Spring 2010

The Effects of an Anterior Cruciate Ligament Prevention Program and Retention Period on Lower Extremity Biomechanics

Ryan S. McCann
Old Dominion University

THE EFFECTS OF AN ANTERIOR CRUCIATE LIGAMENT PREVENTION PROGRAM AND RETENTION PERIOD ON LOWER EXTREMITY BIOMECHANICS

By

Ryan S. McCann, ATC
B.S. May 2008, Northern Kentucky University

A Thesis Submitted to the faculty of
Old Dominion University in Partial Fulfillment of the
Requirement for the Degree of

MASTER OF SCIENCE IN EDUCATION

ATHLETIC TRAINING

OLD DOMINION UNIVERSITY
May 2010

Approved by:

James Oñate (Co-Director)

Bonnie Van Lunen (Co-Director)

Stacie Ringleb (member)

ABSTRACT

THE EFFECTS OF AN ANTERIOR CRUCIATE LIGAMENT PREVENTION PROGRAM AND RETENTION PERIOD ON LOWER EXTREMITY BIOMECHANICS

Ryan S. McCann
Old Dominion University
Co-Directors: Drs. James A. Oñate, Bonnie Van Lunen

Researchers have attempted to determine the effects of strength, flexibility, agility, and plyometric training, as well as expert feedback on biomechanical risk factors for anterior cruciate ligament (ACL) injuries. Currently, the literature lacks information regarding athletes' ability to retain adaptations made during programs designed to reduce biomechanical risk factors for ACL injuries. The purpose of this study was to determine the effects of a 10-week strength and agility program on lower extremity kinetics and kinematics of collegiate athletes immediately following training and after a 11-week retention period. Ten NCAA Division I female soccer players free of lower extremity injury, volunteered to participate in the study. Subjects performed a running stop-jump task at pre-training, after 10-weeks of training (post-training), and after an 11-week retention time from post-training to assess lower extremity biomechanics. The 10-week training program consisted of resistance training two times per week and field training, consisting of plyometric, agility, and speed drills, two times per week. A Certified Strength and Conditioning Specialist provided constant augmented feedback throughout the training. Kinematic and kinetic data were collected during 5 trials of a running-stop task. This study assessed lower extremity kinematic and kinetics at pre-training, post-training and retention during a running stop-jump task. Separate repeated measures

ANOVA was performed to assess differences between testing times (pre, post, and retention). Statistical significance was set *a priori* at $p<0.05$. Participants presented a change from an abduction/valgus knee position at pre-test (-2.2±9.3°) to an adduction/varus knee position at post-test (0.9±4.0°) at initial contact ($F_{2, 18}=4.182$, $p=.014$, d=0.33). No differences were observed for pre to retention (-1.1±3.6°) or post to retention in knee abduction/valgus, $p>0.05$. There were no other statistical differences at any time instance for any dependent measure. The primary finding of this study was that the intervention program positively affected frontal plane knee alignment at initial contact during the running stop-jump. Our current study found an improvement in a theorized biomechanical risk factor for ACL injuries at a time in which the injuries are most likely to occur. There was no retention effect in any variable.

I would like to dedicate this to all of those who have helped me on a personal and/or professional level to this point. There are too many to name, but you know who you are.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Anterior cruciate ligament (ACL) injuries arising from a non-contact mechanism are of continuing prevalence in athletics (Hootman, Dick, & Agel, 2007; Miyasaka, Daniel, Stone, & Hirshman, 1991; Renstrom, et al., 2008). According to Hootman et al., over 2000 ACL injuries occur every year, with a 1.3% annual increase in 15 select NCAA sports (Hootman, et al., 2007). Of these, approximately 70% are due to a non-contact mechanism (Agel, Arendt, & Bershadsky, 2005). Non-contact ACL injuries are 4-8 times more likely to occur in female athletes when compared to males of the same sport (Adams, 1971; Agel, et al., 2005; Amis & Dawkins, 1991; Duthon, et al., 2006; Herman, et al., 2009). Extensive research has been done on ACL injuries in order to identify those athletes most at risk. Numerous extrinsic and intrinsic risk factors for ACL injuries have been identified throughout the literature (Adams, 1971; Chappell, Yu, Kirkendall, & Garrett, 2002; Cowling, Steele, & McNair, 2003; Fayad, Parellada, Parker, & Schweitzer, 2003; Hogervorst & Brand, 1998; Hootman, et al., 2007; Irmischer, et al., 2004; Kaplan, et al., 1992; Kennedy, Alexander, & Hayes, 1982; Krosshaug, Slauterbeck, Engebretsen, & Bahr, 2007; LaPrade & Burnett, 1994; Lephart, et al., 2005; MacDonald, Hedden, Pacin, & Sutherland, 1996). These risk factors can range from anatomical, environmental, hormonal and neuromechanical.

Several possible neuromechanical risk factors have been identified in the literature, including decreased sagittal hip and knee motion as well as increased frontal and transverse hip and knee motion during athletic tasks (Chappell, et al., 2002; Cortes, et al., 2007; Ford, Myer, Toms, & Hewett, 2005; Hewett, et al., 2005; Malinzak, Colby, Kirkendall, Yu, & Garrett, 2001; McLean, Walker, & van den Bogert, 2005; McNair, Prapavessis, & Callender, 2000; Olsen, Myklebust, Engebretsen, & Bahr, 2004; Shimokochi & Shultz, 2008; Yu, et al., 2005). Despite some controversy within the literature over the significance of specific biomechanical risk factors (Hewett, Myer, & Ford, 2006), most authors are in agreement that non-contact ACL injuries occur due to multi-plane motion at the hip and knee while decelerating the body's forces during athletic tasks (Hewett, et al., 2005; Hughes & Watkins, 2006). Greater tension is placed on the ACL as the knee moves under 45° of flexion, while the maximum tension occurs in hyperextension (Markolf, Gorek, Kabo, & Shapiro, 1990; Senter & Hame, 2006). In addition, more stress is placed on the ACL with increased anterior tibial shear from forced knee extension and tibial torque resulting from knee valgus and internal/external tibial rotation (Markolf, Burchfield, & Shapiro, 1995; Senter & Hame, 2006). During dynamic tasks, proper counter-force generated by the musculature, also known as internal moment, is necessary to avoid potentially harmful positions (Senter & Hame, 2006).

Demand for healthy, highly-trained athletes continues to grow with the competitive nature of today's athletics. Education and specific training of high-risk athletes is necessary for prevention of ACL injuries (Boden, Dean, Feagin, & Garrett, 2000; Chappell & Limpisvasti, 2008). In order to be successful, ACL injury prevention programs must consider the mechanism of a non-contact ACL injury, emphasizing dynamic postural control in all three cardinal planes across the lower extremity (Quatman & Hewett, 2009). Many authors have found positive effects of lower extremity training programs on the theorized neuromechanical risk factors for ACL ruptures (Chappell &

Limpisvasti, 2008; Cowley, Ford, Myer, Kernozek, & Hewett, 2006; Herman, et al., 2008; Hewett, Lindenfeld, Riccobene, & Noyes, 1999; Hewett, Stroupe, Nance, & Noyes, 1996; Irmischer, et al., 2004; Lephart, et al., 2005; Myer, Ford, McLean, & Hewett, 2006; Newell, 1974; Olsen, Myklebust, Engebretsen, Holme, & Bahr, 2005; Wilkerson, et al., 2004). Despite the positive effects of these training programs the injury occurrence remained steady over the past decade (Adams, 1971; Agel, et al., 2005), as did the female-to-male injury ratio (Mountcastle, Posner, Kragh, & Taylor, 2007). This may be due to a low rate of utilization of such programs. These prevention programs have incorporated various combinations of muscular strength, flexibility, plyometric, proprioception, and agility training.

In addition, augmented feedback has been shown to be an affective means of improving lower extremity biomechanics during athletic tasks (Cowling, et al., 2003; McNair, et al., 2000; Onate, et al., 2005). Onate et al. found lasting effects of augmented feedback on jump-landing kinetics and kinematics one week after an augmented training session (Onate, et al., 2005). Currently the literature lacks information regarding the ability of athletes to retain adaptations made during programs intended to alter biomechanical risk factors for ACL injuries.

Detraining arises from the reduction or cessation of specific training (Arendt & Dick, 1995; Grood & Suntay, 1983; Hass, et al., 2003). In response, specific adaptations brought on by training are reduced or returned to a normal state of conditioning seen prior to training. Detraining effects have been demonstrated in many studies of muscular strength and endurance as well as cardiovascular endurance, and often these effects are analyzed in middle-aged or elderly populations. Research has demonstrated potential for prevention of ACL injuries through the correction of weak neuromechanics. Various combinations of intervention programs should be tested on a multitude of populations in order to optimize effects. Currently more research is needed regarding detraining effects on biomechanical risk factors of ACL injuries in highly-trained collegiate athletes following ACL prevention programs.

Statement of the Problem

The purpose of this study was to analyze lower extremity kinetics and kinematics in NCAA Division I female soccer players following a ten week neuromuscular training program and an eleven week retention period.

Research Hypotheses

- Research Question: Will there be an overall effect of the three time periods (pre-training, post-training, and retention) on lower extremity kinetics and kinematics during a running stop-jump task?
- Research Hypothesis: Lower extremity kinetics and kinematics will significantly improve over three time periods (pre-training, post-training, and retention) for the running stop-jump. Expected changes include increased knee flexion angle, hip flexion angle, and hip abduction angle, as well as decreased knee valgus angle, knee extension moment, knee adduction moment, hip extension moment, hip adduction moment, vertical ground reaction forces, and posterior ground reaction forces.

- Null Hypothesis: There will be no difference in lower extremity kinetics and kinematics over three time periods (pre-training, post-training, and retention) for the running stop-jump.

Independent Variable

The lone independent variable (within subjects factor) is time, which has three levels (pre-training, post-training, and retention).

Dependent Variables

The dependent variables consisted of kinetic and kinematic measures. The kinematic variables were hip flexion, hip abduction, knee flexion, and knee valgus angles. All kinematic data were measured in degrees (°). The kinetic variables were vertical ground reaction force (VGRF) and posterior ground reaction force (PGRF), knee extension moment, knee valgus moment, hip abduction moment, and hip flexion moment. The kinematic and kinetic variables were measured at initial contact (IC), peak stance, peak PGRF, and peak VGRF. All ground reaction forces were measured in multiples of bodyweight (mBw), and joint moments were normalized to mass and height ($Nm.kg^{-1}.m^{-1}$).

Operational Definitions

- *Running Stop-Jump Task*: The running stop-jump task consisted of subjects running approximately 7-8 m in a forward direction as fast as they could, with a minimum speed of 3.5 meters per second, and then planting both feet onto the forceplates with one foot completely on each plate. This was immediately followed by a jump for maximum height. (Chappell, et al., 2002; Herman, et al., 2008; Yu, et al., 2005)

- *Peak Vertical Ground Reaction Force:* Peak vertical ground reaction force is the greatest vertical force recorded by the forceplates during the running stop-jump task. The force was measured in Newtons and converted to multiples of bodyweight.
- *Peak Posterior Ground Reaction Force:* Peak posterior ground reaction force is the greatest posterior force recorded by the forceplates during the running stop-jump task. The force was measured in Newtons and converted to multiples of bodyweight.
- *Knee Flexion Angle:* Knee flexion angle is the angle formed by sagittal plane motion at the tibiofemoral joint. It was taken at its maximum measure and peak vertical ground reaction force during the running stop-jump task.
- *Knee Valgus Angle:* Knee valgus angle is the angle formed by frontal plane motion at the tibiofemoral joint. It was taken at its maximum measure, peak vertical ground reaction force, and maximum knee flexion angle during the running stop-jump task.
- *Hip Flexion Angle:* Hip flexion angle is the angle formed by sagittal plane motion at the coxofemoral joint. It was taken at its maximum measure, peak vertical ground reaction force, and maximum knee flexion angle during the running stop-jump task.

- *Hip Abduction Angle:* Hip abduction angle is the angle formed by frontal plane motion at the coxofemoral joint. It was taken at its maximum measure, peak vertical ground reaction force, and maximum knee flexion angle during the running stop-jump task.
- *Knee Flexion Moment:* Knee flexion moment is the internal torque in a sagittal plane motion at the tibiofemoral joint. It was taken at it maximum measure during the running stop-jump task.
- *Knee Valgus Moment:* Knee valgus moment is the internal torque in a frontal plane motion at the tibiofemoral joint. It was taken at it maximum measure during the running stop-jump task.
- *Hip Flexion Moment:* Hip flexion moment is the internal torque in a sagittal plane motion at the coxofemoral joint. It was taken at it maximum measure during the running stop-jump task.
- *Hip Abduction Moment:* Hip abduction moment is the internal torque in a frontal plane motion at the coxofemoral joint. It was taken at it maximum measure during the running stop-jump task.
- *Intervention Program*: Following the pre-training session, the subjects underwent a ten-week instructional lower extremity strength and agility program coinciding with their spring soccer off-season. The resistance-training and field-conditioning portions of the program each consisted of two sessions per week. All subjects were placed into one of three resistance-training groups: strength (STR), maintenance (MNT), or endurance (END), which dictated the volume and intensity of the resistance training. The amount of weight utilized for each

exercise was self-selected by each individual participant. During the field-conditioning portion, all subjects participated in the same drills, regardless of group assignment. Each week the first sessions focused on speed and quickness, while the second sessions focused on plyometric and agility drills. A Certified Strength and Conditioning Specialist (CSCS) performed visual demonstrations of each exercise and gave verbalized cues for proper performance. During all testing sessions, the CSCS continued to give verbal and visual augmented feedback to the subjects in regards to their coordination patterns and body positioning.

- *Retention Period*: Eleven weeks after the post-test subjects began the retention testing. In the eleven weeks subjects were active in their personal offseason/summer workouts. In this time, no formal athletic instruction was given. The same procedures utilized during pre- and post-training measures were used for the retention testing. This period concluded one week before the onset of the subjects' fall pre-season

Assumptions

- The equipment used for the assessment is both valid and reliable.
- All subjects properly meet all inclusionary criteria
- The results from the post-testing and retention testing are from the intervention program and detraining, respectively, and not from any other external factor.
- There was minimal practice effect from the subjects' previous testing sessions.

Limitations

- Subjects were not randomly selected due to availability.
- The sample size did not fall within the estimated range determined by the power analysis.
- The subjects' self-selected workouts from the end of the spring season until the retention testing were not documented.
- Subjects were split into three different strength groups, which completed different resistance training protocols.
- No strength tests were utilized to determine changes in muscular strength throughout the study.
- Subjects were not screened to determine if they were at greater risk for non-contact ACL injuries prior to the onset of the study.

