Spring 5-22-2018

Noncontact Anterior Cruciate Ligament Injuries in Collegiate Female Soccer Players: The Effects of a 4-Week Prevention Program on Landing Kinematics

Tess Marcordes
tessmarcordes@yahoo.com

NONCONTACT ANTERIOR CRUCIATE LIGAMENT INJURIES IN COLLEGIATE FEMALE SOCCER PLAYERS: THE EFFECTS OF A FOUR-WEEK PREVENTION PROGRAM ON LANDING KINEMATICS

By

Tess K. Marcordes

Honors Scholarship Project

Submitted to the Faculty of

Olivet Nazarene University

for partial fulfillment of the requirements for

GRADUATION WITH UNIVERSITY HONORS

February 2018

BACHELOR OF SCIENCE

in

Exercise Science

Dr. Scott Armstrong		2/14/18
Scholarship Project Advisor (printed)	Signature	Date
Honors Council Chair (printed)	Signature	Date
Honors Council Member (printed)	Signature	Date

ACKNOWLEDGEMENTS

Thank you to the Olivet Nazarene University Honor's Program for assisting in the funding of this project, for without it, none of this could have happened. Thank you to Dr. Scott Armstrong who helped me with the development of my topic and program design. Thank you to my professors in the Honors Program throughout my entire four years for constantly pushing me to do my best and for challenging me in ways that I never would have on my own. I have one final and an especially large thank you to my parents. Thank you for the constant encouragement you gave me throughout these past four years. Thank you for putting up with my countless phone calls of me crying about this project and boy problems, and for having my back, pushing me through those hard times. You are the greatest.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

BACKGROUND: Noncontact anterior cruciate ligament (ACL) injuries are highly prevalent in soccer as quick changes in direction, stop-start motions, as well as jumping and landing often paired with shooting or passing a ball are occurring continuously throughout a practice or match. Exaggeration of these movements with extreme joint motions increases the likelihood of ACL injury. An ACL injury can be detrimental to an athlete's career as 25% of athletes do not return to their pre-injury level of play (Padua, DiStefano, Beutler, de la Motte, DiStefano, & Marshall, 2015). Myer, Ford, McLean, & Hewitt (2006), Garcia (2011), and Pollard, Sigward, Ota, Langford, & Powers (2006) have all conducted research showing programs consisting of a combination of plyometric, balance, and strengthening exercises constitute effective prevention of ACL injury.

METHODS: This study tests a new, unestablished ACL injury prevention program designed using elements of previous successful programs, increasing in difficulty as the weeks progressed. Three soccer players participated in the program three days a week for four weeks. The Modified Lower Extremity Scoring System (LESS) was used to determine the risk of ACL injury of each participant. Participants were members of a varsity women's soccer team at a small Christian university in the Midwest. None of the participants had sustained any knee injury prior to participation. The control group consisted of five participants, while the experimental group consisted of three participants. Both groups performed vertical drop tests as their landings were evaluated with the Modified LESS prior to implementation of the prevention program on the experimental group. After the program concluded, each group was retested. We hypothesized that after participation in the progressive four-week ACL prevention program, the experimental group would display a decrease in their Modified LESS scores, thus indicating a decrease in the possibility of noncontact ACL injury, whereas the control group would see little to no differentiation of scores.

RESULTS: The hypothesis that a four-week progressive ACL injury prevention program would lower ACL injury risk factors on the Modified LESS was confirmed. A similar decreasing trend was observed in five of the ten categories on the Modified LESS of the experimental group.

CONCLUSION: The decrease of the Modified LESS scores occurred in the same five of the ten categories. This could be due to the auditory cues that were given while the participations were performing. The results found in the study correlated with other research.

Keywords: anterior cruciate ligament, ACL, injury, ACL injury, knee, soccer, landing, LESS

Noncontact Anterior Cruciate Ligament Injuries in Collegiate Female Soccer Players: The Effects of a Four Week Prevention Program on Landing Kinematics

In 2011, 127,000 ACL reconstructive surgeries were performed in the United States (Bates, Nesbitt, Shearn, Myer, & Hewett, 2016). ACL tears often lead to reconstructive surgery that can require up to 24 months of recovery (Otzel, Chow, & Tillman, 2015). Re-tearing the previously injured ACL as well as the tearing of the contralateral ACL post-reconstructive surgery is not an uncommon occurrence either. An injury to the ACL could be detrimental to one's athletic career. About 25% of athletes who sustain an ACL injury and undergo reconstructive surgery may never return to the level of play they were at prior to injury (Padua et al., 2015).

An athlete not only is susceptible to an ACL injury when a force comes in direct contact with the knee, but ACL injury can also occur without any contact to the knee; the latter is known as a noncontact injury. Noncontact ACL injures have two basic factors that increase injury risk for an athlete: extrinsic factors, including playing surface, shoes, weather, and other elements outside the body that can affect the knee and its movements; and intrinsic factors, including gender, anatomy, age, joint movements, and biomechanics (Garcia, 2011). Weiss & Whatman (2015) state that athletes who participate in sports that "involve stop-start movements, changes in direction, jumping and landing both with and without passing and/or shooting a ball" (p. 1326) are more at risk for a noncontact ACL injury. All elements stated by Weiss & Whatman (2015) are fundamental aspects of soccer, therefore it can be concluded that soccer players are at an increased risk of ACL injury. Several studies have discovered the most common movements in soccer that create a high risk are acts of pressing, or defending, as opposed to kicking, dribbling, or trapping the soccer ball (Kaneko, Sasaki, Hirose, Nagano, Fukano, & Fukabayashi, 2017). Exaggeration of these movements paired with extreme joint motions increase the likelihood of ACL injury.

