCAA-national collegiate athletics association

SL-single leg

TRAIN-training group

3D-three dimensional

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CHAPTER 1

INTRODUCTION

Athletic or sport related injuries occur at every level of competition, within nearly every sport domain. As the level of competition increases, sequential changes in maturation promote the increase in factors like size and speed, which influence the amount of force generated by the athlete against other competitors in contact based sports, and against the ground in a non-contact manner. This generation of force is often the mechanism that produces an injury to an athlete. One of the most devastating orthopedic injuries to sustain, is a rupture or tear of the anterior cruciate ligament (ACL). Injury to the ACL of the knee is highly prevalent within competitive sports of all levels and types. Over a 16 year period, more than 300 ACL injuries occurred per year within a 15 sport sample that represented approximately 15% of the population of athletes at the NCAA collegiate level (Hootman, Dick, & Agel, 2007). Researchers have agreed that females are the higher risk gender for sustaining an ACL injury, specifically those participating in field and court based sports that involve large dynamic movements, like soccer, basketball, lacrosse, and gymnastics (Beynnon, Vacek, Newell, Tourville, Smith, Shultz, & Johnson, 2014; Hootman et al., 2007)

While direct contact mechanisms of injury are often unpreventable, high rates of non-contact injuries to the ACL occur in athletes involved in sports that require jumping and cutting functional movements. Of these athletes, research has shown that females are of greater risk than males in sustaining a non-contact ACL injury (Munro, Herrington, & Comfort, 2012). Researchers have used bone bruise and cartilage damage locations of the knee with associated ACL injuries, to determine specific mechanisms for non-contact ACL injuries. Consistent damage to the lateral aspect of the knee indicates that a major mechanism of ACL injury is a knee valgus or abduction movement (when the knee goes inward) during landing or cutting (Quatman et al., 2011). This mechanism of injury has been confirmed by researchers in controlled laboratory settings. Within several studies, cadaveric legs have been fixed to devices that can force the knee into different movements and rotations such as knee valgus and internal rotation. The results of these studies consistently show that the most ACL strain is caused by a knee valgus movement (Levine et al., 2013; Kiapour et al., 2014; Kiapour et al., 2015).

Many studies have proposed that the most effective strategy to reduce a knee valgus movement is the use of neuromuscular training to promote proper mechanics during jumping and change of direction activities (Myer et al., 2011; Munro et al, 2011; Quatman et al., 2011). Several studies have implemented specific prevention programs and have recorded rates of injury within the population observed. In a two-year study, more than 5,500 youth soccer players were monitored for injury (Mandelbaum, Silvers, Watanabe, Knarr, Thomas, Griffin, & Garrett, 2005). Those participating in a knee injury prevention program displayed an incidence rate of 0.05 injuries/per 1000 exposures versus an injury rate of 0.47 injuries/per 1000 exposures for the group participating in a traditional warm up (Mandelbaum et. al, 2005).

Female soccer players from clubs in Sweden displayed similar findings. Of the 4600 athletes participating, those that performed a prevention program twice per week had an ACL tear rate of 0.27% while those not participating in the program had a rate of 0.67% (Waldén, Atroshi, Magnusson, Wagner, & Hägglund, 2012). Many of these programs were multi-component-based with a large majority incorporating some form of neuromuscular/plyometric based movements (Michaelidis, & Koumantakis, 2014; Waldén et al., 2012; Emery & Meeuwisse, 2010; Mandelbaum et al., 2005).

Few studies have examined the direct effect of these neuromuscular training programs specifically on jump landing performance and whether or not it can improve knee valgus movements. Due to high prevalence of ACL injury in female athletic populations and a major mechanism of injury being knee valgus during dynamic movements, it is hypothesized that a specific neuromuscular training program over the course of a season may decrease the amount of knee valgus observed. Thus, the purpose of this study is to determine the effect of a neuromuscular training program on jump landing mechanics in female college athletes.

Statement of Problem

ACL injury is a debilitating injury in athletes of all ages and has been especially prevalent in female athletes participating in dynamic sports like soccer, lacrosse, basketball, and gymnastics. A dynamic knee valgus is a consistent mechanism of injury for ACL tear and other significant knee injuries. Knee injury prevention programs have been developed with the goal of reducing ACL injury and although some have been successful, others have had no effect on injury rate. Due to the multi-component nature of these it is uncertain which components of the prevention programs may be contributing to a reduction in knee injury rate among the athletic populations observed. Few studies have examined a neuromuscular training program effect on jump landing performance and the ability it may have to reduce knee valgus during dynamic movements.

Statement of Purpose

The purpose of this study is to determine the effect of a neuromuscular training program on jump landing mechanics in female college athletes which may have implications on ACL and other knee injury prevention strategies.

Significance of Study

While direct contact injuries are difficult to predict and prevent, non-contact injuries are potentially preventable. Due to a dynamic knee valgus predisposing an athlete to ACL injury, if at risk athletes are able to be identified using a landing error scoring system, and a neuromuscular training program is able to reduce these predisposing factors, then it may have a significant impact on reducing rates of ACL tears and other major knee injury rates within female athletic populations. This potential reduction in injury rate would decrease time missed from play and potentially decrease the heavy financial burden that is often associated with the major reconstructive surgeries needed to repair an ACL after injury.

Research Hypothesis

Participants who perform a neuromuscular training program twice per week for six weeks will improve their jump landing scores more than those in a control group.

Delimitations

The following boundaries will be imposed in the study by the researcher:

1. Only Lindenwood University athletes will be recruited.
2. Only female athletes will be included as participants.
3. Athletes must be free of any significant knee injury within the last 12 months.
4. The Landing Error Scoring System (LESS) protocol will be the only quantitative method used to determine jump landing performance.

Limitations

The following are potential problems that may not be controlled by the researcher:

1. Other training factors will not be controlled due to different training programs from different strength and conditioning coaches depending on sport and season.

2. Due to the nature of an athlete's physical demand during sport and/or training, injuries may occur outside or within the study and may force the athlete to withdraw from the study.
3. The effects of a neuromuscular training program on jump landing performance in a male athlete population will be unknown because this study is limited to female athletes.

Assumptions

The following factors are assumed to be true:

1. It can be assumed that the participating athletes will have little to no experience with neuromuscular training that is specific to jump landing performance.
2. It can be assumed that athletes participating in the control group will not be performing jump landing neuromuscular training outside of the study.
3. It can be assumed that the athletes have provided an accurate knee injury history.

Definitions

The following terms in the study will be defined as:

1. Neuromuscular training program-A plyometric based training program designed to teach muscle memory of proper jump landing mechanics. The training program is intended to be progressive in nature, while incorporating unilateral, bilateral, vertical, and lateral dynamic movements.
2. Landing Error Scoring System (LESS)-A validated method for quantifying performance during a drop jump landing task using video playback from a frontal and lateral view, to score 17 error criteria.

3. Drop jump test- A dynamic movement assessment that requires a participant to stand on a 30cm tall box facing a line on the ground that is half the participant's height in distance from the box. They will jump down to the line and immediately perform a maximal vertical jump for height.

CHAPTER 2

LITERATURE REVIEW

ACL Prevalence

Due to the location of the tibiofemoral joint along the kinetic chain, injuries to the knee are very common within several sports and types. Of the knee injuries, the ACL is one of the most common structures susceptible to injury, and results in a significant amount of time away from sport. Several studies have examined ACL incidence in different populations and among certain sports. A 21-year study was conducted within Olmsted County, Minnesota from 1990-2010 (Sanders, Maradit Kremers, Bryan, Larson, Dahm, Levy, & Krych, 2016). The population of the county included 144,260 people in 2010. Medical records were reviewed within the county, and any incident of an injury to the ACL were identified (Sanders, et. al, 2016). A total of 3494 people met the initial criteria, with 1841 meeting the secondary criteria of an isolated ACL tear with no other structures involved (Sanders, et. al, 2016). The overall mean age for isolated ACL tear was 29 (Sanders, et. al, 2016). Of the isolated tears, 59% were males. The highest incidence of females sustaining an ACL tear was between the ages of 14-18, whereas males peaked between 19-25 years of age (Sanders, et. al, 2016). These age ranges between both genders reflect common ages in which athletes compete in sports at the high school and college level. The results from this study are based off a general population and specific sport and athlete populations were not identified (Sanders, et. al, 2016).

ACL injury incidence and rates were observed over a five year period in the state of Vermont, within eight different colleges and 18 different high schools (Beynnon et al., 2014). Sport and gender related comparisons were examined between all the athletes within the study. The college level competition produced an ACL incident rate of .15 based on athlete exposures compared to .061 in the high school setting (Beynnon et al., 2014). Between genders, females presented an injury rate of .112 compared .063 for males (Beynnon et al., 2014). A total of 7 different field or court based sports were included between the two levels of competition, all of which involving dynamic jumping, cutting based movements, or a combination of both (Beynnon et al., 2014). The sports that yielded the highest ACL incidence rates at the collegiate level were soccer and rugby for men, and soccer, rugby, and volleyball for females (Beynnon et al., 2014). The results from this study indicate there may be a correlation between gender and sport, in determining the prevalence of ACL injury (Beynnon et al., 2014).

An epidemiological study analyzed data for all injuries across 15 different sports at the NCAA level over a 16-year period (Hootman et al, 2007). Lower extremity injuries accounted for 53% of all injuries (Hootman et al, 2007). Nearly 5000 ACL injuries occurred over the time period with an incidence rate of approximately 313 per year within the sample (Hootman et al,, 2007). Within the four sports that sustained the most ACL injuries, three were the female sports of gymnastics, basketball, and soccer (Hootman et al, 2007).

It seems to be consistent that within the literature, athletes participating in elevated risk sports that involve dynamic movements, like football, soccer, basketball, and lacrosse are at a greater risk of sustaining an ACL injury. When comparing by gender, females present with the highest rates of injury to ACL which may indicate that females participating in the identified high-risk sports, may be pre-disposed to significant knee injuries, including ACL tear.

Pre-Disposing Factors and Mechanisms of Injury

ACL injuries occur in many different ways with both direct contact and non-contact mechanisms of injury. With rates of non-contact ACL injuries being so high, especially in female athletic populations, the specific contributing factors and mechanisms for these non-contact injuries have been thoroughly investigated. One study looked at tibiofemoral alignment during simulated landing positions to determine if this may pre-dispose some to injury (Boden, Breit, & Sheehan, 2009). The study population involved twenty-five healthy male and female athletes with an average age of twenty-five years, all of whom had no previous history of knee surgery (Boden, et. al, 2009). Each participant was placed in 3 different unilateral simulated landing positions; safe, provocative, and exaggerated provocative. The provocative position involved an initial point of contact with the heel, subtalar plantar flexion angle of 7 degrees, and a knee flexion angle of 17 degrees versus the safe position which displayed a toe point of contact, a subtalar plantar flexion angle of 23 degrees and a knee flexion angle of 21 degrees (Boden, et. al, 2009). This provocative position was determined by previous literature to be associated with ACL injury and the exaggerated position was used to further exaggerate an ACL injury pre-disposition (Boden, et. al, 2009). Each participant was measured twice in each position, using magnetic resonance imaging. Four separate measurements were taken with each scan to determine tibiofemoral alignment; posterior tibial point to point of contact, point of contact to femoral sulcus point, point of contact to the most anterior point on the circular portion of the posterior aspect of the condyle, and the tibial plateau angle (Boden, et. al, 2009). The provocative positions were found to align the knee in a near sub luxated position which would allow bone bruises to occur and place strain on the ACL (Boden, et. al, 2009).

Often during a game or practice an injury occurs so rapidly that it is sometimes hard for an athlete to describe exactly what happened and without video playback, an athletic trainer, coach, or physician may not be able to obtain a specific mechanism of injury. One way to help understand specific mechanisms is using simulated scenarios in a laboratory setting with cadaveric legs to determine which knee positions and motions put the most strain on the ACL. One study compared knee abduction and tibial internal rotation using cadaveric legs to determine which movement contributed to higher rate of ACL rupture (Levine, Kiapour, Quatman, Wordeman, Goel, Hewett, & Demetropoulos, 2013). Seventeen legs (9 female and 8 male) were fixed to a custom designed drop stand that simulated the load placed on a knee during a vertical jump landing task (Levine et. al, 2013). Within each cadaveric leg, a differential variable reluctance transducer (DVRT) was placed on the ACL which was used to determine the amount of strain that the ACL sustained when specific loads and degrees of tibiofemoral abduction, translation, and internal rotation were induced on the leg (Levine et. al, 2013). The legs were randomly assigned into two separate loading groups, knee abduction or internal tibial rotation. The legs were tested in 25 degrees of knee flexion with an axial load to simulate landing. ACL failure occurred in 15 of the 17 legs (Levine et. al, 2013). Several other structures of the knee were damaged across all legs. Knee abduction was the only significant movement that caused ACL strain to reach its peak at failure (Levine et. al, 2013). Tibial plateau damage location was also dependent on the loading mechanism. Knee abduction caused damage to the mid lateral tibial plateau, while damage to the posterior lateral tibial plateau was associated with tibial internal rotation (Levine et. al, 2013).

In two similar studies conducted out of Harvard by some of the same research team, cadaveric legs were used to assess other knee kinematics that contributed to ACL tear. The first study used 16 cadaveric legs (8 male, and 8 female) fixed to a similar testing apparatus that was used in the previous study, which simulated the load placed on a knee during a vertical jump landing task (Kiapour, Quatman, Goel, Wordeman, Hewett, & Demetropoulos, 2014). Each leg was also equipped with a DVRT to assess the amount of ACL strain sustained by different loads

(Kiapour et. al, 2014). The results found that anterior translation, tibiofemoral abduction and internal rotation all contributed to ACL strain but that strain was initiated as both anterior translation of the tibia and abduction both reached their peaks, while tibiofemoral internal rotation had not yet reached its peak (Kiapour et. al, 2014). The researchers concluded that anterior translation and tibiofemoral abduction were larger contributing factors to ACL injury than internal rotation (Kiapour et. al, 2014). The other study used 19 cadaveric legs (10 females, 9 males) to determine the degrees of knee valgus and tibial internal rotation that placed the greatest stress on the ACL (Kiapour, A. M., Kiapour, A., Goel, Quatman, Wordeman, Hewett, & Demetropoulos, 2015). Within each cadaveric leg, a DVRT was used to determine the amount of strain that the ACL sustained with different loads (Kiapour, A. M. et. al, 2015). Infrared light emitting diodes were attached to the mud shaft of both the femur and the tibia to allow for measurement of specific tibiofemoral kinematics (Kiapour, A. M. et. al, 2015). Each leg was then fixed to a force couple system which was able to place the leg in 0-50 N-m (joint torque) knee valgus and 0-20 N-m tibial internal rotation (Kiapour, A. M. et. al, 2015). The results showed that significant increases in ACL strain occurred when both knee valgus torque and tibial internal rotation torque increased, but knee valgus rotation contributed to higher degrees of ACL strain when compared to tibial internal rotation (Kiapour, A. M. et. al, 2015).

Another method of determining specific mechanisms of injury for ACL injury is the examination of bone bruise locations as well as other associated tissue damage in people that have sustained ACL tears. Yuin Cheng Chin and colleagues (2014) conducted a study examining MRI of people who sustained knee injuries over a six-month period. They reviewed 710 knee MRI's and found 88 people (<50 years old) with knee injury (Chin, Wijaya, Chong, Chang, & Lee, 2014). Of the 88 patients (72 male, 16 female), 58 had ACL injury, 15 had other ligamentous injury, and the remaining 15 had no associated ligamentous injury (Chin et. al, 2014). The found that most patients had some associated bruising of either the lateral femur, medial tibia, or lateral tibia, but those who sustained an ACL injury had a higher prevalence of lateral compartment bruising (both lateral femur and lateral tibia). The difference in the bruising patterns between ACL and non ACL injury could lead to a specific mechanism for knee injury (Chin et. al, 2014).