Delimitations

- Subjects in this study consisted of only NCAA Division I female soccer players having no previous history of cardiovascular or respiratory disease and no operable lower-limb-joint injury that would prevent them from taking part in the running stop-jump task

CHAPTER II

REVIEW OF LITERATURE

Epidemiology of ACL Injuries

Each year in the United States approximately one out of every 3000 people rupture their anterior cruciate ligament (ACL) (Miyasaka, et al., 1991), which equates to approximately 95,000 new cases per year. Of the 95,000 ruptures, over 50,000 undergo reconstructive surgery (Frank & Jackson, 1997; Miyasaka, et al., 1991). In all NCAA sports, over 2000 ACL injuries occur every year with a 1.3% annual increase in 15 of the most common sports (Hootman, et al., 2007).

Reconstructive surgery is often the treatment chosen by those who have ruptured the ACL, especially in patients wanting to return to the activity that resulted in injury. Myklebust and Bahr (Myklebust & Bahr, 2005) found re-rupture rates to be anywhere from 2.3-13% after reconstruction, depending on the specific activity following surgery. Even if the reconstructed ligament remains in tact, there is debate whether an athlete's knee can return to pre-injury functionality following ACL reconstruction, especially in terms of proprioceptive capabilities (Bonfim, Jansen Paccola, & Barela, 2003; MacDonald, et al., 1996). Despite having reconstruction and rehabilitation of the ligament, chronic orthopedic conditions of the knee can still occur. Patients are at an elevated risk for developing osteoarthritis later in life (Fleming, Hulstyn, Oksendahl, & Fadale, 2005; Gelber, et al., 2000; von Porat, Roos, & Roos, 2004). Specific training and education is necessary to prevent acute trauma as well as the long-term effects that can follow (Fleming, et al., 2005; Gelber, et al., 2000).

When comparing gender, ACL injuries are approximately 4-8 times more likely in female athletes (Agel, et al., 2005; Arendt & Dick, 1995; Arendt, Agel, & Dick, 1999; Hootman, et al., 2007; Myer, Ford, & Hewett, 2004). Women are also 3-4 times more likely than males to suffer non-contact ACL injuries when compared to males participating in the same sports. In collegiate women's soccer, non-contact mechanisms of injury account for approximately 53% (in games) to 65% (in practices) of ACL injuries (Dick, Putukian, Agel, Evans, & Marshall, 2007). The non-contact injuries occur without player to player contact, while contact injuries occur during direct contact with another player or object (Dick, et al., 2007; Myklebust, et al., 2003; Olsen, et al., 2004). In both instances, the knee is attempting to decelerate a force (Olsen, et al., 2004).

While gender is one of the most heavily studied risk factors, research has shown there is a wide variety of risk factors can contribute to non-contact ACL injuries. Environmental risk factors include the activity, playing surface, and footwear (Griffin, et al., 2006; Hughes & Watkins, 2006; Olsen, et al., 2004; Orchard & Powell, 2003; Pietrosimone, Grindstaff, Linens, Uczekaj, & Hertel, 2008). Some highly researched intrinsic risk factors include body mass index (Hewett, et al., 2006; Uhorchak, et al., 2003), femoral intercondylar notch width (LaPrade & Burnett, 1994; Shelbourne, Facibene, & Hunt, 1997; Souryal & Freeman, 1993; Staeubli, Adam, Becker, & Burgkart, 1999), hormone fluctuations (Shultz, Sander, Kirk, & Perrin, 2005; Wojtys, Huston, Lindenfeld, Hewett, & Greenfield, 1998; Zazulak, Paterno, Myer, Romani, & Hewett, 2006), joint laxity (Rozzi, Lephart, Gear, & Fu, 1999; Uhorchak, et al., 2003), neuromechanical insufficiencies, and age (Hass, et al., 2003; Swartz, Decoster, Russell, & Croce, 2005; Yu, et al., 2005).

Anatomy and Physiology of the ACL

The anterior cruciate ligament (ACL) is a band of dense connective tissue providing stability in the tibiofemoral joint. The origin of the ACL is on the lateral femoral condyle on the side adjacent to the trochlear grove. From there, the ACL runs anterior, medial, and distal to insert on the anterior part of the central tibial plateau. At its insertion, the ACL's fibers fan out, creating a larger and stronger attachment than its proximal counterpart. Each attachment can range from 11-24 millimeters in width (Duthon, et al., 2006; Woo, Wu, Dede, Vercillo, & Noorani, 2006). The ACL in general is thicker at its attachment sites than at any other point. Compared to the attachments, the mid-substance of the ACL ranges from about 7-12 millimeters in width. The length of the ACL ranges from about 22-41 millimeters (Amis & Dawkins, 1991).

There has been controversy over how many bundles make up the ACL. Most authors accept the notion that two bundles exist: the anterior-medial bundle and the posterior-lateral bundle (Amis & Dawkins, 1991; Duthon, et al., 2006; Woo, et al., 2006). The anterior-medial bundle originates at the anterior-proximal aspect of the femoral attachment and inserts on the anterior-medial aspect of the tibial attachment. The posterior-lateral bundle originates at the posterior-distal aspect of the femoral attachment and inserts on the posterior-lateral aspect of the tibial attachment. The posterior lateral bundle is taught in knee extension, while the anterior-medial bundle is taught in knee flexion (Amis & Dawkins, 1991).

The ACL receives its neurologic innervations from the tibial nerve (Duthon, et al., 2006; Kennedy, et al., 1982). The ACL itself contains several sensory receptors important for afferent feedback. At its surface, the ACL has Corpuscles of Ruffini, proprioceptors that sense stretching. The ACL also uses Vater Pacini receptors to sense rapid movement (Duthon, et al., 2006). Another proprioceptor similar to Golgi-tendon organs senses tension within the ACL (Kennedy, et al., 1982; Schultz, Miller, Kerr, & Micheli, 1984). Free-nerve endings are also present for pain sensation (Duthon, et al., 2006; Hogervorst & Brand, 1998). The ACL's vascular supply comes from the Middle Genicular artery, which originates from the Popliteal artery (Duthon, et al., 2006).

The ACL acts as a stabilizer against anterior tibial translation, as well as axial tibial and valgus knee rotations. Internal and external rotations cause the ACL to become slightly tighter (Duthon, et al., 2006; Woo, et al., 2006). Other restraints against tibial rotation include joint capsule, collateral ligaments, articulating joint surfaces, and meniscus (Duthon, et al., 2006).

Mechanisms of ACL Injuries

Approximately 70% of all ACL injuries are the result of a non-contact mechanism, while the other 30% is of a contact mechanism (McNair, Marshall, & Matheson, 1990). There is some variation in the specific definitions of non-contact versus contact injuries (Hewett, et al., 2006). Myklebust et al. defined a non-contact ACL injury as one that occurs without person-to-person contact (Myklebust, et al., 2003). Conversely, contact ACL injuries are those that occur during person-to-person contact with a direct blow to the knee (Olsen, et al., 2004). Hewett et al. labeled an ACL injury resulting from person-to-person contact without a direct blow to the knee a non-contact ACL injury with perturbation (Hewett, et al., 2006).

Contact ACL injuries consist of an external valgus force collapsing to the knee (Olsen, et al., 2004). Non-contact ACL injuries are generally caused by a deceleration of the body during a dynamic task such as a jump-landing or change of direction. An ACL injury is most likely attributed to forces occurring about the knee in a multilane manner (Quatman & Hewett, 2009; Shimokochi & Shultz, 2008). Frequently, the ACL will be damaged with the involved limb planted, often in a single-leg stance with the knee flexed to less than 30°. Patients commonly recall their knees being in a hyperextended position, which would place the greatest force on the ACL. In addition, the ACL is injured more frequently with the knee in a valgus position and with the tibia internally or externally rotated. While in these positions, non-contact injuries are caused by anterior tibial translation brought on by a forceful quadriceps contraction (Hewett, et al., 2006; Hewett, et al., 2005; Senter & Hame, 2006).

Attempts have been made to determine mechanisms of ACL injuries through observation of tibial and femoral contusions via magnetic resonance imaging (MRI) following ACL injuries. Many authors have identified contusions occurring in the lateral compartment of the knee, which indicate a valgus stress (Kaplan, et al., 1992; Sanders, Medynski, Feller, & Lawhorn, 2000). Viskontas et al. found equal bruising patterns on the lateral and medial femoral condyles and tibial plateaus in non-contact ACL injuries (Viskontas, et al., 2008). The patterns found in their study indicate prominent proximal anterior tibial shear and interior tibial rotation mechanisms. Fayad et al. utilized MRI imaging to attempt to determine gender differences in ACL injury mechanisms (Fayad, et al., 2003). They found posterolateral tibial contusions occurred in 95% of females and 89% of males. These contusions reached depths of 32.5 mm in females and 16 mm in males. Despite the fact these results were not statistically significant ($p=0.18$), it may indicate ACL injuries occur in females with more valgus stress.

Other methods which have attempted to explain ACL injury mechanisms include post-injury surveys of athletes and video analysis (Boden, et al., 2000; Olsen, et al., 2004). Neither method is considered very accurate. Krosshaug et al. have developed a biomechanical analysis method that imposes a model on a standard video, which can then perform kinematic analysis of the subject (Krosshaug, et al., 2007). This method is considered much more accurate than simple video observation, and it should be a valuable tool in furthering the understanding of ACL injury mechanisms.

Risk Factors of ACL Injuries

Environmental Factors

The activity or sport an individual participates in can greatly affect their risk of an ACL injury. Participants of sports such as basketball, volleyball, and soccer are more prone to non-contact ACL injuries due to the high occurrence of jump-landings, change of direction, and deceleration of the body. Higher impact sports, such as football, see more contact ACL injuries than other sports (Hughes & Watkins, 2006).

Another environmental risk factor for ACL injuries is the playing surface and its interaction with footwear. Orchard and Powell studied knee sprains in National Football League games and how they compared to the playing surface and weather of the game (Orchard & Powell, 2003). They concluded that knee injuries are less likely to occur in outdoor venues during cold weather with wet surfaces (either natural grass or Astroturf). They attributed the effect of to reduced shoe-surface contact. Olsen et al. studied ACL injuries in team handball and their results suggest there is a higher risk for ACL injuries in women on artificial floors than wood floors, due to the increased friction from the rubber. They concluded that there must be a balance in shoe-surface contact that allows a safe, low-traction surface that will not inhibit performance (Olsen, et al., 2004). There is limited research defining specific risk variations between different shoe and surface interactions (Griffin, et al., 2006).

Some sports, particularly American football, have attempted to use prophylactic knee braces as a precaution. Currently the research on the effectiveness of bracing is inconclusive. Pietrosimone et al conducted a meta-analysis of seven studies assessing the relative risk reduction (RRR) and numbers needed to treat (NNT) with braced and non-braced collegiate football players (Pietrosimone, et al., 2008). Of the seven studies, only three showed a benefit from bracing. The NNT ranged from 17-42 players needed to treat to prevent one knee injury. The other four studies demonstrated harmful effects of bracing. The NNT indicated 26-63 players would need to be braced to cause one knee injury. Clearly, these results are too inconsistent to make a judgment on knee bracing. More studies with higher levels of evidence need to be conducted to make a determination.

Gender

One of the more commonly studied risk factor for ACL injury is gender. Females have been shown to be 4-6 times more likely to sustain an ACL injury compared to males competing in the same sports (Agel, et al., 2005; Arendt & Dick, 1995; Arendt, et al., 1999; Myer, et al., 2004). There is even more risk for injuries to occur considering female participation in high school sports has increased nearly 1000% from 1971 to 2009

(Associations, 2009). A vast amount of research has been conducted with the intent of determining why females are so much more prone to ACL injuries. Some of the risks studied include hormonal, anthropometrical, and biomechanical factors. Many of the specific hormonal and anthropometrical risk factors are not present until the onset of puberty in females, which is when females are more likely to suffer an ACL injury (Hass, et al., 2003).

Hormonal Factors

Hormones released during the menstrual cycle and their effects on the ACL have become an increasingly greater area of focus. Different hormones can affect various tissues differently. Estrogen can affect soft tissue strength, muscle function, and the central nervous system. Progesterone can act as a central nervous system anesthetic, while relaxin can diminish collagen tension. Increased incidence of ACL injury during the ovulatory phase of the menstrual cycle could be attributed to an increased level of these hormones (Wojtys, et al., 1998). Shultz et al. studied variations in female hormone levels and knee laxity throughout the menstrual compared to males (Shultz, et al., 2005). During the course on the menstrual cycle, the females' knee laxity was higher when estradiol and progesterone were higher than that of males. Schultz et al. concluded that sex hormones are mediators of knee joint laxity. Zazulak et al. conducted a meta-analysis of the time of the menstrual cycle and knee laxity within each phase (Zazulak, et al., 2006). Of the nine studies, only three demonstrated a significant effect of cycle phase on knee laxity. However, the meta-analysis of all studies together showed a significant effect of menstrual cycle phase on knee laxity ($F=56.59$; $p=0.0001$). This meta-analysis showed the greatest change in the ovulatory and post-ovulatory phases. Further research is needed to determine the exact biomechanical effects of specific fluctuations of those hormones (Shultz, et al., 2005).

Body Mass Index (BMI)

Many studies have attempted to find associations between anatomical measures and ACL injury occurrence. Uhorchak et al. conducted a prospective study of ACL injuries in cadets in the United States Military Academy (Uhorchak, et al., 2003). In the study, modifiable (BMI, strength, etc.) and non-modifiable (height, femoral notch width, etc.) anatomical measures were taken to determine which ones could predict the occurrence of ACL injuries. The results showed that BMI was the only modifiable risk factor that significantly affected risk of ACL injury. It is also important to note that the increased risk of ACL injury due to BMI was only seen in female subjects. An increased potential for ACL injuries may be linked to the increase of BMI from the onset of puberty (Hewett, et al., 2006).

Intercondylar Femoral Notch Width

One of the most commonly studied anatomical measure associated with ACL injury is intercondylar femoral notch width. Several studies have showed that males have wider intercondylar notches and thicker ACLs than females (Shelbourne, et al., 1997; Staeubli, et al., 1999). Shelbourne et al. also found that intercondylar notch width was narrower in patients with ACL ruptures when compared to controls (Shelbourne, et al., 1997). Some prospective studies (LaPrade & Burnett, 1994; Souryal & Freeman, 1993) have shown that a narrower intercondylar femoral notch increases the risk of ACL injuries, but discrepancies can be found within the literature. In 1998, Shelbourne et al. found no significant difference in ACL injury rates between men and women with equal notch width and ligament size (Shelbourne, Davis, & Klootwyk, 1998). Regardless of the effects, the benefit of studying anthropometrical measures such as notch width on ACL injury risk is minimal due to the inability to change structures with pathological measures (Hewett, et al., 2006).