Structure of the Knee

As the largest joint of the body, the knee connects the lower leg to the femur with a series of cartilage, bone, and ligaments (Dupler, 2011). Being a hinge joint, the knee works cohesively alongside the muscles surrounding it, moving the body in all directions (Lerner & Wilmoth, 2007c). The four ligaments of the knee joint that connect the femur to the lower leg are the medial collateral ligament (MCL), the lateral collateral ligament (LCL), the anterior cruciate ligament (ACL), and the posterior cruciate ligament (PCL). These ligaments are subject to injury in situations that require quick, explosive, or twisting motions (Lerner & Wilmoth, 2007a). In addition, the medial and lateral menisci create a surface for the knee joint to move smoothly.

The menisci. The medial and lateral menisci are the cartilage that are a part of the knee's anatomy. Anteriorly, the medial meniscus attaches to the tibial plateau by meniscal roots (Koo, Choi, Lee, & Wang, 2015). As it forms a semicircle, the medial collateral ligament (MCL) connects the middle of the medial meniscus to the femur and tibia. The posterior intercondylar fossa is the location of the other end of the meniscus (Goldblatt & Richmond, 2003). The lateral meniscus is circular in shape, covering the majority of the tibial plateau with the anterior portion in connection with the ACL. To prevent the grinding of the bones, the menisci keep the joint lubricated for easy movement as well as acting as a cushion to absorb shock (Koo et al. 2015). Both menisci have the secondary role of restraining the rotation and translation of the knee (Halewood & Amis, 2015).

The collateral ligaments. The medial collateral ligament (MCL) and the lateral collateral ligament (LCL) are located on the either side of the knee joint: the MCL on the medial side of the knee and the LCL on the lateral side (Lerner & Wilmoth, 2007a). Both collateral ligaments are tight while the knee is in flexion, indicating how the two ligaments provide stability to the knee. From 0° to 30°, the LCL is in control of the varus rotation (displacement towards the body's midline) of the knee at all angles (Halewood & Amis, 2015). When the knee is in full flexion, tibial rotation occurs because the LCL is slack (Goldblatt & Richmond, 2003).

The MCL is often referred to in two different parts: the deep MCL (dMCL) and the superficial MCL (sMCL). The sMCL is very important in knee stability as well as being the primary restraint to valgus (displacement away from the body's midline) rotation and external rotation (Goldblatt & Richmond, 2003). When the knee is in flexion, the prevention of internal and valgus rotation is the primary role of the dMCL; however, the sMCL is the most effective to preventing valgus rotation. The dMCL is not as strong as the sMCL due to smaller fibers that compromise the ligament, making it more likely to rupture (Halewood & Amis, 2015). Because of its connection to the dMCL, the medial meniscus is highly susceptible to injury when the dMCL is torn.

The cruciate ligaments. The determination of the motions of the knee is due to the insertions, lengths, and linkages of the ACL and PCL (Halewood & Amis, 2015). If either the ACL or the PCL is injured, the athlete will not be able to perform movements that require twisting and explosion (Goldblatt & Richmond, 2003).

The ACL connects the femur to the tibia providing the knee with a large source of stabilization (Lerner & Wilmoth, 2007a). This connection provides stabilization, restraining anterior translation of the tibia on the femur (Goldblatt & Richmond, 2003). If the ACL is functioning properly, the tibia should not be able to be pushed forward when the knee is in flexion. The secondary roles of the ACL include being a restraint to varus-valgus movements, internal rotation, and hyperextension (Goldblatt & Richmond, 2003).

Prevention of posterior translation of the tibia on the femur when the knee is in flexion is the primary restraint of the PCL, but this role is transferred to the MCL as the knee moves to extension (Bates & Sekiya, 2009). This means that when the knee is in flexion, if the PCL is still intact, the tibia will not be able to move backwards. The secondary role of the PCL is the assistance in the natural external rotation of the tibia as well as a restraint to varus-valgus movements. However, studies have shown that without the PCL, the LCL still acts as a restraint to these movements (Goldblatt & Richmond, 2003).

Female Susceptibility to ACL Injury

In comparison to men, women are two to five times more susceptible to ACL injuries (Padua & Marshall, 2006). Females' quadriceps and hamstrings are not as strong as a male's, contributing to the higher rate of risk, in addition to the female's anatomy revealing a smaller tissue structure of the ACL as well as a smaller intercondylar notch on which the ACL connects

(Lerner & Wilmoth, 2007a). The smaller tissue tears more easily. Biomechanically, the hips and knees of females move in such a way that increases ACL injury risk (Sakaguchi et al., 2014). Women anatomically have a wider hip structure than men do, creating a “Q” angle in which the positioning of the pelvis, femur, and knee become risk factors (“ACL injury prevention,” 2012). The “Q” angle is a result of the femur making an inward angle from the hip to the knee; therefore, the leg is no longer in a perpendicular position to the ground (Lerner& Wilmoth, 2007a). Risk of ACL injury has a direct relationship with the “Q” angle: as the angle increases, the risk of ACL injury increases. A knee that is not fully stabilized while performing motions involving cutting, change in speed, and jumping is at high risk for injury.