Dr. Darius Viskontas and colleagues (2008) recruited patients who had sustained an ACL injury to help identify specific bone bruising characteristics associated with injury. The inclusion criteria for their subject population required a clear mechanism of injury; contact versus non-contact, an MRI within 6 weeks of injury and ACL injury with no associated PCL injury or greater than 2 injured ligaments (Viskontas, Giuffre, Duggal, Graham, Parker, & Coolican, 2008). The 100 included patients were associated to one of two groups; 14 sustaining a contact injury, and 86 sustaining a non-contact injury (Viskontas et. al, 2008). MRI's were analyzed by a musculoskeletal radiologist who classified the location, depth and intensity of the bone bruises using a knee cartilage lesion mapping system from the International Cartilage Repair Society (Viskontas et. al, 2008). Results found that both groups displayed similar locations, depths and intensities, with the lateral femoral condyle and the lateral tibial plateau being the two most prevalent locations for both groups and yielding the greatest intensity and depth of bruising (Viskontas et. al, 2008). The only significant difference between groups was that bruising on the medial tibial plateau was more common with a non-contact mechanism than a direct contact mechanism (Viskontas et. al, 2008).

Another study reviewed the MRIs of eight athletes who had sustained a non-contact ACL injury (Kim, Spritzer, Utturkar, Toth, Garrett, & DeFrate, 2015). All subjects presented with bone bruises in both the medial and lateral compartments of the tibiofemoral joint (Kim et. al, 2015). These MRIs were then used to create 3D modeling of the knee itself as well as an outline of the bone bruise surface for each knee (Kim et. al, 2015). This allowed for measurements of knee kinematics in both the position in which the MRI was done and the predicted position of injury (Kim et. al, 2015). They found that the bone bruise locations lead to a predicted position of injury to include, decreased knee flexion, anterior tibial translation, tibial internal rotation, and a significant knee valgus (Kim et. al, 2015).

Baseline jumping performance was assessed in a study with 399 female athletes using a drop vertical jump test (Quatman, Kiapour, Myer, Ford, Demetropoulos, Goel, & Hewett, 2011. These athletes then reported back after their season had completed on whether or not they had sustained an ACL injury (Quatman et. al, 2011). Of the included participants, nine ACL injuries occurred. These nine injuries served as the dependent variable with the 390 non-injured subjects being the control (Quatman et. al, 2011). At baseline, the injured group displayed an average knee valgus angle of five degrees while the non-injured group had an average of -3.4 degrees (Quatman et. al, 2011). Both groups averaged a 20-degree knee flexion angle and a ground reaction force of 600 N (Quatman et. al, 2011). Based on the data of the jumping performance, injury simulations were created using finite element models, which predicted bone bruise locations and articular cartilage pressure distributions (Quatman et. al, 2011). These simulations also were compared to bone bruise locations of the athletes that sustained ACL injury (Quatman et. al, 2011). They found that combined abduction movement and anterior tibial translation displayed both similar bone bruise locations and cartilage pressure differences on the lateral femur and posterlateral tibia. These results support the evidence that a knee valgus or abduction movement is a major mechanism for ACL injury (Quatman et. al, 2011).

Video analysis of actual ACL injuries has been used to try and determine specific mechanisms of injury. A study out of Norway measured knee kinematics from 10 incidents of ACL tear during both female handball and basketball (Koga, Nakamae, Shima, Iwasa, Myklebust, Engebrestsen, Bahr, & Krosshaug, 2010). Using video footage from at least two separate camera angles during the point at which injury occurred, the researchers constructed 3D images of the player which allowed them to measure specific joint positions, as well as estimate ground reaction force (Koga et. al, 2010). The incidents were classified into different groups; cutting (7) or single legged landing (3). Knee flexion increased on average 24 degrees forty milliseconds after initial contact, knee abduction had an average increase of 12 degrees, and increased internal rotation of 8 degrees (Koga et. al, 2010). Peak ground reaction force was measured at 3.2 times body on average. The results of this study suggest that knee abduction or valgus force and knee internal rotation may be the most significant factors attributing to non-contact ACL injury mechanisms (Koga et. al, 2010).

Gender Differences

There has been evidence that female athletes are at greater risk for ACL tear than males. Timothy Sell and colleagues (2006) conducted a study that examined differences in jumping mechanics between male and female athletes when both directional and reactive components were involved. They recruited 18 male and 17 female high school basketball players to perform a double legged stopped jump task (Sell, Ferris, Abt, Tsai, Myers, Fu, & Lephart, 2006). They performed the task in three separate directions; left, right and vertical, as well as both in a planned setting where they knew which direction they were going, and a reactive setting where their direction flashed in front of them as soon as they jumped (Sell et. al, 2006). Several knee joint kinematics as well as hamstring and quadriceps EMG were measured. They found that medial directed jumps affected knee joint position the most, meaning that a jump to the left put the right knee in a more vulnerable position and a jump to the right put the left knee in a more vulnerable position (Sell et. al, 2006). They also found that when compared to planned jumps, reactive jumps placed the knee in a more susceptible position for ACL injury. Although these were observed in both gender populations, females displayed significantly greater degrees of decreased knee flexion and increased knee valgus than males when performing directional reactive jumps (Sell et. al, 2006).

In another study that compared male and female athletes, 36 recreational athletes (17 male, 19 female) performed a vertical stop jump task and were measure for hip and knee range of motion as well as specific muscle activation using electromyography (Chappell, Creighton, Giuliani, Yu., & Garrett, 2007). The vertical stop jump involved a 2 to 3 step run with a two foot land and takeoff for a maximum vertical jump. Using an EMG system with electrodes placed on several lower extremity muscles, and a 3D video graphic analyzing system with retro reflective markers placed on multiple bony landmarks, both muscle activation and hip and knee joint angles were measured during both the landing and takeoff phase of the vertical stop jump task (Chappell et. al, 2007). They found that females presented with decrease knee flexion, hip flexion, hip abduction, and hip external rotation when compared with male subjects. Both groups displayed increased hamstring activation before landing but females when compared with males had a greater activation of the quadriceps before landing paired with a trend towards decreased hamstring activation after landing (Chappell et. al, 2007). These biomechanical patterns lead to increased loading of the ACL during a landing task and may be a factor in the gender differences seen in the prevalence of ACL injuries for athletes (Chappell et. al, 2007).

Female soccer players were recruited for a study that observed biomechanics differences between two different cutting maneuvers (Imwalle, Myer, Ford, & Hewett, 2009). Nineteen high school and college aged female soccer players had retro reflective markers placed on several anatomical landmarks to assess kinematics of the trunk, hip, knee, and ankle (Imwalle et. al, 2009). The athlete performed a directional cut at either 45 degrees or 90 degrees using a computer screen that would inform them which direction to turn forcing them to perform a reactive movement rather than an anticipated movement. A high speed motion analysis system using 8 cameras was used to determine multi-joint kinematics during the movement (Imwalle et. al, 2009). A force plate was used to determine both initial contact and toe off phase of the cutting maneuver. Kinematic data was observed during the stance phase which was between initial contact and toe off phases (Imwalle et. al, 2009). The 90 degree cut produced significantly increase hip and knee internal rotation when compared to the 45 degree cut. They also found that the greatest predictor for knee valgus/abduction was hip adduction at peak force for both angles of cutting (Imwalle et. al, 2009). This may indicate that hip abduction strength may be a factor in the degree of knee abduction observed in cutting, and or jumping maneuvers (Imwalle et. al, 2009).

A similar study examining landing mechanics in female basketball and soccer players recruited a total of 93 athletes (Munro, Herrington, & Comfort, 2012). Markers were placed on several anatomical landmarks to assist in determining landing performance. Participants performed two landing tasks; a double leg drop jump task that involved stepping down from a 28 cm box and immediately performing a maximal vertical jump, and a single leg landing task that involved stepping down from a 28 cm box and landing on one leg (Munro et. al, 2012). The anterior view of both task was recorded and analyzed using a digital camera and analyzing software. Frontal plane projection angle (FPPA) was the main variable assessed during both tasks, as a positive FPPA indicated a movement towards knee abduction and a negative FPPA indicated a movement towards knee adduction (Munro et. al, 2012). Results showed that both soccer and basketball athletes displayed more positive FPPA values during the single leg task compared with the double leg task but when comparing the two groups of athletes, basketball players displayed significantly greater FPPA values than soccer players during the single leg task (Munro et. al, 2012). The results from the study indicate that both unilateral and bilateral training should be incorporated into prevention programs that aim to decrease pre disposing biomechanical factors that may contribute to knee injury (Munro et. al, 2012).

Knee abduction/valgus is widely accepted as a mechanism of injury for ACL injury, but some of the pre-disposing factors to a dynamic knee valgus are continuingly investigated to help identify at risk individuals. A study examining female athletes, accounted for several variables to help determine risk factors for knee abduction movement during dynamic activities (Myer, Ford, Khoury, Succop, & Hewett, 2011). Over a four year span, 698 youth female athletes who played basketball or soccer with a public school district were included within the study population (Myer et. al, 2011). The data that was obtained on the subjects included anthropometric measurements (height, BMI), joint laxity tests, maturational status, and dynamic strength (knee extension, flexion, hip abduction). The participants each performed three trials of a drop vertical jump task where they step down from a 31cm box and immediately perform a max vertical jump (Myer et. al, 2011). Retro reflective markers were placed on several bony landmarks to allow for analysis of jump landing performance and measurement of knee kinematics using a motion analysis system. The results found that maturational growth of both bone and body mass in the absence of strength gain over the same period of time, contributed significantly to an observed knee abduction movement during a jump landing task. This as well as static knee abduction angle and decreased knee flexion angle during landing, all pre-disposed participants to improper landing mechanics and potential injury (Myer et. al, 2011). With this in mind the study suggests that neuromuscular training for individuals that display knee valgus during dynamic activities may provide a solution to the prevalence of ACL and other knee injuries, especially in a female athlete population (Myer et. al, 2011).

Knee Injury Prevention Strategies

As ACL injury mechanisms become narrowly identified it is important to take in consideration how they may be avoided. Prevention programs have been created with the aim to reduce the prevalence of ACL injuries within athletic populations. Many of these programs are multi-component based including strength training, stretching exercises, proprioceptive training, plyometric training, and training for neuromuscular control and proper biomechanics during dynamic movements. Jonathan Chappell and Orr Limpisvasti (2008) conducted a study on the effect of a neuromuscular training program on jumping performance. They recruited 30 female college Division 1 soccer and basketball players for their study population. The participants were equipped with 18 retro reflective markers for the jumping tests, which included one drop jump and one vertical stop jump (Chappell & Limpisvasti, 2008). Performance based vertical jump and single leg hopping tests were also conducted. All participants completed a 6 week training program that was instructed by a licensed physical therapist. The program consisted of core strengthening lower body strengthening, balance training, and plyometric training ((Chappell & Limpisvasti, 2008). The exercises took 10-15 minutes to complete and were performed 6 days per week. At the end of the training period, post training testing occurred. The results found that both initial and maximum knee flexion angle increased between pre and post training. There was a decrease in kinetic knee valgus during the stop jump after training (Chappell & Limpisvasti, 2008). Both performance based tests improved. These outcomes indicate that a neuromuscular training program may have both a performance benefit and injury prevention capability (Chappell & Limpisvasti, 2008).

Another study examined 22 female high school basketball players and their response to a sports injury prevention training program (Lim, Lee, Kim, An, Yoo, & Kwon, 2009). The participants were randomly divided into a training group and a control group. Pre and post training data was collected on all participants using a rebound vertical jump task. Knee and hip kinematics were measured using a 3D motions analysis system, as well as maximal jump height and quadriceps and hamstring activation was measured using electromyography (Lim et. al., 2009). The training group performed the injury prevention program for 20 minutes prior to every practice for eight weeks while the control group performed their normal warm up. The training protocol consisted of six parts; a warm-up, stretching, strengthening, plyometric, agility training, and a warm down. The results found the training group displayed greater knee flexion angle, greater maximum knee abduction torque and a smaller hamstring to quadriceps activation ratio (Lim et. al., 2009). There were no differences between groups for knee internal rotation or jump height. Although there were statistical differences between groups, the high variety of exercises in the multi-component program may have led to less emphasis on neuromuscular training on landing mechanics which has been proposed as a potential injury prevention component (Lim et. al., 2009).

Thirty female soccer players were recruited for a study that had a similar design, with a multicomponent based injury prevention program incorporated into a warm-up before practice twice a week over a six week period (Ortiz, Trudelle-Jackson, McConnell, & Wylie, 2010).. Baseline measurements included hip and knee strength testing and flexibility of the quadriceps, hamstrings and gastrocnemius, as well as three dimensional knee kinematics during a single leg drop jump, and single leg squat assessment. The participants were randomized into an intervention group and a control group. At the end of the six week training period, post intervention measurements were taken. The results found no difference between groups for strength and flexibility measurements, and varied results on knee kinematics during the squat and drop jump task (Ortiz et. al., 2010). There was slight improvement of knee valgus in the intervention group when compared to the control group, but the finding was not significant. Due to the inconsistent results it was suggested that a similar study be repeated with a similar population and larger sample size (Ortiz et. al., 2010).

A prospective study done with female youth soccer players, compared a sports specific neuromuscular training warm-up with a traditional warm-up, and determined injury outcomes for ACL tears over the course of two seasons (Mandelbaum et al., 2005). Within the two year study 1885 athletes participated in the non-randomized neuromuscular training group and the remaining 3818 athletes acted as the control performing a traditional warm up before activity (Mandelbaum et al., 2005). The neuromuscular training warm-up consisted of three basic warm up activities, five stretches for the trunk and lower extremity, three strengthening exercises, five plyometric activities, and three soccer specific agility drills (Mandelbaum et al., 2005). These were shown via video instruction to coaches and players and coaches helped implement the programs. Injury rates were determined based on athlete exposures which were determined by participation in any practice or game with the potential to get injured (Mandelbaum et al., 2005). During the first year there were 37,476 exposures for the trained group and 68,580 exposures for the control group. The trained group suffered two ACL injuries, while the control group had 32 ACL injuries (Mandelbaum et al., 2005). These numbers contributed to an injury rate of .05 injuries/athlete/1000 exposures for the training group and .47 injuries/athlete/1000 exposures for the control (Mandelbaum et al., 2005). During the second season the injury rates were similar with a .18 injuries/athlete/1000 exposures for the training group, and .51 injuries/athlete/1000 exposures for the control. The results from both seasons indicate an effect for the training group on preventing ACL injury (Mandelbaum et al., 2005).

A similar study randomized 380 soccer players into a training group and 364 into a control group (Emery & Meeuwisse, 2010). The training group completed a neuromuscular training program for their warm-up that consisted of dynamic stretching, eccentric strengthening, agility, balance, and jumping exercises, while the control group completed a traditional warm-up that involved static and dynamic stretching and aerobic components (Emery & Meeuwisse, 2010). Surveillance of all injuries for both groups was done over the course of the season. The overall injury rate in the training group was 2.08 injuries/1000 player hours and 3.35 injuries/1000 player hours in the control, indicating that the neuromuscular training program was effective in reducing injury rates in soccer players (Emery & Meeuwisse, 2010).

A randomized control trial in Sweden used female soccer players as its subject population, and compared a neuromuscular training program to a traditional warm-up on ACL and other knee injury rates (Waldén, et al., 2012). They recruited players from 230 soccer clubs with 4564 athletes participating, including 2479 in the training group and 2085 in the control group (Waldén, et al., 2012). The program that the training group performed twice per week throughout the season consisted of six exercises; single leg squat, pelvic lift, double leg squat, benches, lunges, and jump landing technique (Waldén, et al., 2012). Between both groups 96 knee injuries occurred with 21 involving the ACL. Of the ACL tears, seven were within the intervention group for a total of .28% of the players while 14 occurred in the control for a total of .67% of the players (Waldén, et al., 2012). The results from this study indicate that a neuromuscular training program performed twice per week may reduce the rate of ACL and other significant knee injuries (Waldén, et al., 2012).