Joint Laxity

Another risk factor of ACL injury is the laxity of an individual's ligaments. Lax ligaments, which are more common in females (Rozzi, et al., 1999), allow for extra translation of the articulation. In the ACL's case, it allows for increased anterior tibial translation on the femur. This may be due to a combination of ligament size and decreased tensile strength. Rozzi et al. demonstrated the increase in laxity is also associated with a decrease in proprioception, which can lead to an increased potential for injury (Rozzi, et al., 1999). Uhorchak et al. conducted a four-year prospective study on 1,198 cadets at the United States Military Academy (Uhorchak, et al., 2003). One of the significant factors found for predicting ACL injuries was increased joint laxity. Females who measured one standard deviation above the mean for anterior tibial translation (measured by the KT-2000 arthrometer) were 2.7 times more likely to sustain an ACL injury than those who did not have increased laxity. Uhorchak et al. also found that increased joint laxity (1 SD) with a decreased intercondylar femoral notch width (<13 mm) or a BMI greater than one standard deviation was a significantly greater risk factor for ACL injury than those having just a narrow intercondylar notch or high BMI (Uhorchak, et al., 2003).

Neuromechanical Insufficiencies

According to Sir Isaac Newton's Third Law, for every action, there is an equal and opposite reaction. When a person (or object) lands on the ground, the ground is struck with a force. In turn, the ground creates a reaction force against the person, which is absorbed by the body. Increased vertical ground reaction forces have been theorized as a predictor for ACL as well as many other lower extremity injuries. According to Hewett et al., vertical ground reaction forces (VGRF) can be influenced by landing technique, angular momentum, and vertical height (Hewett, et al., 1996).

An individual's mechanics when performing athletic tasks can present multiple neuromechanical risk factors for ACL injuries, including insufficient joint angles and moments for controlling external forces placed on the body. Moment, also known as torque, is force around an axis. Internal moment can be thought of as the torque a body segment causes to itself through muscle forces and tensile force of non-contractile tissue (Nigg, MacIntosh, & Mester, 2000).

Many authors propose increased sagittal plane movements at the hip, knee, and ankle can help attenuate these forces over a greater distance, reducing stress placed on static structures (Chappell, et al., 2002; Cortes, et al., 2007; Malinzak, et al., 2001; McNair, et al., 2000; Olsen, et al., 2004; Yu, et al., 2005). Reducing these forces is thought to protect structures such as the ACL by limiting the stress placed on it. Debate continues over whether decreased sagittal plane motion can decrease ACL injury risk. Some studies have identified decreased sagittal plane knee motion in females as a risk (Hewett, et al., 2005; Malinzak, et al., 2001), while others have shown no indication that decreased knee flexion angles are associated with increased ACL injury risk (Ford, et al., 2005; McLean, Neal, Myers, & Walters, 1999).

In addition to dissipating forces in the sagittal plane, internal moments prevent joints from becoming positioned in a manner that places greater stress on static structures. Increased valgus motion in the knee is currently one of the most emphasized neuromechanical risk factors (Chappell, et al., 2002; Ford, et al., 2005; Hewett, et al., 2005; McLean, et al., 2005; Olsen, et al., 2004; Shimokochi & Shultz, 2008). Hewett et al. released a prospective study of lower extremity biomechanical measures in 205 adolescent females during a drop jump-landing (Hewett, et al., 2005). The study found that the subjects who went on to injure their ACL had a statistically greater knee valgus angle at initial ground contact by 8.4° ($p<.01$), greater maximum knee valgus angle at midstance phase by 7.6° ($p<.01$), greater knee valgus moment by 250% ($p<.001$), lower maximum knee flexion angle by 10.8° ($p<.05$), and a greater ground reaction force by 20% ($p<.05$). Also found was a significant correlation between knee valgus angle and peak vertical ground reaction force ($R=.67$; $p<.001$) in the injured group, but not the uninjured group. Hewett et al. concluded that knee valgus motion and valgus moments during jump landing activities are predictors of ACL injuries in females.

Age

The effect of age on ACL injuries is becoming a very popular area of research. Prevention programs for non-contact ACL injuries could potentially be developed if more is learned about how age affects injury risk (Yu, et al., 2005). Yu et al. studied landing kinematics in youth soccer players (age 11-16) performing a stop-jump task. Males demonstrated higher knee flexion at initial contact and maximum knee flexion compared to the females. In addition, the females' kinematics declined, with the greatest decrease coming after age 14. Both male and female subjects under age 12 landed with valgus knee angles at initial contact, followed by a change to a varus position. After age 12, males landed in a varus position, while females remained in a valgus position at initial contact. On average, males landed with greater hip flexion angles at initial contact and maximum knee flexion. As age increased these hip flexion measures remained consistent for males, while females declined (Yu, et al., 2005).

Hass et al. studied jump-landing kinetics and kinematics in pre- and post-pubescent females during jump-landing tasks (Hass, et al., 2003). Prepubescent female athletes landed with better mechanics than the post-pubescent female athletes. Swartz et al. also studied the effects of developmental stage and gender on jump-landing kinetics and kinematics(Swartz, et al., 2005). Their subjects consisted of prepubescent males (age 8-11) and females (age 7-10) and post-pubescent (age 19-29) males and females. The adults had greater knee flexion at PVGRF, greater hip flexion and less knee valgus at initial contact and PVGRF, less vertical force and impulse, and a longer time to PVGRF. The authors concluded that jump-landing skills are learned and improved through experience.

Motor Learning

Adams described two theories of motor learning (Adams, 1971). The first, called an open loop theory, does not utilize feedback from the task performed. In this theory a desired outcome from a subject will only occur if the stimulus and subject's motivation and perception are sufficient. Conversely, the close-loop theory utilizes a reference mechanism to which feedback from a task can be compared. Adams states that the output of the system (person performing a task) is fed back and compared to the knowledge of the results of the task. If the result was an error, the output will be altered to correct the error.

Newell's 1974 study was highly supportive of the theories of Adams (Newell, 1974). Newell's study consisted of 140 subjects performing an identical task for 77 trials. The group who received knowledge of their results was far more successful in correcting errors. Newell was able to conclude that knowledge of results provides feedback to reduce error as well as a reference mechanism for the evaluation of the response-produced feedback.

Feedback

Schmidt and Lee defined feedback as sensory information that results from movement (Schmidt & Lee, 2005). Inherent feedback comes from actually performing a task and experiencing successful or unsuccessful outcomes. Extrinsic or augmented feedback comes from information provided by a source outside of the task itself or the person performing the task. For example, when trying to hit a baseball, the result of the attempted swing can give inherent feedback regardless if the person made contact or missed. A coach providing instructions on posture and timing would be considered augmented feedback.

Augmented feedback is divided into two main categories: knowledge of results (KR) and knowledge of performance (KP). Knowledge of results is feedback on the result of a performed task. In the baseball swing example, if the batter was told the ball traveled 300 feet that would be KR. The Empirical Law of Effect says that a response can be rewarding regardless of whether it is positive or negative (Adams, 1971). A positive response to success will lead to a repetition of the event, and a negative response will lead to elimination of the event. Knowledge of performance is feedback related to specific movement patterns of a task. An example is if a batter is told their knees were not bent when swinging (Schmidt & Lee, 2005).

Currently research regarding the effects of augmented feedback on ACL prevention is limited. Onate et al. utilized various forms of video feedback to decrease VRGF and increase knee flexion angle and total knee joint displacement during a jump test used to simulate a basketball rebound (Onate, et al., 2005). The most success was seen in those subjects who watched videos of themselves or a combination of videos of themselves and an expert model. Cowling et al. found more success improving lower extremity kinematics through verbal instruction to change joint angles rather than to activate different muscle groups during athletic tasks (Cowling, et al., 2003). McNair el al. found a decrease in VGRF during a drop-jump task after instructing subjects to land with the quietest landing possible (McNair, et al., 2000).

Other studies have attempted to utilize feedback in combination with other means to alter performance. Herman et al. utilized recreational athletes to determine the effects of strength-training coupled with video feedback on theorized neuromuscular risk factors for ACL injury (Herman, et al., 2009). They found that strength training coupled with video feedback decreased several neuromechanical risk factors including decreased VGRF, knee valgus moment, and hip abduction moment. They concluded that strength-training and assisted feedback may be necessary components of injury prevention.

ACL Injury Prevention Programs

There have been many studies that have attempted to determine the effects of ACL injury prevention programs on injury incidence within various sports at various age levels. The programs commonly consist of dynamic balance and plyometric training, but can also include agility drills, resistance training, core strengthening, stretching, and some sort of instructional feedback. Caraffa et al. utilized 600 semiprofessional and amateur soccer players to analyze the effect of a proprioceptive training program on ACL injury incidence (Caraffa, Cerulli, Projetti, Aisa, & Rizzo, 1996). Half of the teams acted as a control, while the other half participated in the intervention program every day during the preseason and three times per week for the rest of the regular season. During the season, the intervention group had a significantly lower ACL injury incidence (10 total injuries; 0.15 injuries per team/season), while the control group had an incidence of (70 total injuries; 1.15 injuries per team/season). Despite significant findings, the lack of group randomization and reporting of program adherence, along with the utilization of only male subjects may have limited this study.

Following Caraffa's study, other researchers continued to conduct similar studies on various populations. Hewett et al. studied the effects of a six-week jump-training program on 1263 high school athletes (Hewett, et al., 1999). Of these, 366 girls participated in the program (trained group), 463 girls did not receive the intervention (untrained group), and 434 boys did not receive the intervention (control group). The jump-training program consisted of exercises intended to increase maximum vertical jump height and lower extremity strength. The training groups also participated in strength training after the jump-training sessions. Statistical analysis revealed that the incidence of serious knee injuries in the untrained group was 3.6 times higher than in the trained group (P=0.05) and 4.8 times higher than the control (P=0.03). There was no significant difference in serious knee injuries between the trained group and the control group (P=0.83). In addition, there were significantly fewer non-contact ACL injuries in the trained group (0) compared to the untrained group (5) (P=0.05). The results seen here are limited due to the lack of statistical power from the low number of injuries.

In another study, Soderman et al. divided 221 female soccer players into intervention and control groups (Soderman, Werner, Pietila, Engstrom, & Alfredson, 2000). The intervention group participated in progressive balance board exercises at home during the course of the season. The exercises lasted for 15 minutes per session and were done once daily for the first 30 days and then three times per week for the remainder of the season. During the season there was no significant difference in number, type, or incidence of lower extremity injuries between groups. Although statistically insignificant there was a trend towards fewer knee ligament injuries occurring in the control group compared to the intervention group. The intervention group sustained seven knee ligament injuries, while the control group only had two, making this study the only to date to demonstrate a negative outcome after an ACL injury prevention program.

Myklebust et al. studied ACL injury incidence in 58 Norwegian team handball players over three seasons (Myklebust, et al., 2003). The first season acted as a control, and in the second and third seasons an ACL injury prevention program was implemented with the teams. The program consisted of balancing exercises on three different surfaces for 15 minutes per session throughout the preseason and regular season. Teams that competed in the elite division significantly reduced their total number of ACL injuries from the control season (29) to the second intervention season (17), but there was no significant change in the less-skilled divisions. This study was limited by the authors not reporting demographic data for their subjects, making the study difficult to generalize to any specific population.

Research conducted by Mandelbaum et al. found significant effects of the Prevention of Injury and Enhancement of Performance (PEP) program on ACL injury incidence in 1041 female high school soccer players over two years (Mandelbaum, et al., 2005). The PEP program consisted of warm-up activities, stretching, strengthening, plyometrics, and sport-specific drills. In year one the test group experienced an ACL injury rate of 0.05 injuries/athlete/1000 exposures and an injury risk of 1.9 injuries/1000 players. In the same year, the control group had an injury rate of 0.47 injuries/athlete/1000 exposures and an injury risk of 16.8 injuries/1000 players. In year two the injury rate of the test group was 0.13 injuries/athlete/1000 exposures, while the injury risk was 4.74 injuries/1000 players. The control group had an injury rate of 0.51 injuries/athlete/1000 exposures and an injury risk of 18.3 injuries/1000 athletes. These numbers translate into a reduction of ACL injuries per individual athlete of 88% in year one and 74% in year two. The biggest limitation of this study was the lack of randomized intervention and control groups. Teams elected to participate in the PEP program, a choice that may be based on a history of high knee injury incidence.

In a later study, Gilchrist et al. studied ACL injury incidence in 61 NCAA Division I women's soccer teams (Gilchrist, et al., 2008). Teams were placed in either a control group or an intervention group, which participated in a 30 minute warm-up session, three times per week, for 12 weeks during the regular soccer season. The training consisted of stretching, strengthening, plyometrics, agilities, and video-model feedback. They found a significant decrease in ACL injury rate in the intervention group in the second half of the season compared to the control group (0.000 vs. 0.249; P=0.025). Despite a lack of significance in other findings, there were trends towards reducing incidence in the intervention group. The intervention group experienced a 70% decrease in total non-contact ACL injury rate (0.057 vs. 0.189; P=0.066) and a greater than 50% reduction in non-contact ACL injury rate during games (0.233 vs. 0.564; P=0.218) compared to the control group.

Grindstaff et al. performed a numbers-needed-to-treat (NNT) and relative risk-reduction (RRR) analysis of five studies of ACL injury prevention programs (Grindstaff, Hammill, Tuzson, & Hertel, 2006). Collectively, they found 89 (95% CI = 66-136) athletes would need to participate in an ACL prevention program in order to prevent one ACL injury from occurring. In addition, they found that after participating in an ACL prevention program, RRR for noncontact ACL injuries was 70% (95% CI = 54%-80%).

Neuromechanical Training Programs

While some studies analyze changes of injury incidence following ACL prevention programs, others analyze changes in biomechanical risk factors for ACL injuries and motion patterns associated with non-contact mechanisms for ACL injury. Hewett et al. studied high school female volleyball players in a six-week plyometric training program (Hewett, et al., 1996). The training significantly reduced knee valgus and adduction moments and peak landing forces in jumping tasks, meaning plyometric training may be an effective intervention for the prevention of ACL injuries. Irmischer et al. conducted a study of physically active women that found similar results (Irmischer, et al., 2004). After a nine week jump-training program, subjects in the intervention group significantly reduced peak VGRFs in a drop-landing task when compared to those in the control group.