High school and college-aged female athletes are at the greatest risk for ACL injury (Padua & Marshall, 2006). It has been suggested that the increased susceptibility to injury at this age may be due to past training as a child. The average training level of a young girl is often lower in intensity in comparison to that of a young boys’ training. As girls progress to higher levels of competition, with its increasing demands on the body, research suggests that there is a lack of proper training for the average girl participating in soccer. Due to the inadequacy of training, the athletes’ bodies do not transition properly to the elevated intensity. The body’s reactions to quicker movements and harder landings and hits are underdeveloped, often resulting in incorrect movements of the body, particularly in the knee, thus increasing the risk of ACL injury (“ACL Injury Prevention,” 2012). An ACL injury prevention program for female athletes at this age must take into consideration this lack of training. Therefore, the program must include movements and proper instruction for accurate execution of the movements to provide further preparation to the athletes as they progress to higher levels of completion.

Risk Factors of Noncontact ACL Injuries

Kaneko et al. (2017) report that 70-84% of ACL injuries in athletes are noncontact. Noncontact injuries are very complex because several risk factors come into play when an injury occurs. These risk factors include environmental, hormonal, anatomical, genetic, biomechanical and neuromuscular factors. However, the biomechanical and neuromuscular factors are risk factors that can be manipulated in order to decrease injury risk, whereas it is not possible to change the other factors listed (Sugimoto et al., 2015). In the current study, the focus is placed upon two biomechanical/neuromuscular risk factors: the movement and reactions of the hips, and the movements and reactions of the quadriceps and the hamstrings.

The quadriceps and hamstrings. The quadriceps and hamstrings play a key role in the degree of knee flexion when landing from a jump. If the quadriceps are weak, the reduction in the knee flexion ultimately increases the likelihood of ACL rupture (Otzel et al., 2015). In the rehabilitation process after surgery, quadriceps lose strength, making it more likely for the patient or athlete to re-rupture the same ligament. Therefore, quadriceps strengthening is important when preventing initial injury as well as in rehabilitation process after ACL reconstructive surgery. In reference to the hamstrings, extreme quadriceps contraction without equivalent contraction of its counterpart, the hamstrings, puts extreme stress on the knee when landing with an extended leg (Myer et. al, 2006). This action often occurs naturally when the quadriceps are significantly stronger than the hamstrings. Injury risk increases due to the muscle fatigue causing internal rotation of the hip resulting in severe knee abduction (movement away from the body’s midline). However, even if the quadriceps and the hamstrings work together, fatigue results in a change in the movements of the hip and ankle joint, indicating another risk factor of ACL injury (Thomas, Villwock, Wojtys, & Palmieri-Smith, 2013).

The hip. In more recent studies, it has been discovered that a decreased range of motion (ROM) of the hip may also be a contributor to noncontact ACL injuries (Lopes, Gomes, & Spinelli, 2016). In general, knee adduction (movement toward the body's midline) is an indicator of ACL injury. If the ROM of the hip is limited, weight is not distributed properly on the knee, creating more stress on the joint and the ligaments associated, including the ACL, thus increasing the risk of injury. A study of male and female soccer players concluded that the range of motion of the hip of the athletes that re-tore their ACL was significantly smaller (about twenty degrees) than that of the athletes who did not re-rupture their ACL (Gomes, Humberto, & Ruthner, 2014). If the hip is constricted and has little ROM or too small of a degree of flexion, a load placed on the knee will not be properly distributed, therefore placing unnecessary stress on the tendons of the knee, escalating the injury risk (Arendt & Dick, 1995). Aside from a decreased ROM, weakness of the muscles and tendons in association with the hip joint also places an athlete at risk for injury. The hip abductor muscle influences the proximal control of the hip (Park, Kim, & Kim, 2016). If the muscle is weak, the hip compensates by internally rotating and abducting, consequently causing the knee to adduct (Sakaguchi et al., 2014). An increased adduction of the knee joint is another indication to ACL injury. Gomes et al. (2014) performed a study of healthy male soccer players with no ACL injuries or male soccer players with history of rupturing one ACL on two separate occasions. Of the subjects with history of injury, over half had experienced an ACL tear in both knees. Gomes et al. (2014) discovered that the re-occurrence of ACL injuries of the athletes with re-ruptured ligaments or contralateral tears correlates to the weakness of the muscles and tendons that are a part of the knee. With the proper training, the risk of injury can decrease.

Prevention

Measures can be taken in order to change and control the movements of an athlete's knee, to neutralize the uneven contractions of the quadriceps and hamstrings, and to minimize other risk factors. Training the quadriceps and the hamstrings together, encouraging both muscle groups to work collaboratively, will improve the possibility of injury. Strengthening these muscles using coordinating actions provides greater benefit in injury prevention than strengthening of individual muscles (Thomas, Palmieri-Smith, & McLean, 2011). As the individual moves throughout a game or practice, the previous collaborative training of the quadriceps and hamstrings endorses co-contraction, thus decreasing the risk of ACL injury. During the rehabilitation process after ACL reconstruction, isokinetic strengthening of both muscles is an effective training option (Otzel et al., 2015). Isokinetic strengthening is a form of resistance training that includes the combination of tension and speed incorporated into exercises, furthering the strength of the targeted muscles ("Isokinetic," 2003). Researchers find that isokinetic training produces positive results in injury prevention, however, the improvement is limited (Ratamess et al., 2016). Most isokinetic programs are primarily used for the general population; therefore, basic one joint movements are the focus. As the majority of sports require multiple-joint movements, isokinetic training in an ACL injury prevention program would be most effective in developing muscular control when multiple-joint exercises are used (Otzel et al, 2015). Soccer requires a wide variety of irregular movements of several different joints; for that reason, isokinetic training alone may not acknowledge all of the possible movements that can occur in competition. Benefits are still available to an athlete in this type of training, thus the combination of isokinetic and other forms of training may prove to be advantageous for injury prevention and overall athletic performance.