A prospective study examined the rate of injury between three separate groups of high school aged athletes who participated in sports with a high knee injury prevalence (Hewett, Lindenfeld, Riccobene, & Noyes, 1999). The 1263 total participants included a group of 366 female athletes that participated in a neuromuscular training program, 463 untrained females and 434 untrained males. The training program consisted of three phases over a six week period. Training sessions lasted approximately 60-90 minutes a day, three days per week. Injuries were reported over the course of one competitive season per sport (Hewett et. al., 1999). There was a total 14 serious knee injury within all groups with nine being non-contact in nature. The results displayed an injury rate per group of .43 for the untrained females, .12 for the trained females, and .09 for the untrained males, which was based off of the number of athlete exposures per group over the season (Hewett et. al., 1999). These results suggest that a jumping based neuromuscular training program that is progressive n nature may have the potential to reduce rates of ACL and other significant knee injuries for at risk athletes (Hewett et. al., 1999).

Several studies with similar methods have had conflicting results. A two year prospective study that compared the knee ligament injury prevention (KLIP) program to traditional warm up and training methods found no effect in the prevention program (Pfeiffer, Shea, Roberts, Grandstrand, & Bond, 2006). The KLIP program was incorporated into several local high schools with a total of 577 athletes participating. The remainder of schools continued their normal methods of training with 862 athletes used as the control. Over the course of a two year period and two full seasons the athlete injury rates were monitored by the researchers (Pfeiffer et. al., 2006). Of the 56,616 total athlete exposures, only six non-contact ACL tears occurred with three in each group. The control group had an incidence rate of .078 ACL tears per 1000 exposures while the training group displayed an injury rate of .167 per 1000 exposures (Pfeiffer et. al., 2006).

A similar, cluster-randomized control study was done over 2000 female soccer athletes to determine the effect of 10 specific exercises on overall injury prevalence (Steffen, Myklebust, Olsen, Holme, & Bahr, 2008). Of all the players, 1073 participated in the intervention while 947 were used as the control group. The program that was introduced to the intervention group included exercises that focused on core stability, balance, dynamic stabilization, and eccentric hamstrings strength (Steffen et. al., 2008). The players in the intervention performed the program as their warm-up for 15 consecutive practices and then once per week in place of their traditional warm-up for the remainder of the season, while the control maintained their normal routine over the course of the entire season. Injury rate and data was collected for all injures sustained, with the definition of an injury being if it forced the athlete to miss the next game or practice session (Steffen et. al., 2008). Over the eight month period 396 players sustained at least one injury, with an overall total of 483 injuries. Of all injuries, 87% were acute and 86% occurred within the lower extremity (Steffen et. al., 2008). Nearly half the acute injuries that occurred were non-contact in nature. Between the two groups, the injury groups were nearly the same and the intervention group displayed more knee injuries than the control. These results may be due to lack of compliance and or lack of volume of the prevention program within the intervention with them only performing the exercises once per week for the majority of the season (Steffen et. al., 2008). Due to conflicting results between several studies, it does seem that future investigation is needed within similar methodologies to determine the effect that a prevention program may have on ACL injury rate and prevalence.

Landing Error Scoring System

Specific mechanisms of injury for ACL and other significant knee injuries have been identified in previous literature as increased knee valgus (Levine et. al., 2013; Kiapour et. al., 2014; Kiapour et. al, 2015; Kim et. al., 2015; Koga et. al., 2010; Munro et. al., 2012; Quatman, et. al., 2011; Sell et. al., 2006), increased knee internal rotation (Chappell et. al., 2007; Kim et. al., 2015; Koga et. al., 2010; Myer et. al., 2011), and decreased knee flexion angle (Kim et. al., 2015; Sell et. al., 2006) during dynamic activities and movements. Throughout previous research in order to objectively measure these biomechanical differences, 3D imaging and motion analysis software were needed to analyze knee kinematics and joint positions during drop land tests and other dynamic assessments (Chappell et. al., 2007; Chappell & Limpisvasti 2008; Imwalle et. al., 2009; Munro et. al., 2012; Myer et. al., 2011; Quatman et. al., 2011; Sell et. al., 2006). An objective scoring system for a drop land test has been used and validated in several studies as an alternative to these imaging methods that are often expensive and difficult to use for someone with a lack of resources. The Landing Error Scoring System (LESS) is a dynamic movement assessment that allows for an objective measurement of jump landing performance using video playback or to be scored in real time. The test involves a participant to jump from a 30cm high box down to a mark on the ground that is half the distance of the subject's height. As soon as the subject makes contact with the ground, a maximal vertical jump should be performed ending with a land back to the ground. If the test is being scored using video playback, the test should be recorded from both the front and lateral view. Seventeen different scores are recorded based off of joint position and point of contact during the jump. This score is used to determine the jumping performance of the subject, without the use of motion analysis software.

The validity of the LESS test has been investigated in several studies. Darin Padua and colleagues have been very active in investigating the LESS protocol. In 2009 they conducted a study using 2691 participants, both men and women, to determine the validity of the LESS protocol versus the "gold standard" 3D motion analysis system (Padua, Marshall, Boling, Thigpen, Garrett, & Beutler, 2009). The participants were instructed on how to properly perform the drop jump task and then were given two or more practice trials as needed. The participants were then equipped with electromagnetic markers over several anatomical landmarks and digitized (Padua et. al., 2009). Three separate trials were recorded using both the LESS and the motion analysis software. Females displayed worse LESS scores than males with 65% of the scores being moderate to poor performance. The study revealed that the LESS was able to give a valid analysis of jump performance and was also able to have good to excellent interrater and intrarater reliability (Padua et. al., 2009). The overall results from this study indicate that the LESS can be used by a trained clinician in a more practical setting to assess jump landing performance, which can potentially reveal predisposing factors for ACL and other significant knee injuries (Padua et. al., 2009).

They conducted another study using the LESS protocol in a more practical setting. A total of 829 youth soccer athletes of both genders were used for the subject population (Padua, DiStefano, Beutler, de la Motte, DiStefano, & Marshall, 2015).. Baseline LESS scores were obtained for all subjects. They were given three trials and were scored by two blinded research assistants. All participants were monitored for ACL injuries over a four year period (Padua et.

al., 2015). A total of seven participants sustained an ACL injury, with all being non-contact or indirect contact in nature. The results displayed that uninjured athletes performed better on the LESS with lower scores than those who sustained ACL injury (Padua et. al., 2015). Although the data from this study produced few injuries, the results indicate that the LESS could potentially be used to determine at risk individuals for ACL and other knee injuries (Padua et. al., 2015).

Padua and colleagues (2011) also did a study to determine whether the LESS could be reliably scored in real time, without the use of video playback. They recruited 43 healthy younger people both males and females to participate (Padua, Boling, Distefano, Onate, Beutler, & Marshall, 2011). They used a modified LESS scoring table that had 10 separate landing mechanical characteristics to score. Three certified athletic trainers scored the LESS in real time (Padua et. al, 2011). Each participant performed the drop landing jump task on four separate scored trials with as many practice attempts as needed. The results showed good reliability between all three raters approaching near precision of the original LESS protocol with video playback (Padua et. al, 2011). The findings from this study has possible implications as a tool to be used in clinical settings for screening of athletes that may be pre disposed for injury (Padua et. al, 2011).

One question that has been raised with the LESS protocol is the ability of a clinician with no previous experience using the test to be able to accurately score it. A study examined the reliability of a novice clinician to score the LESS test compared to an expert who had prior experience with it (Onate, Cortes, Welch, & Van Lunen, 2010). For the subject population, 19 female college athletes were recruited. The athletes were equipped with 39 reflective markers over specific anatomical landmarks, which were used by the motion analysis system to determine specific joint kinematics and also aid in the scoring of the LESS (Onate et. al., 2010). Each participant performed 3 practice trials of the drop jump task with three scored trials. Both raters of the LESS were certified athletic trainers (ATC). The expert had 15 years' experience as an ATC, was involved in the development of the LESS scoring table and had approximately five years' experience using the LESS (Onate et. al., 2010). The novice ATC had less than one year experience as a certified athletic trainer, and the only training and experience that they had, was the one hour training session provided by the expert rater. The findings from the study found excellent agreement between the novice and expert raters for scores throughout the LESS protocol (Onate et. al., 2010). The validity of the test when compared with the 3D motion analysis system was dependent on the item being scored with the majority of items displaying excellent comparison and few displaying moderate to poor agreement (Onate et. al., 2010). The results of this study suggest that the LESS can accurately be used and scored well, by clinicians of all levels of experience, and only a small amount of training is necessary for the use of the protocol (Onate et. al., 2010).

As the reliability and the validity of the LESS protocol seems to be consistent within the literature, the test has become prevalent in practical applications over several different studies. A study looked at the relationship between LESS scores and the athletes' lower body injury history and prevalence during a soccer season. (James, Ambegaonkar, Caswell, Onate, & Cortes, 2016). Thirty four male and female soccer players who participated at the Division 1 level were recruited for the study. The athletes were separated into two groups; a group that had sustained lower body injuries in the past but were currently not experiencing any symptoms of injury, and a group with no prior history of lower body injury (James et. al., 2016). Each participant performed three scored trials of a drop jump task using the LESS protocol prior to the start of their fall season. All videos of the drop jump task were scored by a single researcher. Injuries were tracked throughout the course of the of the entire fall season. Of the athletes who had no prior lower body history, 11 sustained their first lower body injury during the season (James et. al., 2016). The results displayed no difference in LESS scores between groups, with athletes that had a prior history of injury scoring similar on the LESS than those between groups. There also were no significant differences in LESS scores between athletes who sustained an injury during the season, and those who remained uninjured (James et. al., 2016). These results potentially suggest that the LESS may not necessarily be able to identify or predict athletes who are at risk for a general lower body injury (James et. al., 2016).

In order to determine if there were functional movement differences between athletes who specialized within one sport domain, and those who participated in multiple sports, one study used the LESS protocol as their quantitative measurement tool (Beese, Joy, Switzler, & Hicks-Little, 2015). Forty total female high school aged athletes were recruited, 21 who specialized in one sport and 19 that participated in multiple sports. All participants performed three trials of a drop jump task which was scored using the LESS protocol. Their scores were divided into separate sub groups based on the number of errors displayed during the LESS scoring, with 0-3 errors indicating excellent performance, 4-5 errors indicating good performance, 6 errors indicating moderate performance, and 7 or greater errors indicating poor performance (Beese et. al., 2015). The overall mean score on the LESS for all athletes was 6.48. There were no significant differences between groups for overall LESS score but the athletes that specialized in a single sport displayed moor "poor" scores with a higher number of errors than those who participated in multiple sports (Beese et. al., 2015).

Another study was performed using the LESS protocol on military cadets to observe performance differences between genders and to potentially identify other pre disposing factors for significant knee injuries (Beutler, de la Motte, Marshall, Padua, & Boden, 2009). Certain measures including BMI, hip alignment, and muscle strength have been proposed as contributing factors to ACL injury, and were also assessed as variables within the study (Beutler et al., 2009). An overall total of 2753 cadets participated within the study, 1046 female and 1707 male. The anthropometric and postural alignment measurements that were taken for each participant included, height, weight, BMI, navicular drop, and Q-angle. Isometric muscle strength of the quadriceps, hamstrings, hip external rotators, hip internal rotators, and gluteus maximus and medius was recorded (Beutler et al., 2009). All subjects performed three trials of the drop jump task which were scored for total number of errors using the LESS protocol. When comparing by gender, the results found that females had a statistically significant higher score with more errors on the LESS than men, with a mean of 5.34 versus 4.65 (Beutler et al., 2009). There were no observed correlation between LESS scores and other measurements of BMI, postural alignment, or muscle strength (Beutler et al., 2009).

In relation to ACL injury, some studies have used the LESS protocol to assess performance following surgical intervention of an ACL injury. In a study examining the effect of fatigue on performance, 22 participants of both genders were separated into two groups, ones that had ACL reconstruction within the last year and a control of people with no previous history of knee surgery (Gokeler, Eppinga, Dijkstra, Welling, Padua, Otten, & Benjaminse, 2014). All participants were tested twice using the LESS protocol. After the initial drop jump task, they performed a fatigue protocol, which involved the completion of a counter movement jump (CMJ) measured for height (Gokeler et. al., 2014). The first CMJ was used as their 100% max, and was followed by 10 double leg squats to 90 degrees of knee flexion. These squats were followed by two CMJ and repeated until only 70% of the CMJ max was reached, indicating fatigue (Gokeler et. al., 2014). A post fatigue drop jump test was performed within 30 seconds of point of fatigue, using the LESS protocol for scoring. The results revealed that the LESS score significantly increased between pre and post fatigue tests for all participants (Gokeler et. al., 2014). Participants within the ACL reconstruction displayed much greater mean scores on the LESS at both baseline and post fatigue indicating a relationship between both fatigue and the dynamic knee stability of a person recovering from ACL reconstruction (Gokeler et. al., 2014).

CHAPTER 3

METHODS

Participants

The participants that will be recruited for this study include 45-60 female athletes from four different NCAA collegiate sports at Lindenwood University. These sports include soccer, lacrosse, field hockey, and volleyball. Research has shown that females are at greater risk for sustaining ACL and other knee injuries, while soccer and lacrosse present with some of the highest rates of knee injury between female sports (Beynnon et al., 2014; Hootman et al., 2007; Munro et al., 2012). Due to the similar dynamic movements that are associated with ACL and other knee injury risk, volleyball and field hockey have been chosen to be included within the recruited study population. The recruited participants will all be between the ages of 18-23 years of age. Any participant that has sustained a significant knee injury that has forced them to miss extended practice or game time of more than a week, within the past 12 months will be excluded from the study.

Equipment

The instruments that will be used for this study include a demographics and knee injury history questionnaire. Height will be measured using a standard tape measure. Neon colored markers will be placed on five different anatomical landmarks to assist in the LESS assessment. A 30cm box will be used for the drop jump test. Two Apple iPad Air tablets will be used for video recording and five USB flash drives will be used to store and transfer data. The LESS scoring rubrics and guidelines will be used to determine scores on the LESS protocol. Boxes of two different sizes (20cm, 30cm) will be used for the training program.

Experimental trial

A familiarization meeting will be held prior to any baseline testing. At this time, participants will be provided with an information handout and be presented with additional information regarding the study, including how to perform the drop jump test, associated risks involved with the study, and exclusion criteria. The participants will then complete the consent form. If the participant has met all inclusion criteria they will be contacted via email, and scheduled for a time to complete baseline testing. After baseline testing is complete, participants will be randomized into a training group and a control group using a randomization generator of both name and which group they are in.

Baseline testing will be conducted in the student athlete fitness center on Lindenwood University's campus. The participants must wear tight fitting clothing preferably compression material. All participants will be assigned an alpha numeric code which will provide anonymity to the participant. They complete a knee injury history and brief medical questionnaire. Each participant will be measured for height. All participants will complete a short dynamic warm up and will be allowed time for any additional stretching/warm-up that they may need. Neon colored stickers will be placed on five different anatomical landmarks of the dominant leg: the lateral malleolus, lateral joint line of the knee, greater trochanter, mid shaft of the femur, and the center of the patella. A general demonstration will be provided on how to properly perform the drop jump test. The drop jump test involves the participants standing on a 30cm high box facing a mark on the floor that is half their height in distance from the box. They will jump straight down to the line and immediately perform a maximal vertical jump for height. Participants will be given two practice trials and will then perform two recorded trials of the test. Both trails will be video recorded from the front and lateral view of the dominant leg side. All participants will report back at the end of the six week training period and perform post intervention testing following the same protocol as baseline testing.