Despite some promising findings following the use of plyometric programs, other authors have found conflicting results. Myer et al. utilized high school female athletes to study differences between a plyometric training group and a dynamic stabilization and balance group on single-leg landing forces, single-leg center of pressure (COP) variation, hamstring and quadriceps strength, vertical jump, and one-rep-max for squat, hang clean, and bench press (Myer, Ford, Brent, & Hewett, 2006). The main finding was that the balance group reduced GRFs by approximately 7%, while plyometric group actually increased GRFs by approximately 7% in single-leg landings. Although there were negative effects on landing forces, Myer et al. did find some positive effects on the other performance measures (Myer, Ford, Brent, et al., 2006). Both training groups decreased medial-lateral COP variation in a single-leg hop, improved isokinetic hamstring strength, and improved squat, hang clean, and vertical jump measures. In a similar study of high school female athletes, Myer et al. also found dynamic balance and plyometric training to be affective in reducing knee valgus motion in jumping tasks (Myer, Ford, McLean, et al., 2006). Due to findings such as these, balance and plyometric training are considered valuable components of ACL injury prevention programs. Using the two in conjunction with one another may maximize benefits (Myer, Ford, Brent, et al., 2006; Myer, Ford, McLean, et al., 2006).

In another study, Herman et al. attempted to study the effects of strength training on lower extremity kinetics and kinematics in adult recreational athletes during a running stop-jump task (Herman, et al., 2008). Despite gains made in muscular strength, the intervention group had no significant changes in kinetics and kinematics. They concluded that strength training alone will not alter biomechanics, but may be beneficial if coupled with other forms of training.

In one study of diverse neuromuscular training, Chappell and Limpisvasti studied NCAA Division I female soccer and basketball players in a six-week program (Chappell & Limpisvasti, 2008). Their program consisted of core strengthening, proprioceptive training, and plyometric training. Sessions were held for 10-15 minutes, six times per week, for six weeks. They found increases in knee flexion at initial contact and peak stance, an increase in knee external rotation moment, and a decrease in knee flexion moment in a drop-jump task. In a running stop-jump task, decreases were seen in hip flexion angle at initial contact, maximum hip external rotation angle, and knee valgus moment. Similar studies have found improved lower extremity kinetics and kinematics in highly trained athletes, and with these results the authors concluded that neuromuscular training programs can alter movement patterns that have previously been shown to be predictors of ACL injury.

While neuromuscular training programs have demonstrated some positive changes, they may have a more significant effect on movement pattern alterations if the programs focus on athletes identified as being at risk for ACL injuries. Myer et al. attempted to analyze differences in biomechanical alterations in high-risk and low-risk high school female soccer and basketball players (Myer, Ford, Brent, & Hewett, 2007). After an eight week neuromuscular training program, the high-risk athletes reduced knee valgus moment by 13% in a drop-jump task while the low-risk athletes had no significant change. They indicated that ACL prevention programs may need to be directed towards high-risk athletes rather than everyone, which would be easier and less time consuming in a clinical setting.

Detraining

Detraining arises from the reduction or cessation of specific training (Baechle & Earle, 2000; Mujika & Padilla, 2000a). In response, specific adaptations brought on by training are reduced or returned to a normal state (Mujika & Padilla, 2000a). Aerobic adaptations are the more quickly affected by detraining when compared to strength gains.

Training reduction in soccer players and weight-lifters has been shown to cause a decrease in average cross-sectional muscle-fiber area (Mujika & Padilla, 2000a). After four-weeks of training reduction, isolated muscular strength may be no different, but force production in sport-specific activities is likely to worsen. Currently, the literature lacks information on detraining effects following programs designed to reduce neuromuscular risk factors of ACL injuries.

CHAPTER III

METHODOLOGY

An experimental design consisting of a pre-training baseline measure, a ten week post-training measure, and an eleven week retention measure was conducted. The pre-training baseline measures consisted of recording lower extremity kinetics and kinematics during five successful running stop-jump trials. These measures were taken in January, prior to the onset of the subjects' spring soccer practices. Following the baseline testing, all subjects underwent a ten week instructional lower extremity strength and agility program, which coincided with the subjects' spring soccer season. At the conclusion of the ten weeks, the subjects' kinetic and kinematic data were retested for the post-training measure. The subjects' spring soccer season continued for two weeks after the post-training measure. Eleven weeks following the post-training measure, the subjects were retested a third time for the retention measure. This final testing session was done one week before the onset of the subjects' fall pre-season.

The lone independent variable (within subjects factor) is time, which has three levels (pre-test, post-test, retention). The dependent variables consisted of kinetic and kinematic measures. The kinematic variables were hip flexion, hip abduction, knee flexion, and knee valgus angles. All kinematic data were measured in degrees (°). The kinetic variables were vertical ground reaction force (VGRF) and posterior ground reaction force (PGRF), knee extension moment, knee valgus moment, hip abduction moment, and hip flexion moment. The majority of intervention studies, along with ours, have focused on frontal and sagittal plane kinematics because verbal cues for proper technique and injury prevention are usually based on these planes (Herman, et al., 2009; Hewett, et al., 1996; Mandelbaum, et al., 2005; Onate, et al., 2005). Therefore, transverse plane kinematics was not analyzed. The kinematic and kinetic variables were measured at initial contact (IC), peak stance, peak PGRF, and peak VGRF. All ground reaction forces were measured in multiples of bodyweight (mBw) to normalize the data and make subjects comparable between each other. Likewise, all joint moments were normalized to mass and height ($Nm.kg^{-1}.m^{-1}$).

Subjects

Ten NCAA Division I female soccer players (age = 19.1 yrs, ± 0.88; height = 1.68 m, ± 0.06; mass = 60.4 kg, ± 7.1) volunteered to participate in this study. To determine the approximate sample size needed to establish differences between the three testing times (pre-training, post-training, and retention), an *a priori* power calculation was conducted. By utilizing previous studies (Chappell & Limpisvasti, 2008; Herman, et al., 2009; Hewett, et al., 1999; Hewett, et al., 1996; Myer, Ford, Brent, et al., 2006; Onate, et al., 2005; Onate, Guskiewicz, & Sullivan, 2001; Wilkerson, et al., 2004), it was determined that a sample size between 14 and 20 participants was needed for a power level of 80% and an alpha level of 0.05. The subjects had 14 (± 2) years of experience playing soccer. The athletes were included if cleared by the team physician to practice and play. Athletes with a previous history of lower extremity injuries or surgeries were included. Our study aimed to assess neuromuscular benefits for anyone eligible to play collegiate soccer. The total number of previous left, right, and bilateral ankle, hamstring, and ACL injuries and surgeries are in Table 1. The dominant leg, defined as the leg that the participant would use to kick a soccer ball as far as possible, was used for analysis. Each subject read and signed the informed consent approved by the University's Institutional Review Board prior to each testing session.

Table 1. Previous ankle, hamstring, and ACL injuries and surgeries within the cohort.

Injury	**Number of Injuries**
Left Ankle Sprains	1
Right Ankle Sprains	1
Both Ankle Sprains	7
Ankle Surgeries	0
Left Hamstring Strains	0
Right Hamstring Strains	1
Both Hamstring Strains	0
Hamstring Surgeries	0
Left ACL Sprains	1
Right ACL Sprains	0
Both ACL Sprains	1
ACL Surgeries	3

Instrumentation

Eight high speed cameras (Vicon Motion Systems Ltd, Oxford, UK and Peak Performance Inc., Colorado, USA) were used to obtain kinematic data during the running stop-jump task. The high-speed cameras were calibrated and set to collect data at 270 Hz. Two Bertec forceplates Model 4060-NC (Bertec Corporation, Columbus, OH, USA), calibrated and set to a frequency of 1080 Hz, were used for the collection of ground reaction forces.

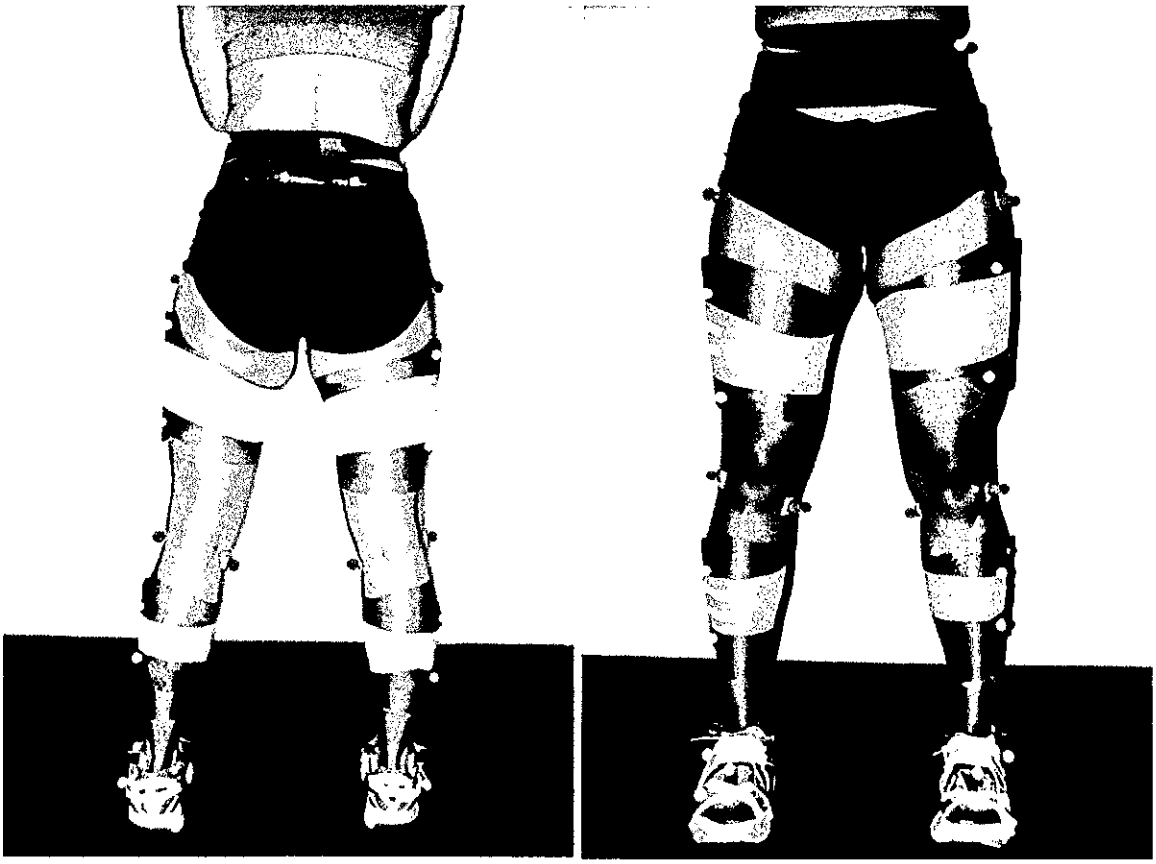
A lower body kinematic model was created for each participant from a standing static calibration trial using Visual 3D (C-Motion, Rockville, MD, USA). The kinematic model was used to quantify the motion at the hip and knee. A standing dynamic calibration trial was used to estimate a functional hip joint center (Begon, Monnet, & Lacouture, 2007; Schwartz & Rozumalski, 2005). Based on a power spectrum analysis, marker trajectory was filtered with a fourth-order Butterworth zero lag filter with a 7 Hz cutoff frequency, and the ground reaction force data were filtered with a similar filter with a 25 Hz cutoff frequency.

Testing Procedures

Participants reported to the Sports Medicine Research Laboratory and completed a demographic questionnaire and signed the informed consent form if they agreed to participate. The participants wore spandex shorts and a sports bra or tight fitting clothing. They used the team running shoes that were provided at the beginning of the season (Adidas Supernova, AG, Herzogenaurach, Germany). The subjects were given a 10-minute warm-up period, consisting of cycling and self-directed stretching. After the warm-up period and stretching, forty reflective markers were placed on specific body landmarks. From those forty, ten were calibration markers, which included greater trochanters, medial and lateral knee joint lines, and medial and lateral malleoli. The other thirty markers were tracking markers, including one on each posterior superior iliac spine, one on each anterior iliac crest, four maker clusters for the thighs and shanks, and five markers on each foot (Figure 1).

A standing static trial and a standing dynamic trial, which consisted of moving the hips in a circular motion, were obtained prior to data collection. After those trials, the calibration markers were removed.

Figure 1. Picture of subject with reflective markers.



Red markers were calibration markers and removed prior to dynamic tasks; white markers were tracking markers left on throughout the entire data collection process.

Pre-Training

During the testing procedure, each subject completed five successful running stop-jump tasks, which were counterbalanced with five successful dominant limb side-step cutting tasks. The subjects were allowed to practice both tasks once prior to testing. The recorded running stop-jumps were counterbalanced to make each task unanticipated, which would more closely resemble a game situation. The running stop-jump task (Chappell, et al., 2002; Herman, et al., 2008; Yu, et al., 2005) consisted of subjects running approximately 7-8 m in a forward direction as fast as they could and then perform the task (running stop-jump or side-step cutting) indicated. The indication was given by a screen facing the subject approximately 6.5 m in front of the force plates. As the subjects approached the forceplate, a timing device (Brown Timing Systems, Draper UT, USA) approximately 2 m behind the force plates was initiated. The gate was coupled with a computer program designed to indicate unanticipated soccer tasks. The program was projected onto the screen in front of the forceplates. Once the signal for stop-jump was given, the subjects jumped onto the force plates with one foot completely on each plate. This was immediately followed by a jump for maximal height. Subjects were instructed to perform the running stop-jump as if they were attempting to "head" the ball in a soccer game. Trials were considered unsuccessful if the subject performed the wrong task, either foot was not completely on its respective forceplate, or if the subject ran slower than 3.5 m/s. The participants had an approach speed of 3.62 (± 0.15) $m.s^{-1}$ for the pre-training running-stop task. They also averaged 5.0 (± 4.5) mistrials during the pre-training testing. Following the pre-training session, the subjects underwent a ten week instructional lower extremity neuromuscular training program.

Resistance Training

The resistance-training portion of the program consisted of sessions on Monday and Wednesday of each week for 60 minutes per session in the university's varsity weight room. A 3-minute jog and individual stretching was completed prior to each session for a team warm-up. All subjects were placed into one of three resistance-training groups: strength (STR), maintenance (MNT), or endurance (END). Each resistance-training group completed the same exercises, but with varied volume and intensity between the groups. Despite kinetic and kinematic analysis being conducted for the dominant leg, both extremities were trained. The STR group, which included three subjects, completed low-volume exercises and chose their own rest interval. The END group, which included two subjects, completed high-volume exercises and was given 30-second rest intervals between exercises. Table 2 demonstrates the resistance-training exercises used from week to week during the course of the intervention as well as the volume differentiation between the STR and END groups. The MNT group, which included five subjects, used a combination of the STR and END groups, completing a STR protocol one day and an END protocol on the next. The MNT group's order switched each week, repeating the STR-END-END-STR cycle every two weeks. The amount of weight utilized for each exercise was self-selected by each individual participant. For the sake of variety, resistance exercises were changed every two weeks.