Myer et al. (2006) conducted a study to compare the effects of plyometric and dynamic exercises on the knees of women, observing the reaction of the knee and its flexion angle when landing from two different jumps: vertical and horizontal. The plyometric exercises used, specifically continuous jumping, are especially effective in training the knee to properly react to the force that is placed on the knee itself when landing. At the completion of the study, it was concluded that plyometric training increases the flexion angle of the knee when landing from a vertical jump but had no effect on the flexion angle of the knee during the horizontal jump. The effect of the stabilization and balance training's effect was the opposite; it did not improve the flexion angle of the vertical landing, but it did decrease the likelihood of injury to the ACL from a sideways jump (Myer et al., 2006). The study concluded that combining both plyometric and stabilization training is best in ACL injury prevention because the movements in each decrease injury risks in separate ways, when landing from vertical and from horizontal jumps, both of which are used in several sporting events (Myer et al., 2006).

In addition to plyometric and stabilization exercises, physical therapist Amado Garcia (2011) suggests 3 additional factors include in the development of ACL injury prevention programs: flexibility, agility, and strength. Flexibility, whether it be achieved by static or dynamic stretching, is important because it allows the muscles and joints to move more freely. Static stretching requires the athlete to maintain a particular position, extending a particular muscle or muscle group that will be involved in the upcoming competition, for 20 to 30 seconds

(Lerner & Wilmoth, 2007d). Dynamic stretching combines walking/jogging to increase heart rate and blood flow to the muscles and simple stretches help for around three to five seconds before returning to walking or jogging.

Balance, agility, plyometrics, and strength all have overlapping benefits and purposes when preventing injury. Research shows strength and plyometric training positively increase the abduction angle in the hip, allowing an athlete to have more control over hip and knee movements (Pollard et al., 2006). These exercises translate directly to soccer as large quantities of energy and motions are required. When playing in a soccer match, athletes use their lower bodies to move in one direction as their upper body moves in the opposite direction to deceive and shield off their opponents (Gomes et al., 2014). The athletes must be placed in situations that are game-like while training, enabling their bodies to learn the correct way to move and adjust in moments that the upper and lower body are moving in different directions.

McNair, Prapavessis, & Callener (2000) discovered the importance of proper instruction (technical, auditory, and metaphoric imagery) during an ACL injury prevention program. The purpose of different cues given to participants is to correct the joint kinematics of the participants when landing from a vertical jump. The current study implements both the technical and auditory cues, as they were the most beneficial in McNair et al.'s (2000) study. Specifically, McNair et al. (2000) compared three experimental groups, all receiving a different form of verbal instruction to improve ground reaction force, with a control group that received no instruction on their jumps. Technical instruction consisting of biomechanical prompts such as, "position yourself on the balls of your feet with bent knee just prior to landing" (p. 294), were given to the first group. The second experimental group was instructed by auditory cues.

By listening to the sound of their landing, the participants were told to use this information to create less sound when landing from future jumps. The third and final experimental group received instruction via metaphoric imagery perspective. Participants were asked to visualize "bubbles floating down toward the ground" (p. 294) or similar imagery. After the experimental groups went through the specific training assigned to them, every participant was retested. The researchers discovered that the second experimental group, those that received auditory cues, presented the greatest decrease in ground reaction force, thus indicating a decrease in risk of knee injury. The group receiving technical instruction also displayed a decrease in ground reaction force as well, however not as significant as the decrease presented by the auditory group. In the current study, when participants were performing vertical jumps throughout the program, technical instruction used by McNair et al. (2000), such as, "position yourself on the balls of your feet with bent knee just prior to landing" (p. 294), as well as auditory cues, including instruction to listen to the volume of their landings, was used.

Materials and Methods

Participants

A sample of 10 female soccer players from a small Christian university in the Midwest participated in this study. Each participant signed a written informed consent, approved by the university's Institutional Review Board before testing. The inclusion criteria of the study required that the participants were part of the women's varsity soccer team during the fall 2016 season, were currently participating in the team's offseason training, and had no prior ACL injury.

Materials

Red, green, and blue TheraBands ™ of increasing resistance were used in the prevention program. They were cut and tied into loops with the circumference of approximately 60 centimeters. These loops were placed around the legs, proximal to the patella, as the participants performed 3 exercises (Duck Walks, Bridges, and Clams) throughout each progression of the program in order to provide resistance to strengthen the muscles that were being activated during the exercise.

Yes4All ™ balance pads were used when performing the sport specific exercise as well as a cushion for other exercises in order to prevent sliding on the carpet of the room in which the program was held. In the first progression, the participants began by jumping with two feet laterally onto the balance pad and landing with one foot. The second progression moved onto the participant balancing on one foot on the pad, as a soccer ball was tossed to participants, which they would volley back towards the thrower with the free foot. Finally, both exercises of the first and second were combined in the third progression: starting on both feet, jumping laterally and landing on one foot, immediately progressing to volleying the soccer ball with the free foot. When performing the Russian hamstrings in all three progressions, participants placed the balance pads underneath their knees in order to minimize the sliding of their knees on the carpet, possibly resulting in “rug burns” on their knees. Participants also placed their forearms on top of the balance pad when performing planks for similar reasons.