Neuromuscular Training

After participants are randomly assigned to the training or control group, the control group will resume their normal daily activities until they return for post intervention testing at the end of the six week training period. The training group will then be scheduled to attend training sessions. Several training sessions throughout the week will be made available for the participants to attend. They must attend an average of two training sessions per week for the six week training period for a total of 12 training sessions. Each session will be approximately 20 minutes long with additional time for warm up and instruction. Several studies with similar study populations and methods suggests that this is an appropriate frequency of neuromuscular training (Waldén et. al., 2012; Ortiz et. al., 2010; Lim et. al., 2009; Chappell & Limpisvasti, 2008; Hewett et. al., 1999).

The participants will complete a short dynamic warm up that consists of a two lap jog around the fitness center and six dynamic stretches to warm up the lower body. When participants report for their scheduled training session they will begin with either vertical or horizontal based movements. During a single session they will perform the assigned number of repetitions for double leg and single leg, vertical and horizontal jumps in both the fontal plane and sagittal plane sequentially. The participants will be doing their vertical movements for the first three weeks of training onto a 20cm box, then increase the height to 30cm for weeks three through six. The two exercises for the vertical movements will be a double leg jump up and down and single jump up and down both forward and laterally. The distance progression for horizontal movements will be 60cm for weeks one through three, 90 cm for weeks three through six for double leg exercises and 90cm for weeks one through three, and 120cm for weeks three through six for single leg movements. The exercises performed for the horizontal movement will include a double leg broad jump and single leg broad jump both forward and laterally. The volume progression for all exercises will be sets of 12 repetitions for weeks one through three, and sets of 8 repetitions for weeks three through six. Participants will be cued on proper landing and jumping mechanics throughout the training session. This will be emphasized in the initial instruction of the exercises.

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Vertical f	DL x12 SL x12 bs	Same	Same	DL x 8 SL x 8 bs	Same	Same
Vertical s	DL x12 SL x12 bs	Same	Same	DL x 8 SL x 8 bs	Same	Same
Horizontal f	DL x12 SL x12 bs	Same	Same	DL x 8 SL x 8 bs	Same	Same
Horizontal s	DL x12 SL x12 bs	Same	Same	DL x 8 SL x 8 bs	Same	Same

Table 1.1 Training program volume progression; f-frontal, s-sagital, DL-double leg, SL-single leg, bs-both sides

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Vertical DL	20cm	Same	Same	30cm	Same	Same
Vertical SL	20cm	Same	Same	30cm	Same	Same
Horizontal DL	60cm	Same	Same	90cm	Same	Same
Horizontal SL	90cm	Same	Same	120cm	Same	Same

Table 1.2 Training program height and distance progression; DL-double leg, SL-single leg, cm-centimeters

Data Analysis

After the two trials of the drop jump task have been recorded during baseline and post training testing they will be stored in a specific folder assigned to each participant's alpha numeric code on each iPad. These folders will then be transferred to the researcher's computer to be stored and organized. The analysis of these videos will be conducted by six separate research team members. The researchers will be organized into two groups in which all three members of each group will score the same videos. The three scores for each participant will be averaged to determine a final score. A group of 8-10 participants will have their jumps scored by all six researchers to determine reliability of scoring. The members of the research team will receive the videos via USB flash drive. Once they have scored the videos they will return the scoring sheets and flash drives to the primary investigator. Scoring of the drop jump test will be done using the LESS protocol. Research members will have both trials and both the frontal and lateral views of each trial to score. There are 17 different scores which use one or both of the angles of the test to score. The researchers analyzing the videos may pause and rewind as needed in order to obtain the best score for each category. A value for a score indicates an error, with an overall score of 0-3 indicating excellent performance, 4-5 indicating good performance, 6 indicating moderate performance, and 7 or greater indicating poor performance on the drop jump task (Beese et. al., 2015). After each trial is scored the average total will be calculated between the two trials and used to indicate the athlete's performance at baseline and post intervention.

The LESS protocol has been validated by researchers as a quantitative jump landing assessment (Padua et. al., 2009) and has shown reliable scoring between expert and novice clinicians using the test (Onate et. al., 2010). In order to ensure reliability, all members of the research team that will participate in the scoring of the drop jump test will attend an approximately 60 minute long presentation and training discussion on the LESS protocol. This will involve a step by step discussion of each category to score, determining what is considered an error, and an interactive session which everyone will score a drop jump test using the LESS criteria and discuss the score they received (Onate et. al., 2010).

Statistical Analysis

All statistics will be analyzed using Microsoft Excel and the Statistical Package for the Social Sciences. (V.23, SPSS Inc., Chicago IL). A 2x2 (group x time) repeated measures ANOVA will be used to assess any interaction effect for the training group and the control between baseline and post testing. A paired samples t- test with repeated measures will be used to determine an effect within groups. Dependent variables include overall LESS score using the 17 scoring criteria, knee valgus at initial contact and knee valgus at maximum knee flexion. Alpha will be set at $p < .05$ level of significance. Descriptive statistics measured at baseline will be assessed using mean and standard deviation.

CHAPTER 4

RESEARCH MANUSCRIPT

This chapter presents a complete manuscript that describes the study in traditional journal article form including a title page, abstract, introduction, methods, results, discussion, references, figures, and tables. It is currently authored by Richard Aley, members of this research team and thesis committee. The references cited are provided at the end of the manuscript.

THE EFFECT OF A NEUROMUSCULAR TRAINING PROGRAM ON JUMP LANDING PERFORMANCE

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ABSTRACT

Injury to the anterior cruciate ligament (ACL) is highly prevalent within competitive sports of all levels and types. Female athletes are at higher risk for sustaining an ACL injury, specifically those participating in field and court based sports involving large dynamic movements, such as soccer, basketball, lacrosse, and gymnastics. The use of neuromuscular training to promote proper mechanics during jumping and change of direction activities may decrease the risk of ACL injury. **PURPOSE:** The purpose of this study is to determine the effect of a neuromuscular training program on jump landing mechanics in female college athletes. **METHODS:** Forty-three female Division II college athletes (20.06±1.2yrs, 67.34±2.5in, 148.76±19.9lbs) were recruited from the rosters of four teams including, soccer (N=11), lacrosse (N=19), field hockey (N=6), and volleyball (N=7). Of the 43 participants that completed baseline testing, 34 completed post testing. Jump landing performance was assessed using the Landing Error Scoring System (LESS) Analysis of the jumps was assessed by three separate evaluators and the scores were averaged to obtain an overall LESS score. Participants were randomized into two groups; a neuromuscular training (TRAIN) and a control (CONT) group. TRAIN performed six weeks of neuromuscular jump training, twice per week for a total of 12 sessions. Data was analyzed using a 2 x 2 (group x time) ANOVA with repeated measures on time. All data are presented as means ± SD. **RESULTS:** There was no interaction effect observed for knee valgus at initial contact ($p=0.16$; $p>0.05$) or at maximum knee flexion angle ($p=0.64$; $p>0.05$). The amount of knee valgus observed at both initial contact and maximum knee flexion remained the same for TRAIN, whereas there was a statistical trend ($p=0.059$) towards an increase in knee valgus at initial contact over time in the CONT. Significance differences between groups and time were found for total LESS score ($p=0.049$; $p<0.05$). A significant difference was observed ($p = 0.019$) for total LESS score in the CONT as performance decreased from baseline (6.03±1.13 errors) to post testing (6.61±1.33 errors), whereas in the TRAIN performance remained the same from baseline (5.69±1.22 errors) to post testing (5.65±1.44 errors). **CONCLUSIONS:** Neuromuscular jump training appears to help maintain jump landing performance over a six-week period while a lack of training appears to result in a decrease in performance. Slight improvements in knee valgus were observed in the TRAIN group which may be further improved over a longer training period. These findings support the use of a neuromuscular jump training program over a

relatively short period of time to improve landing mechanics. Longer investigations are needed to better determine if reductions in injury potential can result.

INTRODUCTION

Athletic or sport related injuries occur at every level of competition, within nearly every sport domain. As the level of competition increases, sequential changes in maturation promote the increase in factors like size and speed, which influence the amount of force generated by the athlete against other competitors in contact based sports, and against the ground in a non-contact manner. This generation of force is often the mechanism that produces an injury to an athlete. One of the most devastating orthopedic injuries to sustain, is a rupture or tear of the anterior cruciate ligament (ACL). Injury to the ACL of the knee is highly prevalent within competitive sports of all levels and types. Over a 16 year period, more than 300 ACL injuries occurred per year within a 15 sport sample that represented approximately 15% of the population of athletes at the NCAA collegiate level (Hootman, Dick, & Agel, 2007). Researchers have agreed that females are the higher risk gender for sustaining an ACL injury, specifically those participating in field and court based sports that involve large dynamic movements, like soccer, basketball, lacrosse, and gymnastics (Beynnon, Vacek, Newell, Tourville, Smith, Shultz, & Johnson, 2014; Hootman et al., 2007)

While direct contact mechanisms of injury are often unpreventable, high rates of non-contact injuries to the ACL occur in athletes involved in sports that require jumping and cutting functional movements. Of these athletes, research has shown that females are of greater risk than males in sustaining a non-contact ACL injury (Munro, Herrington, & Comfort, 2012). Researchers have used bone bruise and cartilage damage locations of the knee with associated ACL injuries, to determine specific mechanisms for non-contact ACL injuries. Consistent damage to the lateral aspect of the knee indicates that a major mechanism of ACL injury is a knee valgus or abduction movement (when the knee goes inward) during landing or cutting

(Quatman et al., 2011). This mechanism of injury has been confirmed by researchers in controlled laboratory settings. Within several studies, cadaveric legs have been fixed to devices that can force the knee into different movements and rotations such as knee valgus and internal rotation. The results of these studies consistently show that the most ACL strain is caused by a knee valgus movement (Levine et al., 2013; Kiapour et al., 2014; Kiapour et al., 2015).

Many studies have proposed that the most effective strategy to reduce a knee valgus movement is the use of neuromuscular training to promote proper mechanics during jumping and change of direction activities (Myer et al., 2011; Munro et al, 2011; Quatman et al., 2011). Several studies have implemented specific prevention programs and have recorded rates of injury within the population observed. In a two-year study, more than 5,500 youth soccer players were monitored for injury (Mandelbaum, Silvers, Watanabe, Knarr, Thomas, Griffin, & Garrett, 2005). Those participating in a knee injury prevention program displayed an incidence rate of 0.05 injuries/per 1000 exposures versus an injury rate of 0.47 injuries/per 1000 exposures for the group participating in a traditional warm up (Mandelbaum et. al, 2005).

Female soccer players from clubs in Sweden displayed similar findings. Of the 4600 athletes participating, those that performed a prevention program twice per week had an ACL tear rate of 0.27% while those not participating in the program had a rate of 0.67% (Waldén, Atroshi, Magnusson, Wagner, & Hägglund, 2012). Many of these programs were multi-component-based with a large majority incorporating some form of neuromuscular/plyometric based movements (Michaelidis, & Koumantakis, 2014; Waldén et al., 2012; Emery & Meeuwisse, 2010; Mandelbaum et al., 2005).

Few studies have examined the direct effect of these neuromuscular training programs specifically on jump landing performance and whether or not it can improve knee valgus movements. Due to high prevalence of ACL injury in female athletic populations and a major mechanism of injury being knee valgus during dynamic movements, it was hypothesized that a specific neuromuscular training program over the course of a season may decrease the amount of knee valgus observed. Thus, the purpose of this study was to determine the effect of a neuromuscular training program on jump landing mechanics in female college athletes.

METHODS

Overview of Research Design

A randomized experimental design was used for this study. Participants were not blinded to the intervention. Members of the research team analyzing the data were blinded to the participants using an alpha numeric code randomly assigned to each participant to keep their identity anonymous (Urbaniak, G. C., & Plous, S. Research Randomizer Version 4.0). All participants were required to attend a familiarization meeting prior to any baseline testing. This provided them information about the study defining exclusion criteria, any risks involved, and outlining the procedures that would be followed over the duration of the study. Informed consent was obtained at this time. After baseline testing was complete, participants were randomized into two separate groups; a training group and a control group using a randomization generator (Urbaniak, G. C., & Plous, S. Research Randomizer Version 4.0).

Testing was conducted in the student athlete fitness center on Lindenwood University's campus. The participants were asked to wear tight fit clothing preferably of compression material. This study was approved by the Lindenwood University Institutional Review Board (IRB; Protocol 954333-1; Approved 10/14/2016), and informed consent was acquired by all participants prior to their participation.

Participants

Forty-three female subjects (20.1± 1.2 yrs, 171.0 ± 6.4 cm, and 67.5 ± 9.0kg) were recruited from the rosters of four NCAA collegiate sports at Lindenwood University. These sports included soccer (N=11), lacrosse (N=19), field hockey (N=6), and volleyball (N=7). Three of the sports were in offseason conditioning (soccer, field hockey, volleyball) while lacrosse was participating in all in season activities. As determined by a review of their medical history submitted for the requirements of participating in their respective sport, all participants were required to be free of health conditions that may deem them unsuitable for participation in physical activity. All participants verified via questionnaire that they had not sustained a significant knee injury that had forced them to miss extended practice or game time of more than a week, within the past 12 months and that they had not participated in any physical activity 24 hours prior to all testing sessions. Any person that had stated they had previously sustained an injury within the past twelve months or sustained any injury during the duration of the intervention that limited them from completing the training protocol were excluded from this study. Thirty four participants (17 training, 17 control) were able to successfully complete post intervention testing which followed the same protocol as baseline testing, at the end of the six week training period.

Procedures

Demographic Information and Warm-Up

All participants' height was measured using a standardized tape measure (Stanley Power Winder 300, Towson, MD) and weight was measured using a digital scale (Health-o-meter Professional Model 349KLX, McCook, IL). Following these measurements participants completed a short dynamic warm up that consisted of two laps around the facility, and six dynamic stretches (toe touches, good mornings, lunge with trunk rotation, lateral lunge, high knee, heel kicks) for 10 meters each and were allowed time for any additional stretching/warm-up that they preferred.

Drop Jump Task

After completing the warm-up, neon colored stickers were placed on five different anatomical landmarks of their dominant leg (lateral malleolus, lateral joint line of the knee, greater trochanter, mid shaft of the femur, and center of the patella). A demonstration of the drop jump task was provided by the researcher prior to the participant performing any practice trials. The drop jump test involves the participants standing on a 30cm high box facing a mark on the floor that is half their height in distance from the box. The participant jumps straight down to the line and immediately performs a maximal vertical jump for height. Participants were given two practice trials and then performed two recorded trials of the test. Both trials were recorded from the front and lateral view of the dominant leg side using iPad tablets (Apple iPad Air MD785LL/B, Cupertino, CA) positioned 4.3 meters away from the box and approximately 1.2 meters high. After the two trials of the drop jump task were recorded during baseline and post training testing they were stored in a specific folder assigned to each participant's alpha numeric code on each iPad. These folders were then transferred to a computer to be stored and organized.

Neuromuscular Training

After participants were randomly assigned to the training or control group, the control group resumed their normal daily activities, including team organized training until they returned for post intervention testing at the end of the six week training period. Participants in the training group were scheduled to attend training sessions. Several training sessions throughout the week were made available for the participants to attend. They were required to attend an average of two training sessions per week for the six week training period for a total of 12 training sessions. Each session lasted approximately 20 minutes long. All training sessions were held in the student athletic performance center or the student athlete center athlete training facility on Lindenwood University's campus.

The participants completed a short dynamic warm up identical to the one that they performed during testing sessions. One researcher was present at every session with no sessions involving more than five participants training at a single time. Instruction and feedback was given throughout the duration of the training session to ensure proper form and corrections were made. During each session the participants performed the assigned number of repetitions for double leg and single leg, vertical and horizontal jumps in both the frontal plane and sagittal plane sequentially. The participants performed the vertical movements for the first three weeks of training onto a 20cm box, then 30cm for weeks three through six (see Table 1.2). The two exercises for the vertical movements were a double leg jump up and down and single leg jump up and down both forward and laterally. The distance progression for horizontal movements were 60cm for weeks one through three, 90cm for weeks three through six for single leg exercises and 90cm for weeks one through three, and 120cm for weeks three through six for double leg movements (see Table 1.2). The exercises performed for the horizontal movement included a double leg broad jump and single leg broad jump both forward and laterally. The volume progression for all exercises were one set of 12 repetitions for weeks one through three, and one set of eight repetitions for weeks three through six (see Table 1.1).