Table 2. Resistance training exercises and volume for the STR and END groups

Exercises	Resistance-training Group (repetitions x 3 sets)	
Weeks 1,2,5,6,9,& 10	STR	END*
Monday		
DB Single Arm Power Clean	6/arm	6/arm
BB Power Jerk	6	6
BB Front Lunge	10/leg	15/leg
Stiff-leg Deadlift	12	20
Back Squat	10	20
BB Bent-Over Row	12	20
Dips - assisted	8	16
Medicine ball side tosses	10/side	10/side
Basket Hangs	12	12
Planks - 3 way x 30 sec		
Wednesday		
BB Hang Clean	10	10
DB Single Arm Jerk	6	6
Box Jumps	6/arm	6/arm
Russian Hamstring Exten	10	16
Front Squat	12	20
Pull-ups - assisted	8	16
DB Incline Chest Press	12	20
Roman chair Hyperextension	12	16
Roman chair sit-ups	12	16
Weeks 3,4,7,8		
Monday		
DB Single Arm Power Clean	6/arm	6/arm
BB Power Jerk	4	4
BB Front Lunge	8/leg	15/leg
Stiff-leg Deadlift	10	20
Back Squat	8	20
Inverted Row	Max	Max
MB Push-ups	10	16
Cable chops	10/side	10/side
Around the world	4/dir	4/dir
Planks - 3 way x 45 sec		
Wednesday		
BB Hang Clean	6	6
DB Single Arm Jerk	6/arm	6/arm
Box Jumps	10	10
Russian Hamstring Exten	10	16
Overhead Squat	8	16
Pull-ups - assisted	8	16
Plyo clapping push-ups	Max	Max
Roman chair Hyperextension	12	16
Roman chair sit-ups	12	16

A Certified Strength and Conditioning Specialist (CSCS) performed visual demonstrations of each resistance exercise and gave verbalized cues for proper performance. During all testing sessions, the CSCS continued to give verbal and visual augmented feedback to the subjects in regards to their coordination patterns and body positioning.

Field Conditioning

The field-conditioning portion of the program consisted of sessions on Tuesday and Thursday of each week on the university's varsity soccer practice field. All subjects participated in the same drills, regardless of group assignment. The training sessions lasted for approximately 60 minutes during the first four weeks and for approximately 30 minutes during the final six weeks. The decrease in session duration coincided with the onset of the team's spring playing season. Running form drills and range-of-motion exercises made up the dynamic warm-up at the beginning of each session. The Tuesday sessions focused on speed and quickness, while the Thursday sessions focused on plyometric and agility drills. Exercises performed during field conditioning are shown in Tables 3-6.

During the field conditioning drills an emphasis was placed on maintaining proper body positioning and producing proper coordination patterns. For each drill, all subjects were instructed to give maximum effort and power while maintaining proper body angles during acceleration and jumping. More instruction was provided for body positioning and force attenuation during deceleration and landing. Prior to each drill, the CSCS performed visual demonstrations of each exercise and verbalized cues for performing the drills properly. During all of the drills, the CSCS provided constant augmented feedback in relation to the individual and team performances. Each subject completed at least 90% of all field conditioning and resistance training sessions.

Table 3. Field conditioning exercises for weeks 1 & 2

Weeks 1-2

Dynamic Warm-up	10 min				
		Tuesday		**Thursday**	
Light Jog	40m x 4	Speed / Quickness		Plyometrics	
Leg swings right	10 reps				
Leg swings left	10 reps	Fast Feet	6 sec x 4	Tuck Jumps	10 reps x 2
Leg swings across body right	10 reps	Falling accelerations	20m x 4	Star Jumps	10 reps x 2
Leg swings across body left	10 reps	Get-up starts - face down	20m x 4	Lateral Hops	10 reps x 2
Skips	20m x 2	Ins and Outs	60m x 4	Split-squat jumps	10 reps x 2
Butt kicks	20m x 2	Flying 40's	60m x 2		
Sprint 50%	20m x 2	Wall Drills		Agility	
Scorpions	10/side	single drive	10 reps/leg		
Eagles	10/side	double drive	6 reps/set	1 Step Crossovers	10 reps x 2
Stiffleg bounds	20m x 2	triple drive	4 reps/set	3 line drill w/ stick	5 reps/side x 2
High knees	20m x 2			Agility ladders	
Sprint 75%	20m x 2			1 foot/box	2 reps
Hamstring rollovers	10/side			2 feet/box	2 reps
Crossover toe touches	5 reps			In-In-Out-Out Forw	2 reps
Carioca - facing same dir	20m x 2			In-In-Out-Out Lat	2 reps
Carioca w/ knee drive	20m x 2			Shuffle	2 reps
Backpedal	20m x 2			Pro-agility	5 reps
Backpedal w/ extension	20m x 2			T-drill	3 reps
Sprint 100%	20m x 4			NFL 3-cone turn	4 reps

Table 4. Field conditioning exercises for weeks 3 & 4

Weeks 3-4

Dynamic Warm-up	10 min				
		Tuesday		**Thursday**	
Light Jog	40m x 4	Speed / Quickness		Plyometrics	
Leg swings right	10 reps				
Leg swings left	10 reps	Fast Feet	10 sec x 4	Single leg tuck Jumps	5 reps leg x 2
Leg swings across body right	10 reps	Falling accelerations	20m x 6	Single leg lateral hops	6 reps leg x 2
Leg swings across body left	10 reps	Get-up starts - face down w/ ball drop	5m x 6	Broad jumps w/ stick	6 reps x 3
Skips	20m x 2	Ins and Outs	60m x 2	Split-squat jumps	10 reps x 3
Butt kicks	20m x 2	Flying 40's	60m x 4		
Sprint 50%	20m x 2	Wall Drills		Agility	
Scorpions	10/side	single drive	10 reps leg		
Eagles	10/side	double drive	8 reps/set	3 Step Crossovers	6 reps x 2
Stiffleg bounds	20m x 2	triple drive	6 reps/set	3 line drill w/ stick and return	5 reps side x 2
High knees	20m x 2			Agility ladders	
Sprint 75%	20m x 2			2 feet/box	4 reps
Hamstring rollovers	10/side			Single leg high knees	4 reps
Crossover toe touches	5 reps			In-In-Out-Out Forw	4 reps
Carioca - facing same dir	20m x 2			In-In-Out-Out Lat	4 reps
Carioca w/ knee drive	20m x 2			Shuffle	4 reps
Backpedal	20m x 2			Carioca	4 reps
Backpedal w/ extension	20m x 2			Snake Drill	4 reps
Sprint 100%	20m x 4			Pro-agility	5 reps
				T-drill	3 reps
				NFL 3-cone turn	4 reps
				Zig-zag plant and cut drill	4 reps
				Zig-zag turn drill	4 reps

Table 5. Field conditioning exercises for weeks 5 & 6

Weeks 5-6

Dynamic Warm-up	10 min
Light Jog	40m x 4
Leg swings right	10 reps
Leg swings left	10 reps
Leg swings across body right	10 reps
Leg swings across body left	10 reps
Skips	20m x 2
Butt kicks	20m x 2
Sprint 50%	20m x 2
Scorpions	10/side
Eagles	10/side
Stiffleg bounds	20m x 2
High knees	20m x 2
Sprint 75%	20m x 2
Hamstring rollovers	10/side
Crossover toe touches	5 reps
Carioca - facing same dir	20m x 2
Carioca w/ knee drive	20m x 2
Backpedal	20m x 2
Backpedal w/ extension	20m x 2
Sprint 100%	20m x 4

Tuesday

Speed / Quickness	
Fast Feet	10 sec x 6
Falling accelerations	20m x 6
Partner resisted starts 10m	20m x 4
Get-up starts - face down w/ ball drop	5m x 6
Ins and Outs	60m x 2
Flying 40's	60m x 4
Gears 4 x 15m	60m x 4
Wall Drills	
single drive	10 reps/leg
double drive	8 reps/set
triple drive	6 reps/set

Thursday

Plyometrics	
Single leg hurdle hops - forward	6 reps/leg x 4
Single leg hurdle hops - lateral	5 reps/leg x 4
Single leg bounds	6 reps/leg x 3
180 turn jumps	10 reps x 3
Agility	
3 Step Crossovers to 5m sprint	6 reps x 2
3 line drill w/ stick and 5m sprint	5 reps/side x 2
3 line angle drill w/ stick and return	5 reps/side x 2
Agility ladders	
2 feet/box	4 reps
Slalom	4 reps
Single leg high knees	4 reps
In-In-Out-Out Forw	4 reps
In-In-Out-Out Lat	4 reps
Shuffle	4 reps
Carioca	4 reps
Snake Drill	4 reps
2 forward-1 back	2 reps
Figure 8 - 10m	6 reps x 3
8 cone circle facing front	2 reps
Sprint-backpedal-sprint	30 sec x 4
Square drills	
Sprint-shuffle-backpedal-carioca	4 reps
X cross	4 reps

Table 6. Field conditioning exercises for weeks 7 & 8.

Weeks 7-8

Dynamic Warm-up	10 min
Light Jog	40m x 4
Leg swings right	10 reps
Leg swings left	10 reps
Leg swings across body right	10 reps
Leg swings across body left	10 reps
Skips	20m x 2
Butt kicks	20m x 2
Sprint 50%	20m x 2
Scorpions	10/side
Eagles	10/side
Stiffleg bounds	20m x 2
High knees	20m x 2
Sprint 75%	20m x 2
Hamstring rollovers	10/side
Crossover toe touches	5 reps
Carioca - facing same dir	20m x 2
Carioca w/ knee drive	20m x 2
Backpedal	20m x 2
Backpedal w/ extension	20m x 2
Sprint 100%	20m x 4

Tuesday Speed / Quickness	
Fast Feet	10 sec x 6
Falling accelerations	20m x 8
Partner resisted starts 10m	20m x 6
Get-up starts - face down w/ ball drop	5m x 8
Ins and Outs	60m x 4
Flying 40's	60m x 6
Gears 4 x 15m	60m x 6
Wall Drills	
single drive	10 reps/leg
double drive	8 reps/set
triple drive	6 reps/set

Thursday Plyometrics	
Single leg hurdle hops - fwd cut to 5m spr	5 reps/leg x 6
Single leg hurdle hops - lat to 5m spr	5 reps/leg x 6
Single leg bounds	6 reps/leg x 5
180 turn jumps	10 reps x 3
Split-squat jumps	10 reps x 3
Agility	
5 Step Crossovers to 5m sprint	6 reps x 2
3 line drill w/ stick and 5m sprint	5 reps/side x 4
3 line single drill w/ stick and return	5 reps/side x 4
Agility ladders	
2 feet/box	4 reps
Slalom	4 reps
Single leg high knees	4 reps
In-In-Out-Out Forw	4 reps
In-In-Out-Out Lat	4 reps
Shuffle	4 reps
Carioca	4 reps
Snake Drill	4 reps
2 forward-1 back	2 reps
Figure 8 - 10m	6 reps x 3
8 cone circle facing front	2 reps
Sprint-backpedal-sprint	45 sec x 4
Square drills	
Sprint-shuffle-backpedal-carioca	6 reps
X cross	6 reps

These same exercises were also used during weeks 9 & 10.

Post-Training

At the conclusion of the ten week training program, the subjects returned to the lab. All subjects were tested within seven days of the final training day. The same testing procedures utilized in the pre-test protocol were followed. The participants' average approach speed was 3.84 (± 0.30) $m.s^{-1}$ for the post-training running-stop task. Subjects averaged 1.7 (± 1.8) mistrials during the post-training testing.

Retention

Eleven weeks after the post-test subjects began the retention testing. In the eleven weeks, the subjects were active in their personal offseason workouts, which were not documented. In this time, no formal athletic instruction was provided to the subjects. The same procedures from pre- and post-testing were utilized for the retention testing. The participants had an approach speed of 3.76 (± 0.15) $m.s^{-1}$ for the retention running-stop task. Subjects averaged 1.2 (± 1.1) mistrials during the retention testing.

Data Analysis

Case-wise diagnostics were performed to assess data normalcy. Data were analyzed between initial contact and peak knee flexion, which defines the stop-jump phase. All data were processed through Visual 3-D (C-Motion Inc., Rockville MD, USA) and reduced using a custom made Matlab 6.1 (The MathWorks, Inc, Natick MA, USA) software program to export into a Microsoft Excel spreadsheet. Each of the five trials were averaged and exported into SPSS version 16.0 (SPSS Inc, Chicago IL, USA) for data analysis. A repeated measure ANOVA was performed for each dependent variable across all testing sessions. Pairwise comparison was used to determine further significant differences in case of a main effect for testing sessions. Statistical significance was set *a priori* at $p < 0.05$.

CHAPTER IV

RESULTS

Initial Contact (IC)

Descriptive statistics of kinematic and kinetic data are presented in Tables 7 and 8, respectively. There was a statistically significant main effect for testing time (pre, post, and retention test) for knee valgus angle at initial contact ($F_{(2, 18)} = 4.182$, $p = 0.032$). Pairwise comparison demonstrates that the participants were in significantly increased knee valgus position during pretest (-2.2 ± 9.3°) when compared to posttest (0.9 ± 4.0°), $p = .014$, d=0.33 (Figure 2). Individual change scores show that eight out of ten subjects decreased their knee valgus angle between pre and posttest (Table 9, Figure 3). Of the two that had an increase in knee valgus, one still remained in a varus position. Only one participant presented knee valgus position at pretest and increased the valgus angle on posttest. It should be noted that both subjects who increased knee valgus after the training program participated in the MNT resistance training group.

There was no statistically significant main effect for testing time for posterior ground reaction force ($F_{(2, 18)} = 1.756$, $p = 0.201$). There was no statistically significant difference for knee flexion angle between testing times ($F_{(2, 18)} = 0.427$, $p = 0.659$). There was no statistically significant difference between pre, post, and retention times for knee flexion moment ($F_{(2, 18)} = 3.130$, $p = 0.068$). There was no statistically significant main effect for testing time for knee valgus moment ($F_{(2, 18)} = 2.447$, $p = 0.115$). There was no statistically significant difference for hip flexion angle between testing times ($F_{(2, 18)} = 0.236$, $p = 0.792$). There was no statistically significant difference for hip abduction angle between testing times ($F_{(2, 18)} = 2.686$, $p = 0.095$). There was no statistically significant difference for hip flexion moment between testing times ($F_{(2, 18)} = 1.340$, $p = 0.287$). There was no statistically significant difference for hip abduction moment between testing times ($F_{(2, 18)} = 1.627$, $p = 0.224$).