Procedure

In the current study, the goal of the 4 week ACL injury prevention program was to improve the participants’ landing kinematics, resulting in a decrease in the scores of the Modified Landing Error Scoring System (LESS). An established ACL injury prevention program was not used in this study. However, a compilation of neuromuscular exercises and strengthening exercises are included in the progressive four-week program as displayed in Tables 1A, 2A, 3A. A program consisting of a variety of exercises produces a greater reduction in injury risk (Nessler et al., 2017). Each session occurred after the participants had taken part in their off-season training for the soccer program in order to ensure the muscles were fatigued for each of the sessions. As fatigued muscles increase the risk of ACL injury, training the participants in a safe environment when their muscles are in this state encourages the improvement of muscular strength and endurance, consequently decreasing injury risk (Thomas et al., 2013). To ensure a safe, minimal risk environment for the participants, high intensity and dynamic exercises are performed first during each session, encouraging endurance and strength development as well as fatiguing the muscles even more to provide a challenge when performing the stabilization and strengthening exercises. The sessions concluded with stabilizing and strengthening exercises, challenging the muscles to activate in a less demanding environment than that of a plyometric exercise.

Overall improvement of landing kinematics is the primary goal of this study. To elicit positive results in landing, teaching the muscles associated to the knees, hips, and core to react properly when landing from a jump is key. The program used in the current study consists of plyometric, stabilization, and strengthening exercises, each with the objective of training the body to land properly. The program includes nine exercises, progressing from high intensity jumping plyometric exercises to lower intensity stability and strengthening exercises. Over four weeks, three overall progressions occurred, beginning with simple exercises and advancing into more complex versions or increasing resistance of the exercises as the participants became acclimated and accomplished with the easier exercises. Each progression was performed in three separate sessions before the participants moved onto the next progression, adding up to a total of twelve sessions performed over the course of four weeks. The program was designed to last no longer than one hour each session. After performing a 10-minute warm-up, including a combination of dynamic stretches and static stretches, the participants began the program. A demonstration of each exercise was given to the participants directly before being asked to perform it. Technical and auditory cues were given to each participant before, during, and after every exercise in order to ensure proper execution.

Alongside proper instruction, the selection of exercises to implement in an ACL injury prevention program is crucial. The current study implements the use of stability and plyometric exercises based upon the discoveries made by Myer et al. (2006). A comparison of the effects of two single-component injury prevention programs, plyometric versus balance training, on the landing kinematics of female athletes was performed by Myer et al. (2006). Aside from the primary goal of differentiating the effects of a plyometric program versus a balance program on injury risk, the secondary goal of the study was to properly instruct and teach the female athletes on the correct and most safe way to land from a jump. As plyometric and stabilization exercises are very different, different forms of instruction and cues are needed to ensure proper execution. The teaching strategies varied between the two groups: the balance group received feedback while performing a particular task. By doing so, participants were able to make adjustments immediately, whereas feedback given to participants in the plyometric program was after an exercise was performed. Due to the high-paced nature of plyometric exercises, this was the best time to give instruction to the participants in order to help them make a conducive response. Several of the exercises used by Myer et al. (2006), stabilizing and plyometric, were used in the current study as they were shown to be successful in decreasing injury.

As ACL injuries have become more prevalent in recent years, several injury prevention programs have been created in order to maximize the reduction of injuries. The current study does not use an established ACL injury prevention program; therefore, several existing ACL injury prevention programs were studied to generate the best results. The discoveries from a review of ACL injury prevention programs conducted by Alentorn-Geli et al. (2009) were implemented in the current study. The purpose of Alentorn-Geli et al.'s study (2009) was to determine what techniques were more effective than others when preventing noncontact ACL injuries. Alentorn-Geli et al. (2009) drew three conclusion from their review. First, not one specific program that is established and standardized works for all soccer players in order to reduce noncontact ACL injuries. Second, when comparing the results of programs that consist of multiple exercise components versus the programs consisting of a single component, the researchers discovered that the studies assessing multi-component programs elicit a more significant decrease in noncontact ACL injury susceptibility. Multi-component programs consist of several different forms of exercises (i.e. plyometrics, agility, strengthening, etc.), as opposed to a single component program that focuses on one particular type of exercise. Finally, Alentorn-Geli et al. (2009) concluded that the majority of noncontact ACL injury prevention programs have a duration of six to eight weeks, resulting in a decrease of injury risk. Due to these findings, the program created for the current study consists of multiple components: plyometric, strengthening, and stabilization exercises. However, as most programs last six or more weeks, the current study aims to observe the effects of a multi-component program in a shorter time period of four weeks.

In the current study, the analysis of the level of risk when landing from a vertical jump was performed using the modified Landing Error Scoring System (LESS). Participants' landings from a vertical jump off of a surface twelve inches above the ground were analyzed using the modified LESS. The jump was performed a minimum of four times following instruction and a practice trial, thus enabling the researcher to view the participants' landing kinematics from the front and the side of the participant.