Landing Error Scoring System (LESS)

Performance of the drop jump test was determined using the LESS protocol. The analysis of the jumps were conducted by six research team members. The researchers were organized into two groups of three in which all three members of each group scored the same videos. The three scores for each participant were averaged to determine a final score. A group of seven participants (4 in the TRAIN, 3 in the CONT) had their jumps scored by all six researchers to determine reliability of scoring. The members of the research team received the videos via USB flash drive (Kootion Technology, 8GB USB2.0. Shenzen, China). Research members used both trials and both the frontal and lateral views of each trial to score the jump. Researchers were able to pause and rewind as needed in order to obtain the most accurate score for each category. There are 17 different scores which use one or both of the angles of the test to score (See Appendix C) A score for each criteria is determined by an error, with a one indicating the presence of an error and a zero indicating proper positioning for that specific criteria. The final two criteria, total joint displacement, and overall impression are subjective in nature and are scored on a 0-2 scale, with zero indicating a good jump, one indicating an average jump and two indicating a poor jump. A total score from all 17 criteria between 0-3 indicate excellent performance, 4-5 good performance, 6 moderate performance, and 7 or greater poor performance on the drop jump task (Beese et. al., 2015). In order to ensure reliability, all members of the research team that participated in the scoring of the drop jump test, received an approximately 60 minute long presentation and training discussion on the LESS protocol. This involved a step by step discussion of each criteria to score, determining what was considered an error, and an interactive session which everyone scored a drop jump test using the LESS criteria (Onate et. al., 2010).

Statistical Analysis

All statistics were analyzed using Microsoft Excel (Seattle, WA) and the Statistical Package for the Social Sciences, version 23 (IBM, Cary, NC). A 2x2 (group x time) repeated measures ANOVA was used to assess an interaction effect for the training group and the control between baseline and post testing. A paired samples t- test was used to determine any within-group differences. Dependent variables included overall LESS score using the 17 scoring criteria, knee valgus at initial contact and knee valgus at maximum knee flexion. Alpha was a priori at $p < 0.05$ level of significance. Descriptive statistics measured at baseline were assessed using mean and standard deviation.

RESULTS

Baseline Measures

Forty three participants reported for baseline measurements. Twenty two participants were randomized into the training group with 21 in the control group. Thirty four successfully completed post training testing with 17 in the training group and 17 in the control. Of the nine participants that did not successfully complete the study, one was excluded for having excellent jump performance at baseline, two were missing data due to an issue with the recording at either baseline or post testing, two did not perform the baseline test properly, and four sustained injuries within their sport during the duration of the study and were unable to complete post testing. All participants that were missing post testing data were treated with an intent to treat approach, using the same scores that they received at baseline as their post testing scores. Those that did not have baseline data were completed excluded from the results. Independent t tests were used to analyze participant demographics at baseline, which revealed significant differences in height ($p=0.031$) and weight ($p=0.038$) between the training and control groups. Independent t-tests revealed there were no significant differences at baseline for: knee valgus at initial contact ($p = 0.89$), max knee valgus ($p = 0.76$), and total LESS score $p = 0.94$).

Reliability

Intraclass correlation coefficients, Pearson correlations and paired samples t-tests were all computed to assess reliability of LESS scoring from pre to post-testing. The average correlation for all assessors was 0.614 and ranged from 0.346 to 0.851(see Table 2.2). Of the six assessors who evaluated all jumps, five were found to not be significantly different from baseline to post ($p > 0.05$) while one was significantly different ($p = 0.021$) (see Table 2.2).

Knee Valgus

No significant group x time interaction was found for knee valgus at initial contact ($p=0.157$) or for maximum knee flexion angle ($p=0.636$). Paired samples t-test were performed to identify the presence of differences across time in both the training group and control group. For the training group, the amount of knee valgus observed at both initial contact ($p = 0.82$) and maximum knee flexion ($p = 0.45$) remained the same for the training group, whereas in the control group there was a trend ($p = 0.059$) towards an increase in knee valgus at initial contact while no difference was observed for maximum knee valgus ($p = 0.98$) over time (see Table 2.1 and Figure 1.1 and 1.2).

Total LESS score

Significance differences between group and time was found for total LESS score (p=0.044). Total LESS score in the control group significantly decreased from baseline to post testing (p=0.019), whereas in the training group performance remained the same (p=0.855) (see Table 2.1 and Figure 2).

DISCUSSION

The aim of the present study was to determine the effect of a neuromuscular jumping based training program on overall jump landing performance which may have implications on ACL injury prevention. The primary findings from this study suggest that such a training program over a six week period does have positive effects on jump landing performance. There was a significant difference between groups over time for total LESS score. Participants in the training group had no change in knee valgus or total LESS score from pre to post testing, but those in the control group displayed increases in knee valgus at initial contact and a decrease in performance for the total LESS score over the six week period. These findings are consistent with those in similar studies that used multicomponent training programs to help improve knee kinematics and jump landing performance (Chappell & Limpisvasti, 2008; Lim et. al., 2009).

Specific mechanisms of injury for ACL and other significant knee injuries have been identified in previous literature as increased knee valgus (Levine et. al., 2013; Kiapour et. al., 2014; Kiapour et. al, 2015; Kim et. al., 2015; Koga et. al., 2010; Munro et. al., 2012; Quatman, et. al., 2011; Sell et. al., 2006), increased knee internal rotation (Chappell et. al., 2007; Kim et. al., 2015; Koga et. al., 2010; Myer et. al., 2011), and decreased knee flexion angle (Kim et. al., 2015; Sell et. al., 2006) during dynamic activities and movements. The findings from the present study indicate that a plyometric based neuromuscular training program that may help improve jump landing mechanics, may have positive implications on knee injury prevention.

When closely examining the effectiveness of knee injury prevention programs on specific injury rates, there has been some conflicting results across the literature. Several studies have used multicomponent training programs and yielded positive results on ACL/knee injury prevention (Mandelbaum et al., 2005; Emery & Meeuwisse, 2010; Waldén, et al., 2012) while some that have used both multi component training programs (Steffen et. al., 2008), and plyometric based training programs (Pfeiffer et. al., 2006) displayed no difference in injury rate between intervention and control groups. The total volume and frequency of training may play a factor in outcomes of the knee injury prevention programs. It appears programs that incorporate neuromuscular training into the warm up prior to every practice or those that incorporate it at least two times per week over a longer time period have had more positives results (Chappell & Limpisvasti, 2008; Lim et. al., 2009; Mandelbaum et al., 2005; Emery & Meeuwisse, 2010; Hewett et. al., 1999). The present study which performed training twice per week for six weeks for a total of only 12 sessions had positive results when compared to the control but no significant improvements in performance by the training group. This is consistent with previous work by Ortiz et al (2010) who had the same training volume (12 total session over six weeks) with inconsistent results in performance improvements, and Steffen et al (2008) who performed training 15 consecutive days and then only once per week for the remainder of the season and saw no difference in injury rates between the training group and the control group.

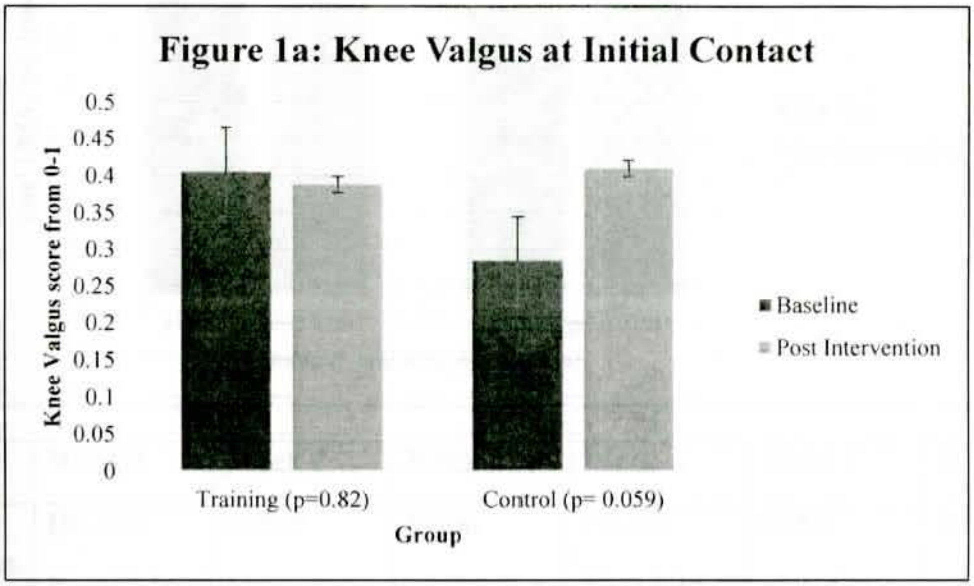
There were several strengths involved with the present study. This study recruited female athletes that compete in sports with large dynamic movements and potential predisposition to ACL injury which indicates that the subject population was the most appropriate and necessary group to recruit. Several studies have identified that females aged 16-24 not only display biomechanical differences and a predisposition to certain knee injuries like knee valgus and decreased knee flexion angle during dynamic movements (Sell et. al, 2006; Chappell et. al, 2007; Imwalle et. al, 2009; Myer et. al, 2011), but also sustained ACL and other knee injuries at a greater rate significantly different from their male counterparts (Beynnon et al., 2014; Hootman et al, 2007). The present study, which focuses on neuromuscular jump training, is fairly unique, as the current literature on jump training based programs have had both positive (Hewett et. al., 1999) and insignificant results (Pfeiffer et. al., 2006). The vast majority of previous literature that have investigated the efficacy of knee injury prevention programs, have utilized training methods that are multi component in nature (Chappell & Limpisvasti, 2008; Lim et. al., 2009; Ortiz et. al., 2010; Mandelbaum et al., 2005; Emery & Meeuwisse, 2010; Waldén, et al., 2012; Steffen et. al., 2008), involving variations of core strengthening, lower body strengthening, flexibility, balance training, plyometric training, and sport specific activities. These programs may decrease the emphasis on jump training and potentially take away from the overall goal of improving dynamic movement/landing mechanics. It seems necessary to determine which component of the knee injury prevention programs is contributing to an increase in performance and potential decrease in injury rates. The design of the training program also was simple enough for the participants to maintain consistency between training sessions while also receiving exposure to dynamic movements in different planes. It also utilized both unilateral and bilateral exercises to help replicate the movements performed on the field or court as accurately as possible which was suggested by previous work (Munro et. al, 2012; Myer et. al, 2011). The LESS protocol has been validated by previous work (Padua et. al., 2009) and has been shown as a reliable means of evaluating jump landing performance even when done by novice assessors (Onate et. al., 2010).

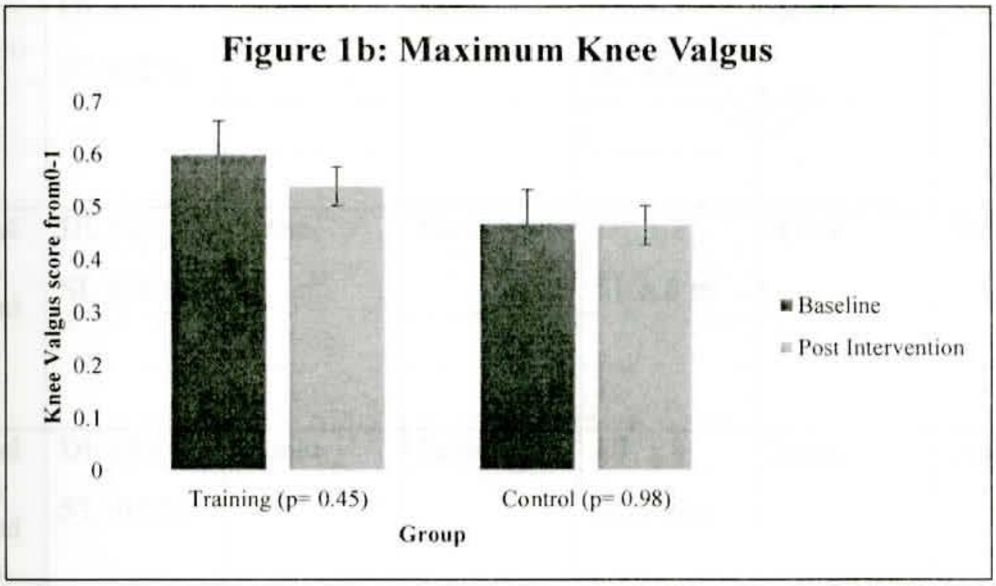
To maximize reliability, six assessors were split into two separate groups to score half the drop jump tests. This provided three separate scores that were averaged into one score for every participant which allowed for the greatest level of reliability in determining the participants jump performance and baseline and post intervention.

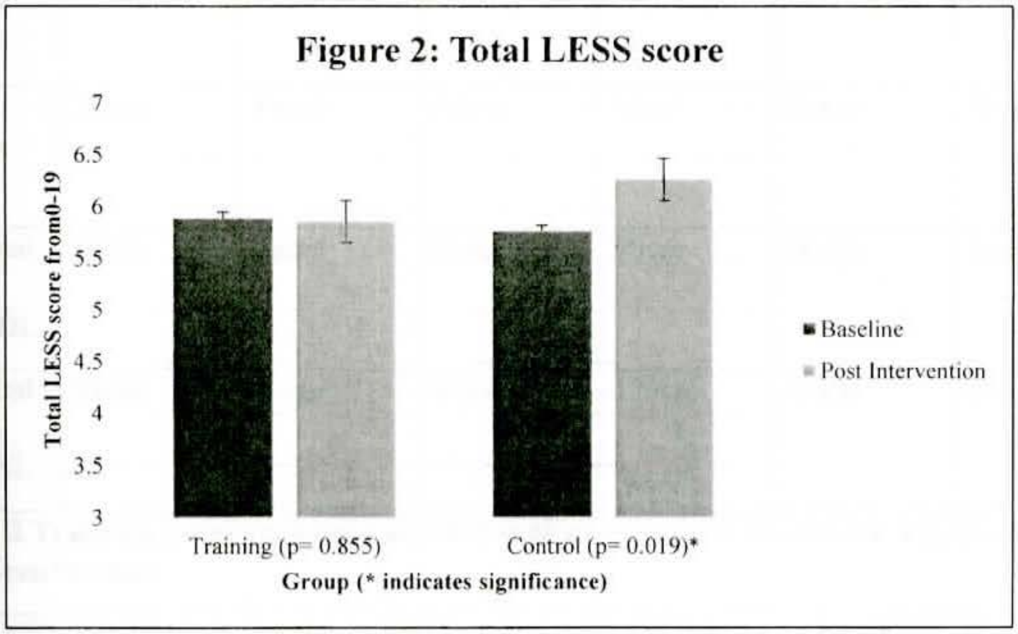
One of the major limitations of the present study was overall sample size and equal sample size per sport. After randomization, an unequal representation was present across the four sports within each group which was the most likely explanation for the observed significant difference between groups at baseline for both height and weight due to the different body types and sizes between sports. Although the sample size in the present study was similar if not larger than previous literature (Chappell & Limpisvasti, 2008; Lim et. al., 2009; Ortiz et. al., 2010), a larger sample size similar to previous work (Pfeiffer et. al., 2006; Emery & Meeuwisse, 2010) would allow for a more equal representation between sports and thus allow for an analysis of performance between sports. This study was also limited on the amount of time allocated for the training period. The training period utilized in previous work (Mandelbaum et al., 2005; Emery & Meeuwisse, 2010; Waldén, et al., 2012; Pfeiffer et. al., 2006; Steffen et. al., 2008) typically lasted over the course of a season or longer. A training period lasting over the course of an entire competitive season or offseason would allow for a more challenging progression of exercises and an increase in overall training volume. A key objective of the present study sought to determine the effect of neuromuscular training specifically on knee valgus during dynamic movements. The presence of knee valgus has been identified in previous work (Levine et al., 2013; Kiapour et al., 2014; Kiapour et al., 2015) to be a major contributing factor to injury mechanisms to the ACL and other structures of the knee. Although there seemed to be a positive effect of the training program utilized in the present study on knee valgus, the degree of change was limited by the nature of the LESS scoring method. Of the 17 total scoring criteria in the LESS, only two specifically analyzed knee valgus at separate time frames during the drop jump test (initial contact and max knee valgus). A score of zero indicates no observed knee valgus and a score of one indicates the presence of knee valgus at the respective time periods, leaving minimal room for change between pre and post testing. Utilizing the LESS system proved to be reasonable and practical to assess overall jump landing performance, but use of a 3D biomechanical software that could measure specific degrees of joint position, may be necessary to accurately assess change in knee valgus. Although data analysis was performed by six different assessors, the average correlation coefficient was 0.61 indicating only a slight positive correlation from pre to post testing for assessor reliability. This may be due to the LESS training session occurring one week prior to baseline data analysis and post testing data analysis occurring sometime between 6-14 weeks later after the assessor's "training" session. Previous literature on LESS inter rater reliability did not include an actual intervention, with no specific mention of the time period between LESS "training" and the actual analysis of the drop jump test, with the assumption that the assessor "training" occurred sometime near data analysis (Onate et. al., 2010). Having three separate scores for each jump averaged together should have offset any discrepancies between assessors, but having a low positive correlation may be a limitation to the present study.