Table 7. Descriptive statistics (mean, standard deviation and 95% confidence intervals) for test time (pre, post, and retention test) for kinematic variables at initial contact, peak vertical ground reaction force (PVGRF) and peak stance. All measured in degrees.

	Pre test			Post test			Retention test		
	Mean	SD	95%	Mean	SD	95%	Mean	SD	95%
Initial Contact									
Knee Flexion (-)/ Extension (+)	-25.5	9.3	-32.2, -18.9	-23.2	6.9	-28.1, -18.2	-22.8	6.2	-27.2, -18.4
Knee Valgus(-) / Varus(+)	-2.2	9.3	-4.9, 0.5	0.9	4.0	-2.0, 3.7	-1.1	3.6	-3.7, 1.5
Hip Flexion	51.7	7.8	46.1, 57.3	53.7	10.4	46.3, 61.2	49.8	17.0	37.6, 61.9
Hip Abduction (-) / Adduction (+)	-4.9	3.6	-7.5, -2.4	-9.3	7.0	-14.3, -4.3	-6.9	4.0	9.7, -4.0
PVGRF									
Knee Flexion (-)/ Extension (+)	-39.5	5.5	-43.5, -35.6	-37.8	5.0	-41.4, -34.2	-35.7	6.9	-40.6, -30.8
Knee Valgus (-) / Varus(+)	-2.4	6.0	-6.7, 1.9	0.9	5.0	-2.7, 4.6	-1.6	5.5	-5.5, 2.4
Hip Flexion	53.0	9.2	46.4, 59.6	56.1	11.1	48.2, 64.1	51.3	16.5	39.5, 63.0
Hip Abduction (-) / Adduction (+)	-4.0	3.1	-6.2, -1.7	-8.4	6.1	-12.8, -4.1	-6.0	4.3	-9.0, -2.9
Peak Stance									
Knee Flexion (-)/ Extension (+)	-58.8	8.7	-65.1, -52.6	-57.3	8.8	-63.6, -51.0	-55.6	6.3	-60.1, -51.2
Hip Flexion	56.4	9.8	49.3, 63.4	59.2	10.8	51.5, 67.0	54.4	15.6	43.3, 65.6
Knee Valgus(-) / Varus(+)	-6.9	4.9	-10.4, -3.4	-3.4	6.1	-7.7, 1.0	-5.8	4.4	-8.9, -2.7

Table 8. Descriptive statistics (mean, standard deviation and 95% confidence intervals) for test time (pre, post, and retention test) for kinetic variables at initial contact, peak vertical ground reaction force (PVGRF), peak knee flexion (PKF) and peak stance. All measured in degrees

	Pre test			Post test			Retention test		
	Mean	SD	95%	Mean	SD	95%	Mean	SD	95%
Initial Contact									
PGRF	0.16	0.16	0.05, 0.27	0.24	0.20	0.09, 0.38	0.19	0.11	0.11, 0.27
Knee Extension (+)/Flexion (-) Moment	0.033	0.175	-0.092, 0.159	0.146	0.239	-0.025, 0.317	0.009	0.147	-0.097, 0.114
Knee Valgus(-)/Varus(+) Moment	0.055	0.069	0.006, 0.105	0.054	0.077	-0.001, 0.110	0.019	0.067	-0.029, 0.067
Hip Flexion(+)/Extension(-) Moment	0.051	0.240	-0.120, 0.223	0.211	0.333	-0.028, 0.449	0.030	0.262	-0.157, 0.217
Hip Abduction (-)/Adduction (+) Moment	0.123	0.153	0.013, 0.232	0.118	0.165	0.000, 0.236	0.064	0.116	-0.019, 0.146
PVGRF									
Vertical Ground Reaction Force	4.58	1.01	3.85, 5.30	5.12	1.72	3.89, 6.35	4.29	0.79	3.72, 4.86
Knee Valgus(-)/Varus(+) moment	0.056	0.257	-0.128, 0.240	-0.139	0.326	-0.372, 0.094	-0.081	0.127	-0.172, 0.010
PKF									
Posterior Ground Reaction Force	1.25	0.37	0.99, 1.52	1.48	0.43	1.17, 1.79	1.33	0.26	1.14, 1.52
Peak Stance									
Posterior Ground Reaction Force	1.82	0.36	1.56, 2.07	1.97	0.40	1.69, 2.26	1.78	0.31	1.55, 2.00
Knee Extension (+)/Flexion (-) Moment	-0.035	0.238	-0.205, 0.135	0.084	0.264	-0.106, 0.273	-0.134	0.322	-0.364, 0.097
Knee Valgus(-)/Varus (+) Moment	-0.191	0.231	-0.356, -0.025	-0.381	0.320	-0.609, -0.152	-0.302	0.212	-0.454, -0.150
Hip Flexion(+)/Extension(-) Moment	0.604	0.468	0.270, 0.939	0.868	0.788	0.305, 1.432	1.020	1.080	0.248, 1.792

Table 9. Change scores between pre- and post-training for knee valgus angle at initial contact.

Case	**Pre**	**Post**	**Change Score**
1	-2.2	-4.9	-2.7
2	2.3	0.2	-2.1
3	2.5	4.5	2.0
4	-7.1	-4.3	2.8
5	-3.8	-0.4	3.4
6	0.5	4.7	4.2
7	-4.1	0.8	4.7
8	0.6	6.4	5.8
9	-8.5	-2.6	5.9
10	-2.4	4.3	6.7

Positive scores represent a varus position, and negative scores represent a valgus position.

Figure 2. Knee varus-valgus angle during a running stop-jump between testing times

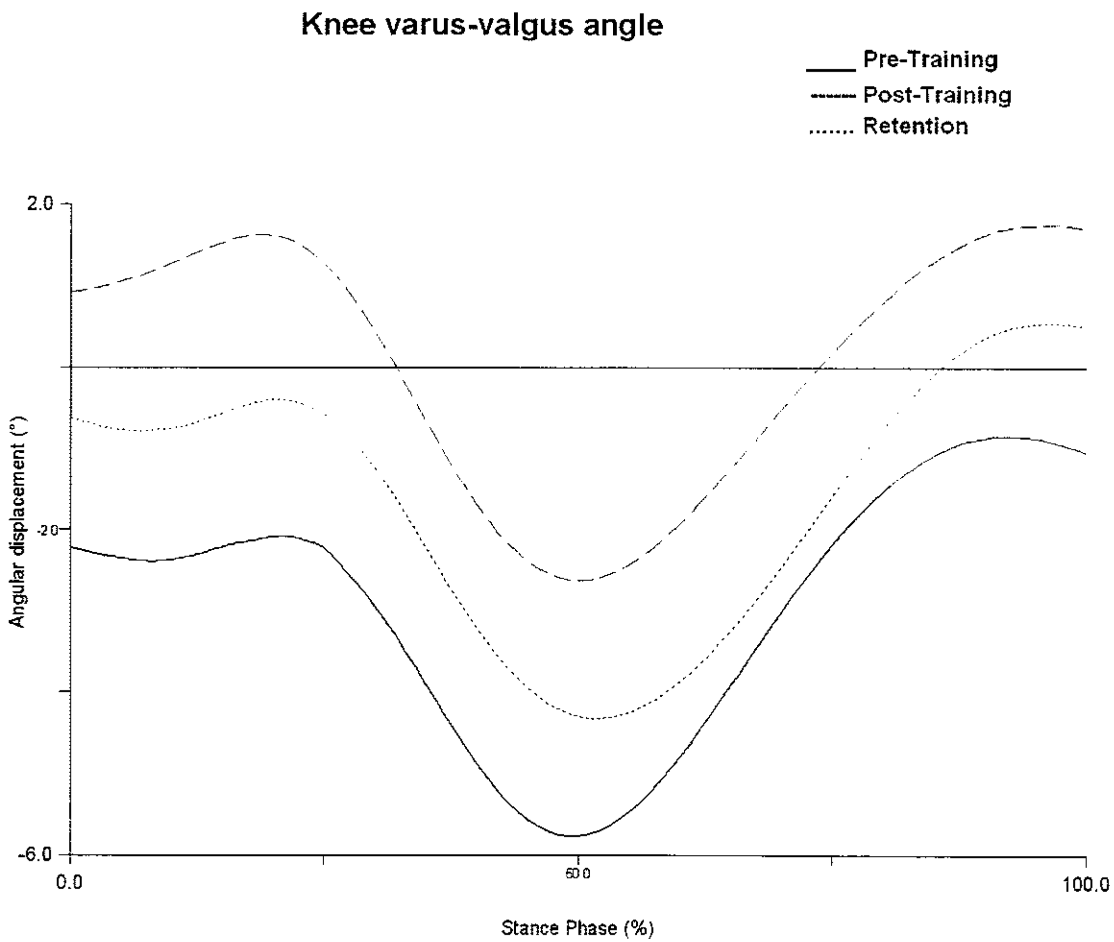
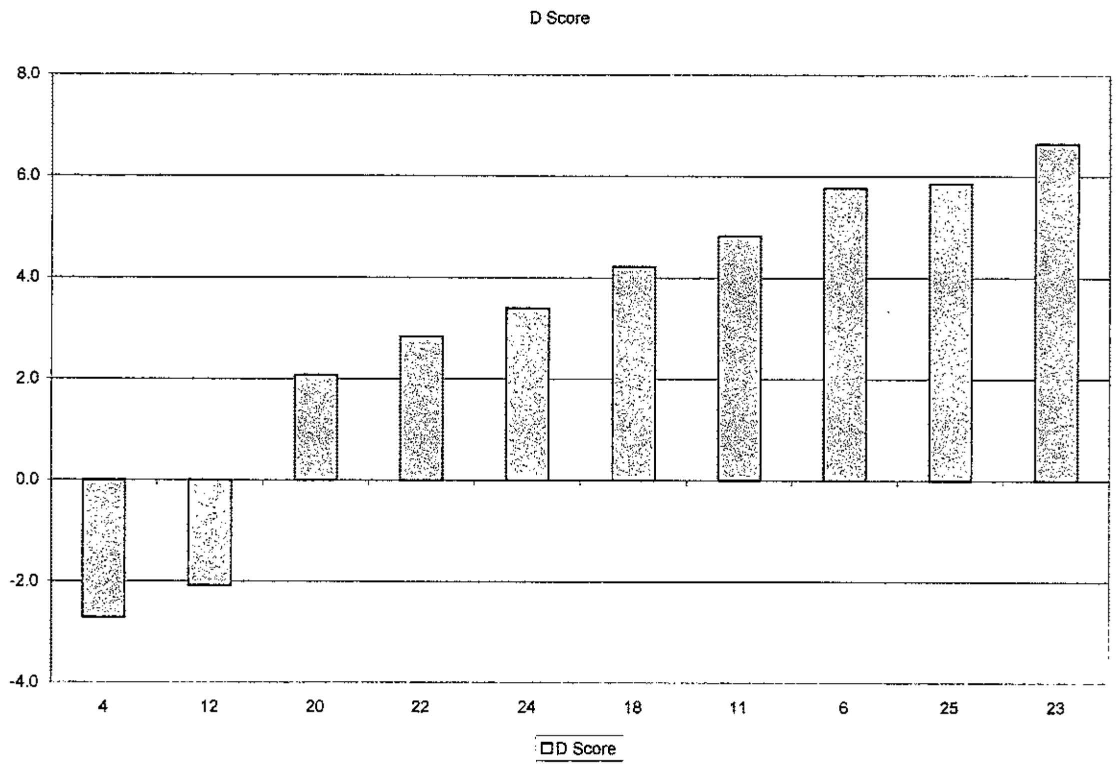


Figure 3. Change scores between pre- and post-training for knee valgus angles at initial contact.



Positive scores represent a decreased valgus, and negative scores represent an increased valgus score.

Peak Knee Flexion (PKF)

There was no statistically significant difference for knee flexion angle between testing times ($F_{(2, 18)} = 0.846$, $p = 0.446$). There was no statistically significant difference for PGRF between testing times ($F_{(2, 18)} = 2.303$, $p = 0.129$). There was no statistically significant difference for knee valgus angle between testing times ($F_{(2, 18)} = 0.799$, $p = 0.465$).

Peak Vertical Ground Reaction Force (PVGRF)

There was no statistically significant difference for vertical ground reaction force between testing times ($F_{(2, 18)} = 2.270$, $p = 0.132$). There was no statistically significant difference for knee flexion angle between testing times ($F_{(2, 18)} = 1.304$, $p = 0.296$). There was no statistically significant difference for knee valgus angle between testing times ($F_{(2, 18)} = 1.555$, $p = 0.238$). There was no statistically significant difference for hip flexion angle between testing times ($F_{(2, 18)} = 0.395$, $p = 0.679$). There was no statistically significant difference for hip abduction angle between testing times ($F_{(2, 18)} = 3.270$, $p = 0.061$).

Peak Stance Phase

There was no statistically significant difference for posterior ground reaction force between testing times ($F_{(2, 18)} = 0.942$, $p = 0.408$) at its peak. There was no statistically significant difference for peak knee valgus angle between testing times ($F_{(2, 18)} = 1.852$, $p = 0.186$). There was no statistically significant difference for peak knee flexion moment between testing times ($F_{(2, 18)} = 2.293$, $p = 0.130$). There was no statistically significant difference for peak knee valgus moment between testing times ($F_{(2, 18)} = 0.658$, $p = 0.530$). There was no statistically significant difference for peak hip flexion angle between testing times ($F_{(2, 18)} = 0.388$, $p = 0.684$). There was no statistically significant difference for peak hip flexion moment between testing times ($F_{(2, 18)} = 0.078$, $p = 0.925$). There was no statistically significant difference for peak hip abduction moment between testing times ($F_{(2, 18)} = 1.301$, $p = 0.297$).

CHAPTER V

DISCUSSION AND CONCLUSIONS

Pre-Training to Post-Training

The purpose of this study was to analyze lower extremity biomechanics in collegiate female soccer players following a ten-week neuromuscular training program and an eleven-week retention period. We hypothesized that the biomechanics of the subjects would significantly improve following the ten-week intervention program. The primary finding of this study was that the intervention program positively affected frontal plane knee alignment at initial contact during the running stop-jump. However, there were no other significant changes for any dependent variable at any time instance from pre- to post-training, post-training to retention, or pre-training to retention.