Results

Assessment of the vertical jumps occurred prior to participation in the ACL injury prevention program and after the program concluded. Out of the 15 possible points attainable when using the modified LESS, the average score of the three participants of the experimental group prior to participation in the prevention program was 7.25. This is a 48.33% risk factor for ACL injury. Of the control group, the average LESS score was slightly lower, at 6.33, resulting in a risk factor incidence of 42.2%. After participation in the four-week ACL injury prevention program, the average LESS score for the experimental group decreased drastically by 38.33%, as the average score was 1.5 on the modified LESS, with a 10% risk factor incidence. A slight variation was observed in the data between the pre- and post-testing LESS scores of the control group, the post-testing average score being 6.25 and a 41.67%. Comparison of average LESS scores of both groups are demonstrated in *Figure 1*.

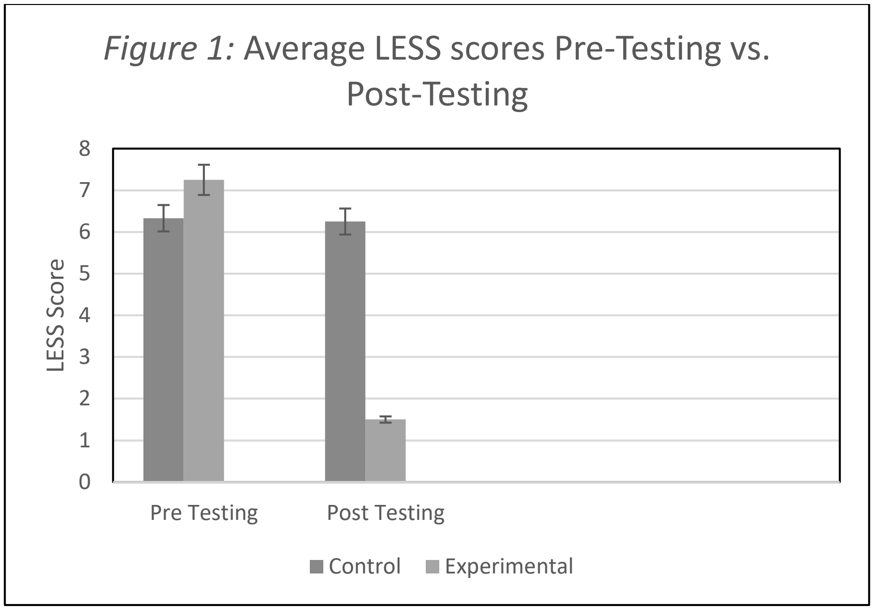

Figure 1. Comparison of average Modified LESS scores of the control and experimental groups before and after implementation of ACL injury prevention.

Discussion

The primary finding of this study was that a progressive, multi-faceted ACL injury prevention program implemented over four weeks decreases several ACL injury risk factors based upon the Modified LESS. A key factor contributing to the decreased injury risk is the instruction given to the participants throughout the program. Exercises were explained and demonstrated to the participants before execution. The current study used the same auditory cues as McNair et al. (2000), by instructing the participants to listen to their landings in order to guide them to land more softly in the following jumps. Technical cues were also used in the current study, however, however not as thorough as those used by McNair et al. (2000). In congruence with the research of McNair et. al (2000), an overall decrease in the risk of ACL injury was seen in the subjects in the experimental group, as they were given instruction while performing the exercises. A trend seen between the three participants of the experimental group reveals a reduction in score of the same five categories: “stance width,” “amount of lateral trunk flexion,” “amount of knee-flexion displacement,” “total displacement in the sagittal plane,” and “overall impression.” These results correlate positively with the technical cues that were given throughout the program as the participants were instructed before and during each exercise throughout the four-week program.

Myer et al. (2006) conducted a study comparing the results of two different single-component programs: plyometric versus balance. The current study included similar exercises in both the plyometric and balance programs that Myer et al. (2006) studied, resulting in similar results between the two studies. In congruence to the results found by Myer et al. (2006), an increase in knee flexion was displayed after the participants completed the prevention programs in both studies. Myer et al. (2006) discovered that the implementation of a plyometric program elicits such results. Therefore, it can be concluded that the increase in the amount of knee-flexion displacement observed in the current study resulted from the implementation of the several plyometric exercises in the program. The improvements of lower extremity valgus in both the hip and the ankle observed by Myer et al. (2006) in both the plyometric and balance programs correlated with the results seen in the current study. However, the current study did not include resistance training. This factor could have impacted the comparison of the results.

The ACL injury prevention programs analyzed in the literature review of Alentorn-Geli et al. (2009), present decreases in the athlete’s risk of ACL injury due to improved coactivation of muscles; increased strength and stability of the knee and hip; reduced valgus, varus, internal rotation, and adduction of the knee and hip. The current study includes a program lasting 4 weeks, with the hypothesis that a decrease in ACL injury risk factors would still be observed. Improvement was observed in the participants' Modified LESS scores in the current study, specifically in knee flexion when landing from a jump. Of the studies focusing on improvement on landing biomechanics by implementing programs including plyometric, stabilization, and strengthening exercises reviewed by Alentorn-Geli et al. (2009), similar results were observed. However, it is important to note that the Modified LESS was not the primary analyzation tool used in each of these studies. In comparison, the studies reviewed by Alentorn-Geli (2009) lasted 6 to 9 weeks as opposed to the 4-week implementation of the prevention program of the current study. Therefore, it can be concluded that ACL injury risk associated with landing biomechanics can be reduced in 4 weeks.