Overall, it appears that the use of a neuromuscular training program that focuses on jump landing mechanics in female college athletes, is effective in preventing an increase in knee valgus and a decrease in overall jump landing performance. In order to better understand the efficacy of a jump training program that may have implications on knee injury prevention, further research is necessary utilizing a longer training period and larger sample size.

FIGURES AND TABLES







	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Vertical jumps onto box in frontal plane	DL x12 SL x12 bs	Same	Same	DL x 8 SL x 8 bs	Same	Same
Vertical jumps onto box in sagittal plane	DL x12 SL x12 bs	Same	Same	DL x 8 SL x 8 bs	Same	Same
Horizontal jumps on the ground in frontal plane	DL x12 SL x12 bs	Same	Same	DL x 8 SL x 8 bs	Same	Same
Horizontal jumps on the ground in sagittal plane	DL x12 SL x12 bs	Same	Same	DL x 8 SL x 8 bs	Same	Same

Table 1.1 Training program volume progression; DL-double leg, SL-single leg, bs-amount of repetitions were performed on both sides

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Vertical onto box DL	20cm	Same	Same	30cm	Same	Same
Vertical onto box SL	20cm	Same	Same	30cm	Same	Same
Horizontal on the ground DL	60cm	Same	Same	90cm	Same	Same
Horizontal on the ground SL	90cm	Same	Same	120cm	Same	Same

Table 1.2 Training program height and distance progression; DL-double leg, SL-single leg, cm-centimeters

	TRAIN	CONT	p value for interaction effect (*indicates significance)
Total Pre	5.88±1.29	5.75±1.41	
Total Post	5.85±1.46	6.26±1.65	0.044*
Knee Valgus IC Pre	0.4±0.33	0.28±0.32	
Knee Valgus IC Post	0.38±0.33	0.41±0.34	0.146
Knee Valgus max Pre	0.59±0.41	0.47±0.41	
Knee Valgus max Post	0.54±0.31	0.46±0.34	0.645

Table 2.1: Values at baseline (Pre) and post testing (Post) for total LESS score, knee valgus at initial contact, and max knee valgus; TRAIN=training group, CONT=control group, IC=initial contact, max=maximum displacement of knee valgus

	Baseline average total LESS score	Post Testing average total LESS score	Correlation	p value (*indicates significance)
Assessor 1	7.78	7.42	0.851	0.49
Assessor 2	6.14	7.92	0.693	0.02*
Assessor 3	6.64	6.50	0.62	0.859
Assessor 4	5.92	5.28	0.346	0.579
Assessor 5	5.35	5.57	0.831	0.718
Assessor 6	7.07	7.64	0.348	0.431

Table 2.2: Reliability of assessors from baseline to post testing

CHAPTER 5

RECOMMENDATIONS FOR FUTURE RESEARCH

The present study and previous work seem to support the use of neuromuscular training programs as a means to positively affect jump landing performance and decrease an athlete's predisposition to injury especially in more susceptible populations like young female athletes. Further research still needs to be done to identify the key contributing factors (frequency, duration, and mode of training) to help further improve the effectiveness of these programs and further prevent injury. Several inconsistencies exist within the literature in terms of frequency and duration, with some utilizing higher volume and longer training programs (Chappell & Limpisvasti, 2008; Lim et. al., 2009; Mandelbaum et al., 2005; Emery & Meeuwisse, 2010; Hewett et. al., 1999; Pfeiffer et. al., 2006; Waldén, et al., 2012) and some with shorter, lower volume programs, including the present study (Ortiz et. al., 2010; Steffen et. al., 2008). It is fairly well understood that improvements in most skills occur over long term progressions which would make it appropriate to conduct a similar study with a longer training period. It also seems fairly consistent that most of the literature that incorporates knee injury prevention programs utilize training modes that are multi component in nature (Chappell & Limpisvasti, 2008; Lim et. al., 2009; Ortiz et. al., 2010; Mandelbaum et al., 2005; Emery & Meeuwisse, 2010; Waldén, et al., 2012; Steffen et. al., 2008). There have been inconsistencies in the results of these multi component based programs which is a reason the present study chose to focus on specific neuromuscular jump training, similar to that utilized in previous work (Hewett et. al., 1999; Pfeiffer et. al., 2006). Future research focusing training on one specific area of improving knee injury pre dispositions, like a neuromuscular jump training program or lower body strength training program may provide a better understanding on the efficacy of single component

REFERENCES

Beese, M. E., Joy, E., Switzler, C. L., & Hicks-Little, C. A. (2015). Landing Error Scoring System Differences Between Single-Sport and Multi-Sport Female High School-Aged Athletes. *Journal Of Athletic Training*, *50*(8), 806-811.

Beutler, A., de la Motte, S., Marshall, S., Padua, D., & Boden, B. (2009). Muscle Strength and Qualitative Jump-Landing Differences in Male and Female Military Cadets: The Jump-ACL Study. *Journal Of Sports Science & Medicine*, *8*663-671.

Beynnon, B. D., Vacek, P. M., Newell, M. K., Tourville, T. W., Smith, H. C., Shultz, S. J., & Johnson, R. J. (2014). The Effects of Level of Competition, Sport, and Sex on the Incidence of First-Time Noncontact Anterior Cruciate Ligament Injury. *The American Journal Of Sports Medicine*, *42*(8), 1806-1812.

Boden, B. P., Breit, I., & Sheehan, F. T. (2009). Tibiofemoral alignment: contributing factors to noncontact anterior cruciate ligament injury. *The Journal Of Bone And Joint Surgery. American Volume*, *91*(10), 2381-2389.

Chappell, J. D., & Limpisvasti, O. (2008). Effect of a neuromuscular training program on the kinetics and kinematics of jumping tasks. *The American Journal Of Sports Medicine*, *36*(6), 1081-1086.

Chappell, J. D., Creighton, R. A., Giuliani, C., Yu, B., & Garrett, W. E. (2007). Kinematics and electromyography of landing preparation in vertical stop-jump: risks for noncontact anterior cruciate ligament injury. *The American Journal Of Sports Medicine*, *35*(2), 235-241.

Chin, Y. C., Wijaya, R., Chong, L. R., Chang, H. C., & Lee, Y. D. (2014). Bone bruise patterns in knee injuries: where are they found?. *European Journal Of Orthopaedic Surgery & Traumatology: Orthopédie Traumatologie*, *24*(8), 1481-1487.

Emery, C. A., & Meeuwisse, W. H. (2010). The effectiveness of a neuromuscular prevention strategy to reduce injuries in youth soccer: a cluster-randomised controlled trial. *British Journal Of Sports Medicine*, *44*(8), 555-562.

Gokeler, A., Eppinga, P., Dijkstra, P. U., Welling, W., Padua, D. A., Otten, E., & Benjaminse, A. (2014). Effect of fatigue on landing performance assessed with the landing error scoring system (less) in patients after ACL reconstruction. A pilot study. *International Journal Of Sports Physical Therapy*, *9*(3), 302-311.

Hewett, T. E., Lindenfeld, T. N., Riccobene, J. V., & Noyes, F. R. (1999). The effect of neuromuscular training on the incidence of knee injury in female athletes. A prospective study. *The American Journal Of Sports Medicine*, *27*(6), 699-706.

Hootman, J. M., Dick, R., & Agel, J. (2007). Epidemiology of collegiate injuries for 15 sports: summary and recommendations for injury prevention initiatives. *Journal Of Athletic Training*, *42*(2), 311-319.

Imwalle, L. E., Myer, G. D., Ford, K. R., & Hewett, T. E. (2009). Relationship between hip and knee kinematics in athletic women during cutting maneuvers: a possible link to noncontact anterior cruciate ligament injury and prevention. *Journal Of Strength And Conditioning Research / National Strength & Conditioning Association*, *23*(8), 2223-2230.

James, J., Ambegaonkar, J. P., Caswell, S. V., Onate, J., & Cortes, N. (2016). Analyses of Landing Mechanics in Division I Athletes Using the Landing Error Scoring System. *Sports Health*, *8*(2), 182-186.

Kiapour, A. M., Kiapour, A., Goel, V. K., Quatman, C. E., Wordeman, S. C., Hewett, T. E., & Demetropoulos, C. K. (2015). Uni-directional coupling between tibiofemoral frontal and axial plane rotation supports valgus collapse mechanism of ACL injury. *Journal Of Biomechanics*, *48*(10), 1745-1751.

Kiapour, A. M., Quatman, C. E., Goel, V. K., Wordeman, S. C., Hewett, T. E., & Demetropoulos, C. K. (2014). Timing sequence of multi-planar knee kinematics revealed by physiologic cadaveric simulation of landing: implications for ACL injury mechanism. *Clinical Biomechanics (Bristol, Avon)*, *29*(1), 75-82.

Kim, S. Y., Spritzer, C. E., Utturkar, G. M., Toth, A. P., Garrett, W. E., & DeFrate, L. E. (2015). Knee Kinematics During Noncontact Anterior Cruciate Ligament Injury as Determined From Bone Bruise Location. *The American Journal Of Sports Medicine*, *43*(10), 2515-2521.

Koga, H., Nakamae, A., Shima, Y., Iwasa, J., Myklebust, G., Engebretsen, L., & Krosshaug, T. (2010). Mechanisms for noncontact anterior cruciate ligament injuries: knee joint kinematics in 10 injury situations from female team handball and basketball. *The American Journal Of Sports Medicine*, *38*(11), 2218-2225.

Levine, J. W., Kiapour, A. M., Quatman, C. E., Wordeman, S. C., Goel, V. K., Hewett, T. E., & Demetropoulos, C. K. (2013). Clinically relevant injury patterns after an anterior cruciate ligament injury provide insight into injury mechanisms. *The American Journal Of Sports Medicine*, *41*(2), 385-395.

Lim, B., Lee, Y. S., Kim, J. G., An, K. O., Yoo, J., & Kwon, Y. H. (2009). Effects of sports injury prevention training on the biomechanical risk factors of anterior cruciate ligament injury in high school female basketball players. *The American Journal Of Sports Medicine*, *37*(9), 1728-1734.

Mandelbaum, B. R., Silvers, H. J., Watanabe, D. S., Knarr, J. F., Thomas, S. D., Griffin, L. Y., & Garrett, W. J. (2005). Effectiveness of a neuromuscular and proprioceptive training program in preventing anterior cruciate ligament injuries in female athletes: 2-year follow-up. *The American Journal Of Sports Medicine*, *33*(7), 1003-1010.

Munro, A., Herrington, L., & Comfort, P. (2012). Comparison of landing knee valgus angle between female basketball and football athletes: possible implications for anterior cruciate ligament and patellofemoral joint injury rates. *Physical Therapy In Sport: Official Journal Of The Association Of Chartered Physiotherapists In Sports Medicine*, *13*(4), 259-264.

Myer, G. D., Ford, K. R., Khoury, J., Succop, P., & Hewett, T. E. (2011). Biomechanics laboratory-based prediction algorithm to identify female athletes with high knee loads that increase risk of ACL injury. *British Journal Of Sports Medicine*, *45*(4), 245-252.

Onate, J., Cortes, N., Welch, C., & Van Lunen, B. L. (2010). Expert versus novice interrater reliability and criterion validity of the landing error scoring system. *Journal Of Sport Rehabilitation*, *19*(1), 41-56.

Ortiz, A., Trudelle-Jackson, E., McConnell, K., & Wylie, S. (2010). Effectiveness of a 6-week injury prevention program on kinematics and kinetic variables in adolescent female soccer players: a pilot study. *Puerto Rico Health Sciences Journal*, *29*(1), 40-48.

Padua, D. A., DiStefano, L. J., Beutler, A. I., de la Motte, S. J., DiStefano, M. J., & Marshall, S. W. (2015). The Landing Error Scoring System as a Screening Tool for an Anterior Cruciate Ligament Injury-Prevention Program in Elite-Youth Soccer Athletes. *Journal Of Athletic Training*, *50*(6), 589-595

Padua, D. A., Boling, M. C., Distefano, L. J., Onate, J. A., Beutler, A. I., & Marshall, S. W. (2011). Reliability of the landing error scoring system-real time, a clinical assessment tool of jump-landing biomechanics. *Journal Of Sport Rehabilitation*, *20*(2), 145-156.

Padua, D. A., Marshall, S. W., Boling, M. C., Thigpen, C. A., Garrett, W. J., & Beutler, A. I. (2009). The Landing Error Scoring System (LESS) Is a valid and reliable clinical assessment tool of jump-landing biomechanics: The JUMP-ACL study. *The American Journal Of Sports Medicine*, *37*(10), 1996-2002.

Pfeiffer, R. P., Shea, K. G., Roberts, D., Grandstrand, S., & Bond, L. (2006). Lack of effect of a knee ligament injury prevention program on the incidence of noncontact anterior cruciate ligament injury. *The Journal Of Bone And Joint Surgery. American Volume*, *88*(8), 1769-1774.

Quatman, C. E., Kiapour, A., Myer, G. D., Ford, K. R., Demetropoulos, C. K., Goel, V. K., & Hewett, T. E. (2011). Cartilage pressure distributions provide a footprint to define female anterior cruciate ligament injury mechanisms. *The American Journal Of Sports Medicine*, *39*(8), 1706-1713.

Sanders, T. L., Maradit Kremers, H., Bryan, A. J., Larson, D. R., Dahm, D. L., Levy, B. A., & ... Krych, A. J. (2016). Incidence of Anterior Cruciate Ligament Tears and Reconstruction: A 21-Year Population-Based Study. *The American Journal Of Sports Medicine*, *44*(6), 1502-1507.

Sell, T. C., Ferris, C. M., Abt, J. P., Tsai, Y., Myers, J. B., Fu, F. H., & Lephart, S. M. (2006). The effect of direction and reaction on the neuromuscular and biomechanical characteristics of the knee during tasks that simulate the noncontact anterior cruciate ligament injury mechanism. *The American Journal Of Sports Medicine*, *34*(1), 43-54.

Steffen, K., Myklebust, G., Olsen, O. E., Holme, I., & Bahr, R. (2008). Preventing injuries in female youth football--a cluster-randomized controlled trial. *Scandinavian Journal Of Medicine & Science In Sports*, *18*(5), 605-614.