Non-contact ACL injuries generally occur within the first 40 milliseconds of initial foot contact with the ground when decelerating the body during a dynamic task (Shimokochi & Shultz, 2008). The ACL is usually damaged while the knee is in a valgus, extended, and internally rotated position (Hewett, et al., 2006; Hewett, et al., 2005; Kaplan, et al., 1992; Sanders, et al., 2000; Senter & Hame, 2006). In a prospective study of ACL injury risk factors, Hewett et al. found that knee valgus at initial contact in a drop-jump task was one of the strongest predictors of future ACL injury (Hewett, et al., 2005). Knee valgus at initial contact was 8.4° higher in subjects who went on to sustain an ACL injury compared to those who did not. Our current study found a decrease in a commonly theorized biomechanical risk factor for ACL injuries at a time in which the injuries are most likely to occur.

In a previous study, Herman et al. found that nine weeks of strength training alone had no significant effect on lower extremity kinematics and kinetics during a running stop-jump (Herman, et al., 2008). They concluded that further research should include the use of strength training in conjunction with other forms of prevention to improve biomechanical risk factors. We coupled strength training with agility exercises. The training also included frequent verbal and visual feedback from a CSCS, which has shown to be useful in improving biomechanics during athletic tasks (McNair, et al., 2000; Onate, et al., 2005; Onate, et al., 2001). The subsequent change from a valgus to varus knee position at initial contact is promising. Further research of neuromuscular training programs should attempt to optimize the amount knee valgus alteration as well as identify exercises that can alter other biomechanical risk factors. Varying types of feedback should also be included in future studies attempting to prevent ACL injuries.

Post-Training to Retention

We hypothesized that following the eleven-week retention period, the subjects would show a significant deterioration of lower extremity biomechanics compared to the post-training measure, but not to the point of returning to the pre-training measure. Our results showed no significant difference between post-training and retention testing time. While not statistically significant, the positive change in knee valgus observed from the pre- to post-training began to decline between post-training and retention measures. The knee valgus angles observed at the retention measure ($-1.1° \pm 3.6$) did not return to pre-training values ($-2.2° \pm 9.3$), but were almost in a neutral position, as seen during post-training ($0.9° \pm 4.0$). Based on this statistically insignificant result, it cannot be stated that a detraining effect occurred once the training program was removed. Mujika and Padilla defined detraining as the partial or complete loss of training-induced anatomical, physiological, and performance adaptations, as the result of training reduction or cessation (Mujika & Padilla, 2000a, 2000b). Detraining following strength training programs has been well-documented within the literature. Retention of strength gains can be seen from four to 32 weeks following the cessation of training programs (Lemmer, et al., 2000).

While strength training has demonstrated long-term retention capabilities, Onate et al. has attempted to study the short-term retention of augmented feedback on lower extremity biomechanics (Onate, et al., 2005). They found videotape augmented feedback of the subjects' own trials and of an expert model's trials improved lower extremity biomechanics immediately after feedback and after a one-week retention period. Short-term improvements in biomechanical risk factors for ACL injuries have been demonstrated following the use of neuromuscular training programs (Chappell & Limpisvasti, 2008; Cowley, et al., 2006; Herman, et al., 2008; Hewett, et al., 1999; Hewett, et al., 1996; Irmischer, et al., 2004; Lephart, et al., 2005; Myer, Ford, McLean, et al., 2006; Olsen, et al., 2005; Wilkerson, et al., 2004). Currently, there is no research demonstrating the long-term effects of neuromuscular training and augmented feedback on biomechanical risk factors for ACL injuries. Our study is the first to analyze such effects, utilizing an 11-week retention period following the conclusion of the neuromuscular training program.

In our study, no significant differences were seen for any dependent measure from post-training to retention testing. Despite knee valgus angles experiencing no significant change from post-training to retention, there was a trend towards returning to its baseline level. Due to the lack of literature indicating how long adaptations from ACL injury prevention programs are expected to last, we cannot predict when the dependent measures would return to baseline levels. The post-training to retention testing period was only eleven weeks and may not have been long enough to demonstrate possible detraining effects. More research is required to understand the long-term detraining effects following cessation of ACL injury prevention programs.

Pre-Training to Retention

There was no significant change on any dependent variable from the pre-training to retention measure. We hypothesized that the subjects would retain some of their improved kinematics and kinetics following the post-training measure, thus remaining significantly better than at the pre-training measure. All but one dependent variable, knee valgus at initial contact, remained the same after the training program, and there was no significant detraining effect afterwards. Hence, a significant difference would not be expected from pre-training to retention.

The subjects used in this study were highly trained NCAA Division I soccer players who had 14 (± 2) years of experience playing soccer. The pre-training testing coincided with the onset of practices for the spring season (which took place during the team's official off-season). Throughout the course of the training program, all subjects participated in organized soccer practices and games. In the time from the post-training to retention measure, which was taken one week prior to the onset of the fall pre-season, all subjects participated in their own workouts, which may have consisted of different activities with varying frequency, duration, and intensity. These factors may explain the lack of changes from post-training to retention testing. If these subjects were already trained to a high level, the intensity, frequency, and duration of this particular training program may not have been high enough to extract a significant improvement and subsequent decline in lower extremity kinetics and kinematics. Also, there was no assessment of injury risk prior to the onset of the study. If the subjects were at low risk, the program may not have been as effective (Myer, et al., 2007).

Although our study did not find all of the expected or desired effects of the training programs, other authors have found success in other training programs with various populations. Hewett et al. found improved kinetics and kinematics after a six week jump-training program (Hewett, et al., 1996). Their subjects consisted of younger high school volleyball players who had only 2 (± 1) years of experience in the sport. Chappell and Limpisvasti found improvements in certain lower extremity kinematics and kinetics during athletic tasks, including a running stop-jump, following a six week training program with NCAA Division I female soccer and basketball players (Chappell & Limpisvasti, 2008). In future studies, the benefits of the training program used within this study should be analyzed in younger and lesser-trained athletes. When testing highly-trained subjects similar to ours, future studies should utilize off-season training programs with higher intensities, frequencies, and durations as well as various forms of feedback. An off-season neuromuscular training program should overload the athletes' bodies to cause specific adaptations that will help prevent ACL injuries.

The long-term retention of benefits from ACL injury prevention programs is currently unknown. Once gains are made in the off-season, they need to be carried over to the pre-season and the regular season, which is the time when they are most needed. In order to prevent a detraining effect from the end of a prevention program to the onset of pre-season, one or more reinforcement training sessions may be required. This may be difficult to accomplish due to the time limits for mandatory training of NCAA athletes. Other options might include home exercise programs or inclusion of players during high school and youth summer camps held at the school. Home exercises may be less affective due to the lack of feedback, and camp participation may be limited due to travel and time-restraints. Ideally, all training would be completed during the off-season training sessions, which would be placed at a time that would allow the gains to be retained for the pre-season. Further research should explore how long gains made in neuromuscular training programs last. In addition, research should identify how much, if any, reinforcement is required from the end of training to the onset of the pre-season.

Limitations

Limitations of this study included non-randomized sample size (n=10) that did not meet the needs estimated by the power analysis (n=14-20). The subjects had an undetermined level of risk for non-contact ACL injuries within our cohort prior to the onset of the study. In addition, varied resistance-training protocols between strength groups and a lack of controlled subject activity from the post-training measure to the retention measure limited this study. Despite these limitations, our subjects completed a ten-week training program and found an overall decrease in a commonly theorized biomechanical risk factor for ACL injuries. Our results support those of other authors, who have found positive effects from neuromuscular training programs (Chappell & Limpisvasti, 2008; Hewett, et al., 1996; Wilkerson, et al., 2004).

Conclusions

Neuromuscular training had a significant impact on knee valgus angle at IC in NCAA Division I soccer players. These results show that a commonly theorized biomechanical risk factor can be decreased at a time when ACL injuries are likely to occur and in a group that is frequently exposed to high-level athletic situations. Training programs should continue to be used to reduce biomechanical risk factors for ACL injuries. Each athlete's level of risk should be determined prior to training to assess the needs of each individual. Future studies should utilize different training protocols for various skill levels, and the training should include an assortment of augmented feedback groups. In addition, retention periods should be more controlled, documenting all training activity of each subject. The retention measures should be taken at various instances in order to understand the long-term detraining effects.

References

Adams, J. A. (1971). A closed-loop theory of motor learning. *J Mot Behav, 3*(2), 111-149.

Agel, J., Arendt, E. A., & Bershadsky, B. (2005). Anterior cruciate ligament injury in national collegiate athletic association basketball and soccer: a 13-year review. *Am J Sports Med, 33*(4), 524-530.

Amis, A. A., & Dawkins, G. P. (1991). Functional anatomy of the anterior cruciate ligament. Fibre bundle actions related to ligament replacements and injuries. *J Bone Joint Surg Br, 73*(2), 260-267.

Arendt, E., & Dick, R. (1995). Knee injury patterns among men and women in collegiate basketball and soccer. NCAA data and review of literature. *Am J Sports Med, 23*(6), 694-701.

Arendt, E. A., Agel, J., & Dick, R. (1999). Anterior Cruciate Ligament Injury Patterns Among Collegiate Men and Women. *J Athl Train, 34*(2), 86-92.

Associations, N. F. o. S. H. S. (2009). High School Athletics Participation Survey. Retrieved October 18, 2009, from National Federation of State High School Associations:

Baechle, T. R., & Earle, R. W. (2000). *Essentials of Strength and Conditining* (2nd ed.). Champaign, IL: Human Kinetics.

Begon, M., Monnet, T., & Lacouture, P. (2007). Effects of movement for estimating the hip joint centre. *Gait Posture, 25*(3), 353-359.

Boden, B. P., Dean, G. S., Feagin, J. A., Jr., & Garrett, W. E., Jr. (2000). Mechanisms of anterior cruciate ligament injury. *Orthopedics, 23*(6), 573-578.

Bonfim, T. R., Jansen Paccola, C. A., & Barela, J. A. (2003). Proprioceptive and behavior impairments in individuals with anterior cruciate ligament reconstructed knees. *Arch Phys Med Rehabil, 84*(8), 1217-1223.

Caraffa, A., Cerulli, G., Projetti, M., Aisa, G., & Rizzo, A. (1996). Prevention of anterior cruciate ligament injuries in soccer. A prospective controlled study of proprioceptive training. *Knee Surg Sports Traumatol Arthrosc, 4*(1), 19-21.

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

Chappell, J. D., Yu, B., Kirkendall, D. T., & Garrett, W. E. (2002). A comparison of knee kinetics between male and female recreational athletes in stop-jump tasks. *Am J Sports Med, 30*(2), 261-267.

Cortes, N., Onate, J., Abrantes, J., Gagen, L., Dowling, E., & Van Lunen, B. (2007). Effects of gender and foot-landing techniques on lower extremity kinematics during drop-jump landings. *J Appl Biomech, 23*(4), 289-299.

Cowley, H. R., Ford, K. R., Myer, G. D., Kernozek, T. W., & Hewett, T. E. (2006). Differences in neuromuscular strategies between landing and cutting tasks in female basketball and soccer athletes. *J Athl Train, 41*(1), 67-73.

Cowling, E. J., Steele, J. R., & McNair, P. J. (2003). Effect of verbal instructions on muscle activity and risk of injury to the anterior cruciate ligament during landing. *Br J Sports Med, 37*(2), 126-130.

Dick, R., Putukian, M., Agel, J., Evans, T. A., & Marshall, S. W. (2007). Descriptive epidemiology of collegiate women's soccer injuries: National Collegiate Athletic

Association Injury Surveillance System, 1988-1989 through 2002-2003. *J Athl Train, 42*(2), 278-285.

Duthon, V. B., Barea, C., Abrassart, S., Fasel, J. H., Fritschy, D., & Menetrey, J. (2006). Anatomy of the anterior cruciate ligament. *Knee Surg Sports Traumatol Arthrosc, 14*(3), 204-213.

Fayad, L. M., Parellada, J. A., Parker, L., & Schweitzer, M. E. (2003). MR imaging of anterior cruciate ligament tears: is there a gender gap? *Skeletal Radiol, 32*(11), 639-646.

Fleming, B. C., Hulstyn, M. J., Oksendahl, H. L., & Fadale, P. D. (2005). Ligament Injury, Reconstruction and Osteoarthritis. *Curr Opin Orthop, 16*(5), 354-362.

Ford, K. R., Myer, G. D., Toms, H. E., & Hewett, T. E. (2005). Gender differences in the kinematics of unanticipated cutting in young athletes. *Med Sci Sports Exerc, 37*(1), 124-129.

Frank, C. B., & Jackson, D. W. (1997). The science of reconstruction of the anterior cruciate ligament. *J Bone Joint Surg Am, 79*(10), 1556-1576.

Gelber, A. C., Hochberg, M. C., Mead, L. A., Wang, N. Y., Wigley, F. M., & Klag, M. J. (2000). Joint injury in young adults and risk for subsequent knee and hip osteoarthritis. *Ann Intern Med, 133*(5), 321-328.

Gilchrist, J., Mandelbaum, B. R., Melancon, H., Ryan, G. W., Silvers, H. J., Griffin, L. Y., et al. (2008). A randomized controlled trial to prevent noncontact anterior cruciate ligament injury in female collegiate soccer players. *Am J Sports Med, 36*(8), 1476-1483.

Griffin, L. Y., Albohm, M. J., Arendt, E. A., Bahr, R., Beynnon, B. D., Demaio, M., et al. (2006). Understanding and preventing noncontact anterior cruciate ligament injuries: a review of the Hunt Valley II meeting, January 2005. *Am J Sports Med, 34*(9), 1512-1532.

Grindstaff, T. L., Hammill, R. R., Tuzson, A. E., & Hertel, J. (2006). Neuromuscular control training programs and noncontact anterior cruciate ligament injury rates in female athletes: a numbers-needed-to-treat analysis. *J Athl Train, 41*(4), 450-456.

Grood, E. S., & Suntay, W. J. (1983). A Joint Coordinate System for the Clinical Description of Three-Dimensional Motions: Application to the Knee. *J Biomech Eng, 105*(2), 136-144.

Hass, C. J., Schick, E. A., Chow, J. W., Tillman, M. D., Brunt, D., & Cauraugh, J. H. (2003). Lower Extremity Biomechanics Differ in Prepubescent and Postpubescent Female Athletes During Stride Jump Landings. *J Appl Biomech, 19*, 139-152.

Herman, D. C., Onate, J. A., Weinhold, P. S., Guskiewicz, K. M., Garrett, W. E., Yu, B., et al. (2009). The Effects of Feedback With and Without Strength Training on Lower Extremity Biomechanics. *Am J Sports Med, 37*(7), 1301-1308.

Herman, D. C., Weinhold, P. S., Guskiewicz, K. M., Garrett, W. E., Yu, B., & Padua, D. A. (2008). The effects of strength training on the lower extremity biomechanics of female recreational athletes during a stop-jump task. *Am J Sports Med, 36*(4), 733-740.