The limitations of this study include the number of participants. Although five participants began the program in the experimental group, two dropped out due to not having the time to participate in the program three times a week for one hour. This may have limited my ability to observe accurate results in the Modified LESS scores of the participants. Because of the size of the experimental group, I suggest replicating this study with more participants. Due to the limited time frame of which the participants were evaluated for risk, as well as the participants being in the much less rigorous off-season, there was a 0% incidence of ACL injury observed. In comparison, most studies of the ACL injury prevention programs, ACL injuries are often observed while the study is undergoing. Confirmation bias may have impacted the results as well, due to the researcher not being blinded as to which participants participated in the injury prevention program and those who did not.

I suggest that this study be replicated while the participants are in-season as opposed to being in the off-season in order to determine if the 0% incidence of ACL injury found in this study was due to the diminished stress of the off-season.. As no studies were found to be limited to a four-week prevention program, conducting studies with different variables over a four-week time span is suggested. The variables can include separate programs that consists of a single exercise component (plyometric, stabilizing, strengthening) in order to observe which constituent is most effective at reducing the Modified LESS score. The women's varsity soccer team at the university where the study was conducted does not participate in resistance training while in season nor in their off season. Therefore, we recommend comparing the athletes from this team to another university's soccer team who participates in resistance training to compare the effects of resistance training paired with an ACL injury prevention program.

References

ACL injury prevention in the female athlete: 3-step warm-up program. (2012). *Performance Conditioning Soccer, 17*(1), 12-13.

Alentorn-Geli, E., Myer, G. D., Silvers, H. J., Samitier, G., Romero, D., Lázaro-Haro, C., & Cugat, R. (2009). Prevention of non-contact anterior cruciate ligament injuries in soccer players. Part 2: A review of prevention programs aimed to modify risk factors and to reduce injury rates. *Knee Surgery, Sports Traumatology, Arthroscopy*, *17*(8), 859–879. doi: 10.1007/s00167-009-0823-z

Arendt, E., & Dick, R. (1995). Knee injury patterns among men and women in collegiate basketball and soccer NCAA data and review of literature. *The American Journal of Sports Medicine*, *23*(6), 694–701. https://doi.org/10.1177/036354659502300611

Bates, N. A., Nesbitt, R. J., Shearn, J. T., Myer, G. D., & Hewett, T. E. (2016). Sex-based differences in knee ligament biomechanics during robotically stimulated athletic tasks. *Journal of Biomechanics, 49*(9), 1429-1436. https://doi.org/10.1016/j.jbiomech.2016.03.001

Bowman, K. F. Jr., & Sekiya, J. K. (2009). Anatomy and biomechanics of the posterior cruciate ligament and other ligaments of the knee. *Operative Techniques in Sports Medicine*, *17*(3), 126-134. https://doi.org/10.1053/j.otsm.2009.07.001

Dupler, D. (2011). Knee injuries. In J. L. Longe (Ed.), *The Gale encyclopedia of children's health*: *infancy through adolescence* (2nd ed.) (pp. 1288-1291). Detroit, MI: Gale.

Garcia, A. (2011). Designing an ACL injury prevention program. *Rehab Management: The Interdisciplinary Journal of Rehabilitation, 24*(9), 24-26.

Goldblatt, J. P., & Richmond, J. C. (2003). Anatomy and biomechanics of the knee. *Operative Techniques in Sports Medicine*, *11*(3), 172-186.

Gomes, J., Humberto, M., & Ruthner, R. (2014). Influence of hip restriction on noncontact ACL re-rupture. *Knee Surgery Sports Traumatol Arthroscopy,* 22, 188-190. https://doi.org/10.1007/s00167-012-2348-0

Halewood, C. & Amis, A. A. (2015). Clinically relevant biomechanics of the knee capsule and ligaments. *Knee Surgery, Sports Traumatology, Arthroscopy*, *23*(10), 2789-2796. https://doi.org/10.1007/s00167-015-3594-8

Isokinetic. (2003). *Miller-Keane encyclopedia and dictionary of medicine, nursing, and allied health*. Retrieved from https://medical-dictionary.thefreedictionary.com/

Kaneko, S., Sasaki, S., Hirose, N., Nagano, Y., Fukano, M., & Fukabayashi, T. (2017). Mechanism of anterior cruciate ligament injury in female soccer players. *Asian Journal of Sports Medicine, 8*(1), 1-6. https://doi.org/10.5812/asjsm.38205

Koo, J. H., Choi, S. H., Lee, S. A., & Wang, J. H. (2015). Comparison of medial and lateral meniscus root tears. *PLoS ONE, 10*(10), 1-9. https://doi.org/10.1371/journal.pone.0141021

Lerner, E. K. L., & Wilmoth, B. L. (Eds.). (2007a). ACL injury and female athletes. *World of sports science* (pp. 10-12). Detroit, MI: Gale

Lerner, E. K. L., & Wilmoth, B. L. (Eds.). (2007b). Knee: Anatomy and physiology. *World of sports science* (pp. 428-430). Detroit, MI: Gale

Lerner, E. K. L., & Wilmoth, B. L. (Eds.). (2007c). Knee injuries. *World of sports science* (pp. 432-434). Detroit, MI: Gale

Lerner, E. K. L., & Wilmoth, B. L. (Eds.). (2007d). Warm-up/cool-down. *World of Sports Science* (pp. 767-768). Detroit, MI: Gale

Lopes, O. Jr., Gomes, J., & Spinelli, L. (2016). Range of motion and radiographic analysis of the hip in patients with contact and non-contact anterior cruciate ligament injury. *Knee Surgery, Sports Traumatology, Arthroscopy*, *24*, 2868-2873. https://doi.org/10.1007/s00167-015-3532-9