Viskontas, D. G., Giuffre, B. M., Duggal, N., Graham, D., Parker, D., & Coolican, M. (2008). Bone bruises associated with ACL rupture: correlation with injury mechanism. *The American Journal Of Sports Medicine*, *36*(5), 927-933.

Waldén, M., Atroshi, I., Magnusson, H., Wagner, P., & Hägglund, M. (2012). Prevention of acute knee injuries in adolescent female football players: cluster randomised controlled trial. *BMJ (Clinical Research Ed.)*,

Appendix A: IRB Application

LINDENWOOD

<u>Expedited</u> Application for IRB Review of Research Proposal Involving Human Subjects

If you have any questions about whether you need to complete a full or expedited application, please review the expedited application criteria at <u>http://www.lindenwood.edu/academics/irb/</u>

1. Title of Project: **Neuromuscular Training on Jump Landing Performance**

2. Date of Last Revision (if this is the first submission, list NA): **N/A**

3. List the names of all researchers/faculty advisors and their contact information in the table below.

Name	Email	Phone Number	Department	Student/Faculty
Richard Aley	raley@lindenwood.edu	509-981-4602	SRES	Graduate Student
Chad Kerksick	ckerksick@lindenwood.edu	636-627-4629	SRES	Faculty
Tom Godar	tgodar@lindenwood.edu	636-949-4628	SRES	Faculty
Boston Alverson	balverson@lindenwood.edu	636-949-4140	Strength and Conditioning	Faculty
Jake Tanner	jtanner@lindenwood.edu	636-949-4799	SRES	Graduate Student
Charles Smith	Csmith3@lindenwood.edu	609-330-4372	SRES	Graduate Student
Tom VanBuskirk	tvanbuskirk@lindenwood.edu	507-440-6842	SRES	Graduate Student

Note: adjunct faculty may only serve as researchers with the approval of the Dean of the appropriate school.

4. Anticipated starting date for this project: **Upon IRB approval** Anticipated ending date: **One year from IRB approval**

(Collection of *primary* data – data you collect yourself - <u>cannot</u> begin without IRB approval. Completion/Amendment form required yearly, even if stated anticipated ending date is more than one year in the future.)

5. Will the results of this research be published in any way?

(Publication involves dissemination of results to the public in any manner, including but not limited to: publication in print or online, presentation at a conference, display at an event open to the public, etc.)

☒ Yes* ☐ No

* If yes, briefly describe how you intend to publish this research:

Results of this research may be represented as a poster presentation at a National or Regional Sports Medicine or Strength and Conditioning Conference, the Lindenwood Student Research Symposium, and/or in publication of the Journal of Athletic Training.

6. Lay Summary

Summarize the proposed research using non-technical language that can be readily understood by IRB members whose primary concerns are nonscientific. The summary should include a statement of the purpose of the project (what you want to accomplish), background information necessary to understand the study including definitions of terms that may be unfamiliar to the reader, and the hypothesis(es) or research question(s) of the proposed project. The complete summary must not exceed 500 words. Use complete sentences.

Injury to the anterior cruciate ligament (ACL) of the knee is highly prevalent within competitive sports of all levels and types. An injury to the ACL is often season and/or career ending for the athlete and usually requires reconstructive surgery to the ligament and other structures within the knee. These surgeries as well as rehabilitation are accompanied by high financial burden to the athlete and the family and also increase the likelihood for chronic knee issues in the future. Thus, many researchers aim to seek how these injuries occur and to develop prevention strategies to keep athletes injury free and healthy.

While direct contact mechanisms of injury are often unpreventable, high rates of non-contact injuries to the ACL occur in athletes involved in sports that require jumping and cutting functional movements. Of these athletes research has shown that females are of greater risk than males in sustaining a non-contact ACL injury (Munro, Herrington, & Comfort, 2012). Researchers have used bone bruise and cartilage damage locations of the knee with associated ACL injuries, to determine specific mechanisms for non-contact ACL injuries. Consistent damage to the lateral aspect of the knee indicates that a major mechanism of ACL injury is a knee valgus or abduction movement (when the knee goes inward) during landing or cutting (Quatman et al., 2011).

Many studies have proposed that the most effective strategy to reduce a knee valgus movement is the use of neuromuscular training to promote proper mechanics during jumping and change of direction activities (Myer et al., 2011; Munro et al, 2011; & Quatman et al., 2011). Several studies have implemented specific prevention programs and have recorded rates of injury within the population observed. Many of these programs were multi component based with a large majority of incorporating some form of neuromuscular/plyometric based movements (Michaelidis,& Koumantakis, 2014).

Few studies have examined the direct effect of these neuromuscular training programs specifically on jump landing performance and whether or not it can improve knee valgus movements. Due to high prevalence of ACL injury in female athletic populations and a major mechanism of injury being a knee valgus during dynamic movements, it is hypothesized that the average female athlete presents with increased knee valgus during a jump landing task and that a specific neuromuscular training program over the course of a season may decrease the amount of knee valgus observed. <u>Thus, the purpose of this study is to determine the effect of a neuromuscular training program on jump landing mechanics in female college athletes.</u>

7. Research Funding

a. Is this research funded?

☒ No. Continue to question 8.

☐ Yes or pending. Complete the rest of this section (below).

b. Check all of the appropriate boxes for funding sources (including pending sources) for this research.

☐ Federal Agency Name:

☐ Foundation Name:

☐ State Agency Name:

☐ Industry Sponsor Name:

☐ Other – Name:

Please attach a copy of the grant or contract to this application for federally funded research where Lindenwood University is the awardee institution or lead site.

8. a. Has this research project been reviewed or is it currently being reviewed by an official or institutional research department at another institution?

☐ Yes ☒ No ☐ Pending

c. Has this research project been reviewed by another department or educational institution?

No, it has not been reviewed elsewhere.

If yes, please state where the research has been/will be reviewed. Provide a copy of any related documents in the appendix if the research was approved.

Note: if another institution's review procedure requires changes to the research protocol after Lindenwood IRB approval has been granted, the researcher must submit an amendment to the LU IRB and gain approval before research can commence or continue as amended.

9. What is the PI's relationship with the participants in the study or research site? If you have no relationship, indicate that. Explain how any coercion will be reduced or how the identities of the participants will remain anonymous if the PI is a superior.

The primary investigator and other research team members are graduate student athletic trainers at Lindenwood University. The PI is an athletic trainer for the proposed athlete population. Data collection will be performed by the PI and other investigators and video analysis will be assessed from the torso to the feet therefore keeping the identity of the participant anonymous. Neuromuscular training will be instructed weekly by the PI and/or other research team members.

10. Participants involved in the study:

a. Indicate the minimum and maximum number of persons, of what type, will be recruited as participants in this study.

Total requested number of LU subjects: **60**

Total subjects enrolled at sites that do not fall under the responsibility of the LU IRB: **0**

b. Primary Focus of Age Range (check all that apply):

☐ Newborn to 17 years of age *(students in the LPP that are 17 years of age have a signed parental consent form on file and can be treated as consenting adults)*
☒ 18-64 Years
☐ 65+ Years

c. Populations that are the PRIMARY FOCUS of this research. Remember to take into account the location in which recruitment will occur and where the research will be conducted. Also note that additional information and/or safeguards will be required when a subject population has been designated as vulnerable (with an asterisk *).
Check all that apply:
☒ Adults: Health Subjects or Control Subjects (for biomedical research)
☐ Pregnant Women, Neonates, Fetuses/Fetal Tissue*
☐ Prisoners*
☐ Decisionally-Impaired*
☐ Economically and/or Educationally Disadvantaged*
☐ Vulnerable to Coercion or Undue Influence*
☐ LU Employees**
☐ LU Students (not LPP)**
☐ Lindenwood Participant Pool (LPP)**
☐ Other: specify

Note: groups listed above marked with an asterisk (*), as well as subjects under the age of 18, are considered "vulnerable" and require special consideration by the federal regulatory agencies and/or by the LU IRB.

Note: any survey of more than 100 LU faculty, staff, or students, marked above with two asterisks (**), requires approval by the Provost after IRB approval has been granted. Electronic surveys of LU faculty, staff, or students must use the University's Survey Monkey account, which must be created by an authorized administrator.

d. From what source(s) will the potential participants be recruited?

Participants will be recruited from Lindenwood University's Women's Lacrosse, Women's Soccer, Women's Field Hockey, and Women's Volleyball.

e. Describe the process of participant recruitment.

An announcement will be made to all teams about the opportunity to participate in the research study. Students will be able to contact study investigators via email or phone communication to learn more about participation in the study, at which point they will be given a brief summary of the purpose, methods, as well as benefits and risks of the study in addition to a preliminary determination of their eligibility. If the participant expresses interest in the study, an appointment will then be scheduled to complete paperwork and begin data collection according to the protocol.

f. Will any participants be excluded?

☒ Yes ☐ No

If yes, explain why and how.

- **Males will be excluded from this study due to lower prevalence of ACL injury.**
- **Females aged less than 17 or greater than 25 years of age will be excluded. Participants younger than 17 are excluded due to necessity of parental consent. Participants greater than 25 years old is a cut-point established by the research team to identify a specific population (college athletes)**
- **All female participants within this age range must also participating in a competitive college level sport.**
- **Any individual who reports as being under the care of a physician or has previously been diagnosed with cardiac (heart), pulmonary (lung), metabolic (pancreas, thyroid, etc.), renal (kidneys), hepatic (liver), musculoskeletal (bones, muscles, tendons, ligaments) or psychiatric conditions that will compromise their safe participation in the prescribed exercise**
- **Any individual who has sustained a significant knee injury will be excluded. A significant knee injury is defined as an athlete missing more than 25% of scheduled practices and games while receiving care for that injury or the athlete has surgery performed on their injured knee regardless of how time was missed. For example, an athlete could suffer a significant knee injury requiring surgery two weeks before the season ends and not miss 25% of scheduled games and/or practices.**
- **Participants who do not agree to follow the training program will be excluded from the study.**

g. Where will the study take place?

☒ On campus – Explain: **Baseline and post intervention testing will be conducted in the Lindenwood University athlete fitness center and participation of the supervised training program will be performed either before, after or on a designated off day at Hunter stadium. All testing sessions will take place at approximately the same time each day and each athlete will have not undergone any strenuous and unaccustomed exercise with their lower bodies for 24 hours prior to testing. All training sessions will take place at approximately the same location throughout the six-week training program.**

☐ Off campus – Explain:

11. Methodology/procedures:

a. Which of the following data-gathering procedures will be used?
Provide a copy of all materials to be used in this study with application.

☒ Observing participants (i.e., in a classroom, playground, school board meeting, etc.)

When? **Baseline testing prior to the 6 week training program and post intervention testing at the end of the 6 weeks.**

Where? **Lindenwood University fitness center**

For how long? **10 minutes**

How often? **Twice**

What data will be recorded? **Jumping landing performance using video recording and scored using the landing error scoring system.**

☐ Survey / questionnaire: ☐ paper ☐ email or Web based
Source of survey:

☐ Interview(s) ☐ (in person) ☐ (by telephone)

☐ Focus group(s)

☐ Audio recording

☒ Video recording

☐ Analysis of deidentified secondary data - specify source (who gathered data initially and for what purpose?):

☐ Test ☐ paper ☐ email or Web based

Source of test:

Type of test (such as memory, verbal skills):

☐ Interactive

Describe (e.g., completed time puzzle, watch video and respond to questions, sample items to compare):

☒ Other (specify): **Direct interaction with human participants through described study protocol.**

b. Based on the boxes checked above, provide a detailed description of how the participants will be treated and what will happen to all information and/or materials collected for the research.

Participants will arrive for baseline testing in the Student Athlete fitness center on Lindenwood University's campus. Participants will need to refrain from strenuous exercise 24 hours prior to testing. The testing procedure will include a 5-10 min instructional session, with the PI demonstrating the jump landing movement and what is required for a successful repetition. No instruction on proper landing mechanics will be given at this time. The participants will be given the opportunity to practice the movement twice before executing their final trials. Two trials will be recorded using two standard video cameras, one with a frontal view and one with a lateral view. Both angles will be recorded from the torso of the participant to ground to keep the identity of the participant anonymous and each participant will be assigned a number. Videos will be saved and analyzed at a later time. All study investigators will be blinded to who is performing testing on each video recording when completing their evaluation.

Jump landing performance will be measured using the Landing Error Scoring System (LESS). This system uses 17 different areas of observation and is scored using pause

and rewind playback of the videos from both the frontal and lateral view. The investigator may pause and rewind as many times as needed in order to score the movement. The scores for both trials will be averaged for each participant, and this will be the score used for the baseline determination of jump landing performance. Each involved investigator will participate in an approximately 60 minute LESS training session to ensure validity and reliability in the jumping landing analysis. This will include a discussion on each individual compensation that may or may not be observed for each area of scoring, as well as a practice/mock test that will be analyzed and scored by each investigator, which will be compared to determine reliability.

After baseline testing is completed each participant will begin a neuromuscular training program that will last 6 weeks. Participants will be randomized into two groups: training group and control. The training group will be perform exercise twice a week at the beginning or end of a practice session in Hunter Stadium on Lindenwood University campus. Prior to the beginning of the first training session, the participants will be instructed on how to perform each exercise and what proper mechanics of each exercise look like. Each training session will last 20 minutes, with 10 minutes spent on vertical landing and plyometric movements, and 10 minutes on horizontal landing and plyometric movements. Within each 10 minute session participants will perform as many repetitions as possible for each instructed exercise. Throughout the sessions, the participants will be monitored and cued, to inform them of any improper technique or execution of the exercises. The control group will not perform the training program.

At the conclusion of the 6 weeks, the participants will return to the student athlete fitness center to conduct post intervention LESS testing. The testing/protocol for this will remain the same as baseline testing. After video analysis and scoring of the post intervention testing has been completed, scores between the two sessions will be compared an analyzed for any changes in landing performance.

12. Will the results of this research be made accessible to participants, institutions, or schools/district?

☒ Yes ☐ No

If yes, explain when and how: **Results of this research may be presented as a poster presentation at a National or Regional Conference, the Lindenwood Student Research Symposium and/or in a peer-reviewed publication.**

13. Potential benefits and compensation from the study:

a. Identify and describe any known or anticipated benefits <u>to the participants</u> (perhaps academic, psychological, or social) from their involvement in the project.

Participants will be provided neuromuscular training as well as education on proper jump landing mechanics that may increase their athletic performance as well as

potentially prevent them from sustaining significant knee injuries that may impact their athletic success.

b. Identify and describe any known or anticipated benefits to society from this study.

It is possible that findings from this study may introduce a preventative program that coaches, athletic trainers, and athletes may use as a method for reducing the prevalence of ACL and other significant knee injuries that occur during competitive sport participation.

c. Describe any anticipated compensation to participants (money, grades, extra credit).

No compensation will be provided.

Note: this information must exactly match the compensation described in the consent form.

14. Potential risks from the study:

a. Identify and describe any known or anticipated risks (i.e., physical, psychological, social, economic, legal, etc.) to participants involved in this study:

Any perceived risks are not any greater than what exists to the participants in their daily participation within their sport. Due to the inclusion of only athletes within the study, it is anticipated that all participants will be young, healthy, active individuals free of injury, and able to participate in the proposed exercises with ease. The exercises and movements that they will be performing are comparable to those that they would perform within all aspects of their sport, including training, practice, and competition. The intensity of the exercises they perform will not achieve a level higher at which they would perform during their sport.

b. Describe, in detail, how your research design addresses these potential risks:

The risks outlined above will be minimized first by recruiting college aged females participating in a varsity NCAA competitive sport. This will allow for a non-sedentary population to reduce the risk of any health related issues from participating in exercise. Risk will further be minimized by reviewing and confirming that all participants have completed a detailed medical history that is associated with their pre participation examinations which includes physician clearance and is required for activity within their sport. This will outline risk factors, specifically orthopedic based injuries to the knee. Due to the impact that plyometric movements have on the knee, any participant with a significant knee injury within the past 12 months will be excluded from the study to decrease any risk of re-injury.

c. Will deception be used in this study? If so, explain the rationale.

No, deception will not be used in this study.

d. Does this project involve gathering information about *sensitive topics*?

[*Sensitive topics* are defined as political affiliations; psychological disorders of participants or their families; sexual behavior or attitudes; illegal, antisocial, self-incriminating, or demeaning behavior; critical appraisals of participants' families or employers; legally recognized privileged relationships (lawyers, doctors, ministers); income; religious beliefs and practices.]

☐ Yes ☒ No

If yes, explain:

e. Indicate the identifiable elements that will be collected and/or included in the research records. Check all that apply:

☒ Names
☐ Device identifiers/Serial numbers
☐ Medical record numbers
☐ Street address
☐ City or State
☐ Zip Code
☐ Account numbers
☐ Vehicle ID numbers
☐ License/Certificate numbers
☐ Financial account information (including student ID)
☐ Social Security Numbers*
☒ Phone numbers
☐ Web URLs
☐ Health plan numbers
☐ IP address numbers
☐ Biometric identifiers**
☐ Fax numbers
☒ E-mail address
☐ Facial Photos/Images
☒ Date of Birth

☐ Any other unique identifier – Specify:

☐ None of the identifiers listed above

* *If Social Security Numbers will be collected, explain below why they are necessary and how they will be used:*

** *Biometric identifiers are observable biological characteristics which could be used to identify an individual, e.g., fingerprints, iris/retina patterns, and facial patterns.*

f. Indicate how data will be stored and secured. Please mark all that apply.

All computers used in this study will be located in the graduate assistant athletic training office located in the student athlete center athletic training room. This office will be locked when no athletic trainers are present. All videos will be immediately uploaded to the PI's computer which is password protected. Videos will only be

accessed by investigators scoring the test. No other information will be collected on the recorded video besides the athlete's jumps. All paperwork will be stored in a filing cabinet in the same locked office in the student athlete center athletic training room. No information will be disclosed to those other than the participant themselves (in receiving a printout of their results upon request) and the principal investigator. De-identified printouts will be used to transfer information from all computers and all computers where will be housed will be password-protected to which only the investigators have access. Only the principle investigator and other study investigator will be aware of the data collection and have access to the data. All information will be retained for three years before being destroyed as per federal regulations.

Electronic data:
☐ Not applicable
☐ De-identified only (i.e., no personal identifiers, including 18 HIPAA identifiers, are included with or linked to the data via a code)
☐ Password access
☐ Coded, with a master list secured and kept separately
☐ Encryption software will be used. Specify encryption software:
☐ Secure network server will be used to store data. Specify secure server:
☒ Stand-alone desktop/laptop computer will be used to store data
☐ Not connected to server/internet
☐ An organization outside of the LU covered entity will store the code key. The organization will have a business associate agreement with LU.
☐ Other (specify):

Hardcopy data (consents and other study documents, recordings, artifacts, and specimens):
☐ Not applicable
☒ De-identified only (i.e., no personal identifiers, including 18 HIPAA identifiers, are included with or linked to the data via a code)
☐ Coded, with a master list secured and kept separately
☐ Locked file cabinet
☒ Locked office/lab
☒ Locked suite
☐ Locked refrigerator/freezer
☐ Specimens coded with a master list secured and kept separately
☐ Other (specify):

g. Explain the procedures to be used to ensure anonymity of participants and confidentiality of data during the data-gathering phase of the research, in the storage of data, and in the release of the findings.

All testing forms will be de-identified throughout testing. In all forms of presentation and publication, only references to group changes will be made, subsequently no single person will be identified.

h. How will confidentiality be explained to participants?

The participants will be told that their information will be kept confidential throughout and following their participation. All information will be provided on the consent form as well as verbally expressed prior to participation in study. All investigator interactions regarding data will take place in the student athlete center athletic training room graduate assistant office.

i. Indicate the duration and location of secure data storage and the method to be used for final disposition of the data.

Paper Records

☒ Data will be retained for 3 years according to federal regulation.
☐ Data will be retained indefinitely in a secure location.
Where?

Audio/Video Recordings

☒ Audio/video recordings will be retained for 3 years according to federal regulation.
☐ Data will be retained indefinitely in a secure location.
Where?

Electronic Data (computer files)

☒ Electronic data will be retained for 3 years according to federal regulation.
☐ Data will be retained indefinitely in a secure location.
Where?

15. Informed consent process:

a. What process will be used to inform the potential participants about the study details and (if necessary) to obtain their written consent for participation?

☒ An information letter / written consent form for participants or their legally authorized agents will be used; <u>include a copy with application</u>.

☐ An information letter from director of institution involved will be provided; <u>include a copy with application</u>.

☐ Other (specify):

☐ If any copyrighted survey or instrument has been used, include a letter or email of permission to use it in this research.

b. What special provisions have been made for providing information to those not fluent in English, mentally disabled persons, or other populations for whom it may be difficult to ensure that they can give informed consent?

All participants will be English-speaking. However, some participants may not be native English speakers. Therefore, all participants will be given plenty of time to answer questions about the protocol, contact investigators via phone or email, and be also offered extra time to read the consent prior to providing their consent.

16. All supporting materials/documentation for this application are to be uploaded to IRBNet and attached to the package with your protocol and your credentials. Please indicate which appendices are included with your application. Submission of an incomplete application package will result in the application being returned to you unevaluated.

☐ Recruitment materials: A copy of any posters, fliers, advertisements, letters, telephone, or other verbal scripts used to recruit/gain access to participants.

☒ Data gathering materials: A copy of all surveys, questionnaires, interview questions, focus group questions, or any standardized tests used to collect data.

☐ Permission if using a copyrighted instrument

☒ Information letter for participants

☒ Informed Consent Form: Adult

☐ Informed Consent Form: guardian to sign consent for minor to participate

☐ Informed Assent Form for minors

☐ Information/Cover letters used in studies involving surveys or questionnaires

☐ Permission letter from research site

☒ Certificate from NIH IRB training for all students and faculty

☐ IRBNet electronic signature of faculty/student

☐ PPSRC Form (*Psychology Applications Only*)

Adapted, in part, from LU Ethics Form 8/03
Revised 10/14/2013

References

1. Michaelidis, M., & Koumantakis, G. A. (2014). Effects of knee injury primary prevention programs on anterior cruciate ligament injury rates in female athletes in different sports: a systematic review. Physical Therapy In Sport: Official Journal Of The Association Of Chartered Physiotherapists In Sports Medicine, 15(3), 200-210.

2. Munro, A., Herrington, L., & Comfort, P. (2012). Comparison of landing knee valgus angle between female basketball and football athletes: possible implications for anterior cruciate ligament and patellofemoral joint injury rates. Physical Therapy In Sport: Official Journal Of The Association Of Chartered Physiotherapists In Sports Medicine, 13(4), 259-264

3. Myer, G. D., Ford, K. R., Khoury, J., Succop, P., & Hewett, T. E. (2011). Biomechanics laboratory-based prediction algorithm to identify female athletes with high knee loads that increase risk of ACL injury. British Journal Of Sports Medicine, 45(4), 245-252.

4. Quatman, C. E., Kiapour, A., Myer, G. D., Ford, K. R., Demetropoulos, C. K., Goel, V. K., & Hewett, T. E. (2011). Cartilage pressure distributions provide a footprint to define female anterior cruciate ligament injury mechanisms. The American Journal Of Sports Medicine, 39(8),

Appendix B: Informed Consent

LINDENWOOD

INFORMED CONSENT FOR PARTICIPATION IN RESEARCH ACTIVITIES

Neuromuscular Training effect on Jump Landing Performance

Student (Primary) Investigator: Richard A. Aley

Phone: 509-981-4602

Email: raley@lindenwood.edu

Faculty Investigator: Chad M. Kerksick, PhD

Phone: 636-627-4629

Email: ckerksick@lindenwood.edu

Explanation of Study Purpose

1. You are invited to participate in a research study conducted by Richard Aley, a graduate student in the Human Performance program at Lindenwood University under the supervision of Chad Kerksick, PhD, a faculty member at Lindenwood University. The purpose of this research is to determine the effect of a neuromuscular training program on jump landing performance in female college athletes.

Explanation of Study Participation

2. Your participation will involve the completion of one familiarization visit and two testing visits to the student athlete fitness center as well as adherence to a neuromuscular training program over the course of six weeks. You will be randomized into either a training group or control group, with participants within the control group completing testing sessions but no training sessions. The familiarization visit will involve an instructional demonstration of the landing error scoring system test and how it should completed as well as 2 practice trials. The two testing visits will be identical in nature and separated by approximately six week. Prior to both baseline testing and post-training testing you must refrain from strenuous exercise for 24 hours. On the day you will arrive for your baseline testing you will again be given a short instructional demonstration and will be given two

practice trials of the task before your two recorded trials. The two test trials will be recorded with a standard video camera from the front as well as from the side. The test requires you to stand on top of a 30cm (almost 12 inches) high box, and jump down towards a mark on the ground that will be placed at a distance equal to half of your height away from the edge of the box. Upon landing on this mark, you will immediately jump back up as high as you can. The cameras will record your jump from your shoulders down to the ground and this video will be analyzed to determine the quality of your jumping mechanics.

The neuromuscular training program will begin after the completion of baseline testing and will require each person to complete a total of 12 sessions (two sessions per week for six weeks). Each training session will consist of a 20 minute session either before or after practice, or on a recovery day. Ten minutes of the training will consist of vertical plyometric exercises (hops, jumps, etc) both forward and laterally with close attention being paid to the landing aspect of each movement. The other 10 minutes will consist of similar exercises but will have more horizontal movements, again with a significant emphasis on the quality of your landing. The volume and intensity of these exercises will be no more than any intensity you may experience during your normal training, practice or competition.

At the completion of the 6 week training program you will return to the student athlete fitness center to complete an identical post intervention testing session using the landing error scoring system. You will again be reviewed on the proper way to complete the task with a short instructional demonstration. You will again be given two practice trials before you complete your two recorded trials. Again, these will be recorded using standard video camera from both the frontal and side view.

The amount of time involved in your participation will involve a familiarization visit, the two separate testing visits that will take approximately 15 minutes to complete and the completion of twelve training sessions over a six week period that are anticipated to take approximately 20 minutes to complete for each session.

Approximately forty-five female college aged athletes will be involved in this research study.

Risks Involved in Study Participation

1. There may be certain risks or discomforts associated with this research. The landing error scoring system test involves a forceful jump and landing from a 30cm (approximately 12 inches) height. Although this is a similar movement to what you may experience during your everyday training, practice, and/or competition there is still a slight risk for injury. This risk of injury will be minimalized by a review of your knee injury history within the last year, in which a significant knee injury will disqualify you from this study. The neuromuscular training program involves a moderate intensity 20 minute bout of anaerobic exercise that involves mostly jumping exercises. The risk from

participating in this exercise is already minimalized by your participation in a collegiate sport, which requires you to have a pre participation physical examination before you are able to participate.

Benefits of Study Participation:

4. There are no direct benefits for you participating in this study. Your participation will contribute to the knowledge of how a neuromuscular training program effects landing performance in athletes, which in turn could potentially lead to more effective prevention programs to reduce the risk of knee injuries in female athletes. The neuromuscular training program has the potential to increase your performance within in your sport and reduce your risk of injury. You will not be compensated for your participation.

Voluntary Participation:

5. Your participation is voluntary and you may choose not to participate in this research study or to withdraw your consent at any time. You will NOT be penalized in any way should you choose not to participate or to withdraw.

Privacy and Confidentiality:

6. We will do everything we can to protect your privacy. As part of our effort to protect your privacy, your identity will not be revealed in any publication or presentation that may result from this study and the information collected will remain in the possession of the investigator in a safe location. All data collected as part of your study involvement will be kept in filing cabinets located at the Student Athlete Center inside the student investigator's office. All files will be locked in a cabinet that only study investigators can access. All data will remain in this filing cabinet for three years whereby at that time it will be shredded.

Study-Related Questions and Concerns:

7. If you have any questions or concerns regarding this study, or if any problems arise, you may contact Richard Aley by calling (509)-981-4602 or emailing him at raley@lindenwood.edu and you can also contact the Faculty Supervisor on the project, Chad M. Kerkisick PhD by calling (636)-627-4629 or emailing him at ckerksick@lindenwood.edu. You may also ask questions of or state concerns regarding your participation to the Lindenwood Institutional Review Board (IRB) through contacting Dr. Marilyn Abbott, Interim Provost at mabbott@lindenwood.edu or 636-949-4912.

I have read this consent form and have been given the opportunity to ask questions. I will also be given a copy of this consent form for my records. I consent to my participation in the research described above.

Participant's Signature Date

Participant's Printed Name

Signature of Principal Investigator Date

Investigator Printed Name

Appendix C: LESS Scoring Rubric

LESS item	Operational definition	Camera view	LESS score
1	At the time point of initial contact, if the knee of the test leg is flexed more than 30 degrees, score YES. If the knee is not flexed more than 30 degrees, score NO.	Side	Y=0 N=1
2	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.	Side	Y=0 N=1
3	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.	Side	Y=0 N=1
4	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.	Side	Y=0 N=1
5	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.	Front	Y=1 N=0
6	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.	Front	Y=1 N=0
7	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 then greater than shoulder width (wide), scoreYES. If the test foot is internally or externally rotated, grade the stance width based on heel placement.	Front	Y=1 N=0
8	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 thetest leg is outside of the foot then score less than shoulder width (narrow), score YES. If the test foot is internally or externally rotated, grade the stance width based on heel placement.	Front	Y=1 N=0
9	If the foot of the test leg is internally morethan 30 degrees between the time period of initial contact and max knee flexion, then 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.	Front	Y=1 N=0
10	If thefoot of the test leg is externally rotated more than 30 degrees between the time period of initial contact and max knee flexion, then 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.	Front	Y=1 N=0
11	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.	Front	Y=0 N=1
12	If the knee of the test leg flexes more than 45 degrees from initial contact to max knee flexion, score YES. If the knee of the test leg does not flex more than 45 degrees, score NO.	Side	Y=0 N=1
13	If the thigh of the test leg flexes more on the trunk from initial contact to max knee flexion angle, score YES.	Side	Y=0 N=1
14	If the trunk flexes more from the point of initial contact to max knee flexion, score YES. If the trunk does not flex more, score NO.	Side	Y=0 N=1
15	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.	Front	Y=1 N=0
16	Watch the sagittal plane motion at the hips and knees from initial contact to max knee flexion angle. If the subject 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, then AVERAGE. If the subject goes through very little, if any trunk, hip, and knee displacement, then STIFF.	Side	Soft=0 Average=1 Stiff=2
17	Score EXCELLENT if the subject displays a soft landing and no frontal plane motion at the knee. Score POOR if the subject displays a stiff landing and large frontal plane motion at the knee. All other landings, score AVERAGE.	Front Side	Excellen=0 Average=1 Poor=2

Y: yes, N: no

	Trial 1	Trial 2	Average
1. Knee flexion angle at initial contact			
2. Hip flexion angle at initial contact			
3. Trunk flexion angle at initial contact			
4. Toe to heel or heel to toe landing			
5. Knee valgus angle at initial contact			
6. Lateral trunk flexion angle at initial contact			
7. Stance width-wide			
8. Stance width-narrow			
9. Foot position-IR			
10. Foot position-ER			
11. Symmetric initial foot contact			
12. Knee flexion displacement			
13. Hip flexion at max knee flexion			
14. Trunk flexion at max knee flexion			
15. Knee valgus displacement			
16. Joint displacement			
17. Overall impression			
Total			

Korean J Sports Med. 2015 Dec;33(2):88-95.