McNair, P., Prapavessis, H., & Callener, K. (2000). Decreasing landing forces: effect of instruction. *British Journal of Sports Medicine, 34*(4), 293-296. https://doi.org/10.1136/bjsm.34.4.293

Myer, G.D., Ford, K. R., McLean, S.G., & Hewett, T.E. (2006). The effects of plyometric versus dynamic stabilization and balance training on lower extremity biomechanics. *American Journal of Sports Medicine 34*(3), 450-455. https://doi.org/10.1177/0363546505281241

Otzel, D. M., Chow, J. W., & Tillman, M. D. (2015). Long-term deficits in quadriceps strength and activation following anterior cruciate ligament reconstruction. *Physical Therapy in Sport*, *16*(1), 22–28. https://doi.org/10.1016/j.ptsp.2014.02.003

Padua, D. A. & Marshall, S. W. (2006). Evidence supporting ACL-injury-prevention exercise programs: a review of the literature. *Athletic Therapy Today*, *11*(2), 11-72. https://doi.org/10.1123/att.11.2.11

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 (Allen Press)*, *50*(6), 589–595. https://doi.org/10.4085/1062-6050-50.1.10

Park, S.J., Kim, Y.M., & Kim, H.R. (2016). The effect of hip joint muscle exercise on muscle strength and balance in the knee joint after meniscal injury. *Journal of Physical Therapy Science*, *28*(4), 1245-1249. https://doi.org/10.1589/jpts.27.1245

Pollard, C. D., Sigward, S. M., Ota, S., Lanford, K., & Powers, C. M. (2006). The influence of in-season injury prevention training on lower-extremity kinematics during landing in female soccer players. *Clinical Journal of Sport Medicine*, *16*(3), 223-227. https://doi.org/10.1097/00042752-200605000-00006

Ratamass, N. A., Beller, N. A., Gonzalez, A. M., Spatz, G. E., Hoffman, J. R., Ross, R. E., Faigenbaum, A. D., & Kang, J. (2016). The effects of multiple-joint isokinetic resistance training on maximal isokinetic and dynamic muscle strength and local muscular endurance. *Journal of Sports Science and Medicine, 15*(1), 34-40.

Sakaguchi, M., Ogawa, H., Shimizu, N., Kanehisa, H., Yanai, T., & Kawakami, Y. (2014). Gender differences in hip and ankle joint kinematics on knee abduction during running. *European Journal of Sport Science, 14*, S302-309. https://doi.org/10.1080/17461391.2012.693953

Sugimoto, D., Alentorn-Geli, E., Mendiguchía, J., Samuelsson, K., Karlsson, J., & Myer, G. (2015). Biomechanical and neuromuscular characteristics of male athletes: Implications for the development of anterior cruciate ligament injury prevention programs. *Sports Medicine*, *45*(6), 809–822. https://doi.org/10.1007/s40279-015-0311-1

Thomas, A. C., Palmieri-Smith, R. M., & McLean, S. G. (2011). Isolated hip and ankle fatigue are unlikely risk factors for anterior cruciate ligament injury. *Scandinavian Journal of*

Medicine and Science in Sport, 21, 359-368. https://doi.org/10.1111/j.1600-0838.2009.01076.x

Thomas, A.C., Villwock, M., Wojtys, E.M., & Palmieri-Smith, R.M. (2013). Lower extremity muscle strength after anterior cruciate ligament injury and reconstruction. *Journal of Athletic Training*, *48*(5), 610-620. https://doi.org/10.4085/1062-6050-48.2.14

Weiss, K., & Whatman, C. (2015). Biomechanics associated with patellofemoral pain and ACL injuries in sports. *Sports Medicine*, *45*(9), 1325-1337. https://doi.org/10.1007/s40279-015-0353-4

Appendix A: Tables

Table 1

Protocol for Experimental Group: Progression 1

Exercise	Sets	Reps	Time, s
Ankle jumps	3		10
Lateral jumps	3		10
Lunges	3	10 (each leg)	
Duck walks with TB (R)	2	15 yards	
Jump to SL balance on foam pad	3	10 (each leg)	
Bridges	3	20	
Clams with TB (R)	3	10 (each leg)	
Russian hamstrings	3	10	
Planks	3		45

Note. Reps = repetitions; TB = TheraBand; (R) = red; s = seconds.

Table 2

Protocol for Experimental Group: Progression 2

Exercises	Sets	Reps	Time, s
Ankle jumps to squats	3	10 (squats)	20 (ankle jumps)
Lateral jumps	3		20
Switch jumps	3		20
Duck walks with TB (G)	2	15 yards	
SL balance and volley on foam pad	3	10 (each leg)	
Bridges with TB (R)	3	20	
Clams with TB (G)	3	10 (each leg)	
Russian Hamstrings	3	15	
Planks	3		45

Note. Reps = repetitions; TB = TheraBand; (R) = red; (G) = green; SL = single leg; s = seconds

Table 3

Protocol for Experimental Group: Progression 3

Exercise	Sets	Reps	Time, s
Ankle jumps to squat jumps	3		40, 20 each
Lateral jumps	3		30
Prisoner switch jumps	3		30
Duck walks with TB (B)	2	15 yards	
Jump to SL balance with volley on foam pad	3	10 (each leg)	
SL bridge	3	10	
Clams with TB (B)	3	10 (each leg)	
Russian hamstrings	3	20	
Planks	3		75

Note. Reps = repetitions; TB = TheraBand;(B) = blue; SL = single leg; s = seconds.