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. *Am J Sports Med, 27*(6), 699-706.

Hewett, T. E., Myer, G. D., & Ford, K. R. (2006). Anterior cruciate ligament injuries in female athletes: Part 1, mechanisms and risk factors. *Am J Sports Med, 34*(2), 299-311.

Hewett, T. E., Myer, G. D., Ford, K. R., Heidt, R. S., Jr., Colosimo, A. J., McLean, S. G., et al. (2005). Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. *Am J Sports Med, 33*(4), 492-501.

Hewett, T. E., Stroupe, A. L., Nance, T. A., & Noyes, F. R. (1996). Plyometric training in female athletes. Decreased impact forces and increased hamstring torques. *Am J Sports Med, 24*(6), 765-773.

Hogervorst, T., & Brand, R. A. (1998). Mechanoreceptors in joint function. *J Bone Joint Surg Am, 80*(9), 1365-1378.

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

Hughes, G., & Watkins, J. (2006). A risk-factor model for anterior cruciate ligament injury. *Sports Med, 36*(5), 411-428.

Irmischer, B. S., Harris, C., Pfeiffer, R. P., DeBeliso, M. A., Adams, K. J., & Shea, K. G. (2004). Effects of a knee ligament injury prevention exercise program on impact forces in women. *J Strength Cond Res, 18*(4), 703-707.

Kaplan, P. A., Walker, C. W., Kilcoyne, R. F., Brown, D. E., Tusek, D., & Dussault, R. G. (1992). Occult fracture patterns of the knee associated with anterior cruciate ligament tears: assessment with MR imaging. *Radiology, 183*(3), 835-838.

Kennedy, J. C., Alexander, I. J., & Hayes, K. C. (1982). Nerve supply of the human knee and its functional importance. *Am J Sports Med, 10*(6), 329-335.

Krosshaug, T., Slauterbeck, J. R., Engebretsen, L., & Bahr, R. (2007). Biomechanical analysis of anterior cruciate ligament injury mechanisms: three-dimensional motion reconstruction from video sequences. *Scand J Med Sci Sports, 17*(5), 508-519.

LaPrade, R. F., & Burnett, Q. M., 2nd (1994). Femoral intercondylar notch stenosis and correlation to anterior cruciate ligament injuries. A prospective study. *Am J Sports Med, 22*(2), 198-202; discussion 203.

Lemmer, J. T., Hurlbut, D. E., Martel, G. F., Tracy, B. L., Ivey, F. M., Metter, E. J., et al. (2000). Age and gender responses to strength training and detraining. *Med Sci Sports Exerc, 32*(8), 1505-1512.

Lephart, S. M., Abt, J. P., Ferris, C. M., Sell, T. C., Nagai, T., Myers, J. B., et al. (2005). Neuromuscular and biomechanical characteristic changes in high school athletes: a plyometric versus basic resistance program. *Br J Sports Med, 39*(12), 932-938.

MacDonald, P. B., Hedden, D., Pacin, O., & Sutherland, K. (1996). Proprioception in anterior cruciate ligament-deficient and reconstructed knees. *Am J Sports Med, 24*(6), 774-778.

Malinzak, R. A., Colby, S. M., Kirkendall, D. T., Yu, B., & Garrett, W. E. (2001). A comparison of knee joint motion patterns between men and women in selected athletic tasks. *Clin Biomech (Bristol, Avon), 16*(5), 438-445.

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

Markolf, K. L., Burchfield, D. M., & Shapiro, M. S. (1995). Combined knee loading states that generate high anterior cruciate ligament forces. *J Orthop Res, 13*(6), 930-935.

Markolf, K. L., Gorek, J. F., Kabo, J. M., & Shapiro, M. S. (1990). Direct measurment of resultant forces in the anterior cruciate ligament. An in vitro study performed with a new experimental technique. *J Bone Joint Surg Am, 72*, 557-567.

McLean, S. G., Neal, R. J., Myers, P. T., & Walters, M. R. (1999). Knee joint kinematics during the sidestep cutting maneuver: potential for injury in women. *Med Sci Sports Exerc, 31*(7), 959-968.

McLean, S. G., Walker, K. B., & van den Bogert, A. J. (2005). Effect of gender on lower extremity kinematics during rapid direction changes: an integrated analysis of three sports movements. *J Sci Med Sport, 8*(4), 411-422.

McNair, P. J., Marshall, R. N., & Matheson, J. A. (1990). Important features associated with acute anterior cruciate ligament injury. *N Z Med J, 103*(901), 537-539.

McNair, P. J., Prapavessis, H., & Callender, K. (2000). Decreasing landing forces: effect of instruction. *Br J Sports Med, 34*(4), 293-296.

Miyasaka, K. C., Daniel, D. M., Stone, M. L., & Hirshman, P. (1991). The incidence of knee ligament injuries in general population. *Am J Knee Surg, 4*, 3-8.

Mountcastle, S. B., Posner, M., Kragh, J. F., Jr., & Taylor, D. C. (2007). Gender differences in anterior cruciate ligament injury vary with activity: epidemiology of anterior cruciate ligament injuries in a young, athletic population. *Am J Sports Med, 35*(10), 1635-1642.

Mujika, I., & Padilla, S. (2000a). Detraining: loss of training-induced physiological and performance adaptations. Part I: short term insufficient training stimulus. *Sports Med, 30*(2), 79-87.

Mujika, I., & Padilla, S. (2000b). Detraining: loss of training-induced physiological and performance adaptations. Part II: Long term insufficient training stimulus. *Sports Med, 30*(3), 145-154.

Myer, G. D., Ford, K. R., Brent, J. L., & Hewett, T. E. (2006). The effects of plyometric vs. dynamic stabilization and balance training on power, balance, and landing force in female athletes. *J Strength Cond Res, 20*(2), 345-353.

Myer, G. D., Ford, K. R., Brent, J. L., & Hewett, T. E. (2007). Differential neuromuscular training effects on ACL injury risk factors in"high-risk" versus "low-risk" athletes. *BMC Musculoskelet Disord, 8*, 39.

Myer, G. D., Ford, K. R., & Hewett, T. E. (2004). Rationale and Clinical Techniques for Anterior Cruciate Ligament Injury Prevention Among Female Athletes. *J Athl Train, 39*(4), 352-364.

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. *Am J Sports Med, 34*(3), 445-455.

Myklebust, G., & Bahr, R. (2005). Return to play guidelines after anterior cruciate ligament surgery. *Br J Sports Med, 39*(3), 127-131.

Myklebust, G., Engebretsen, L., Braekken, I. H., Skjolberg, A., Olsen, O. E., & Bahr, R. (2003). Prevention of anterior cruciate ligament injuries in female team handball players: a prospective intervention study over three seasons. *Clin J Sport Med, 13*(2), 71-78.

Newell, K. M. (1974). Knowledge of Results and Motor Learning. *J Mot Behav, 6*(4), 235-244.

Nigg, B. M., MacIntosh, B. R., & Mester (2000). *Biomechanics and Biology of Human.* Champaign, IL: Human Kinetics.

Olsen, O. E., Myklebust, G., Engebretsen, L., & Bahr, R. (2004). Injury mechanisms for anterior cruciate ligament injuries in team handball: a systematic video analysis. *Am J Sports Med, 32*(4), 1002-1012.

Olsen, O. E., Myklebust, G., Engebretsen, L., Holme, I., & Bahr, R. (2005). Exercises to prevent lower limb injuries in youth sports: cluster randomised controlled trial. *BMJ, 330*(7489), 449.

Onate, J. A., Guskiewicz, K. M., Marshall, S. W., Giuliani, C., Yu, B., & Garrett, W. E. (2005). Instruction of jump-landing technique using videotape feedback: altering lower extremity motion patterns. *Am J Sports Med, 33*(6), 831-842.

Onate, J. A., Guskiewicz, K. M., & Sullivan, R. J. (2001). Augmented feedback reduces jump landing forces. *J Orthop Sports Phys Ther, 31*(9), 511-517.

Orchard, J. W., & Powell, J. W. (2003). Risk of knee and ankle sprains under various weather conditions in American football. *Med Sci Sports Exerc, 35*(7), 1118-1123.

Pietrosimone, B. G., Grindstaff, T. L., Linens, S. W., Uczekaj, E., & Hertel, J. (2008). A systematic review of prophylactic braces in the prevention of knee ligament injuries in collegiate football players. *J Athl Train, 43*(4), 409-415.

Quatman, C. E., & Hewett, T. E. (2009). The anterior cruciate ligament injury controversy: is "valgus collapse" a sex-specific mechanism? *Br J Sports Med, 43*(5), 328-335.

Renstrom, P., Ljungqvist, A., Arendt, E., Beynnon, B., Fukubayashi, T., Garrett, W., et al. (2008). Non-contact ACL injuries in female athletes: an International Olympic Committee current concepts statement. *Br J Sports Med, 42*(6), 394-412.

Rozzi, S. L., Lephart, S. M., Gear, W. S., & Fu, F. H. (1999). Knee joint laxity and neuromuscular characteristics of male and female soccer and basketball players. *Am J Sports Med, 27*(3), 312-319.

Sanders, T. G., Medynski, M. A., Feller, J. F., & Lawhorn, K. W. (2000). Bone contusion patterns of the knee at MR imaging: footprint of the mechanism of injury. *Radiographics, 20 Spec No*, S135-151.

Schmidt, R. A., & Lee, T. D. (2005). *Motor Control and Learning: A Behavioral Emphasis* (fourth ed.). Champaign, IL: Human Kinetics.

Schultz, R. A., Miller, D. C., Kerr, C. S., & Micheli, L. (1984). Mechanoreceptors in human cruciate ligaments. A histological study. *J Bone Joint Surg Am, 66*(7), 1072-1076.

Schwartz, M. H., & Rozumalski, A. (2005). A new method for estimating joint parameters from motion data. *J Biomech, 38*(1), 107-116.

Senter, C., & Hame, S. L. (2006). Biomechanical analysis of tibial torque and knee flexion angle: implications for understanding knee injury. *Sports Med, 36*(8), 635-641.

Shelbourne, K. D., Davis, T. J., & Klootwyk, T. E. (1998). The relationship between intercondylar notch width of the femur and the incidence of anterior cruciate ligament tears. A prospective study. *Am J Sports Med, 26*(3), 402-408.

Shelbourne, K. D., Facibene, W. A., & Hunt, J. J. (1997). Radiographic and intraoperative intercondylar notch width measurements in men and women with unilateral and bilateral anterior cruciate ligament tears. *Knee Surg Sports Traumatol Arthrosc, 5*(4), 229-233.

Shimokochi, Y., & Shultz, S. J. (2008). Mechanisms of noncontact anterior cruciate ligament injury. *J Athl Train, 43*(4), 396-408.

Shultz, S. J., Sander, T. C., Kirk, S. E., & Perrin, D. H. (2005). Sex differences in knee joint laxity change across the female menstrual cycle. *J Sports Med Phys Fitness, 45*(4), 594-603.

Soderman, K., Werner, S., Pietila, T., Engstrom, B., & Alfredson, H. (2000). Balance board training: prevention of traumatic injuries of the lower extremities in female soccer players? A prospective randomized intervention study. *Knee Surg Sports Traumatol Arthrosc, 8*(6), 356-363.

Souryal, T. O., & Freeman, T. R. (1993). Intercondylar notch size and anterior cruciate ligament injuries in athletes. A prospective study. *Am J Sports Med, 21*(4), 535-539.

Staeubli, H. U., Adam, O., Becker, W., & Burgkart, R. (1999). Anterior cruciate ligament and intercondylar notch in the coronal oblique plane: anatomy complemented by magnetic resonance imaging in cruciate ligament-intact knees. *Arthroscopy, 15*(4), 349-359.

Swartz, E. E., Decoster, L. C., Russell, P. J., & Croce, R. V. (2005). Effects of Developmental Stage and Sex on Lower Extremity Kinematics and Vertical Ground Reaction Forces During Landing. *J Athl Train, 40*(1), 9-14.

Uhorchak, J. M., Scoville, C. R., Williams, G. N., Arciero, R. A., St Pierre, P., & Taylor, D. C. (2003). Risk factors associated with noncontact injury of the anterior cruciate ligament: a prospective four-year evaluation of 859 West Point cadets. *Am J Sports Med, 31*(6), 831-842.

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. *Am J Sports Med, 36*(5), 927-933.

von Porat, A., Roos, E. M., & Roos, H. (2004). High prevalence of osteoarthritis 14 years after an anterior cruciate ligament tear in male soccer players: a study of radiographic and patient relevant outcomes. *Ann Rheum Dis, 63*(3), 269-273.

Wilkerson, G. B., Colston, M. A., Short, N. I., Neal, K. L., Hoewischer, P. E., & Pixley, J. J. (2004). Neuromuscular Changes in Female Collegiate Athletes Resulting From a Plyometric Jump-Training Program. *J Athl Train, 39*(1), 17-23.

Wojtys, E. M., Huston, L. J., Lindenfeld, T. N., Hewett, T. E., & Greenfield, M. L. (1998). Association between the menstrual cycle and anterior cruciate ligament injuries in female athletes. *Am J Sports Med, 26*(5), 614-619.

Woo, S. L., Wu, C., Dede, O., Vercillo, F., & Noorani, S. (2006). Biomechanics and anterior cruciate ligament reconstruction. *J Orthop Surg Res, 1*, 2.

Yu, B., McClure, S. B., Onate, J. A., Guskiewicz, K. M., Kirkendall, D. T., & Garrett, W. E. (2005). Age and gender effects on lower extremity kinematics of youth soccer players in a stop-jump task. *Am J Sports Med, 33*(9), 1356-1364.

Zazulak, B. T., Paterno, M., Myer, G. D., Romani, W. A., & Hewett, T. E. (2006). The effects of the menstrual cycle on anterior knee laxity: a systematic review. *Sports Med, 36*(10), 847-862.

APPENDIX 1

INFORMED CONSENT

INFORMED CONSENT DOCUMENT
OLD DOMINION UNIVERSITY

PROJECT TITLE: Lower Extremity Biomechanical Evaluation During Various Foot Landing Patterns and Athletic Tasks – A Gender Comparison

INTRODUCTION

The purposes of this form are to give you information that may affect your decision whether to say YES or NO to participation in this research, and to record the consent of those who say YES. The name of research project is "Lower Extremity Biomechanical Evaluation During Various Foot Landing Patterns and Athletic Tasks in Collegiate Soccer Athletes". The data collection will take place in the Motion Analysis Laboratory, Room 1007, in Student Recreation Center on the Old Dominion University campus.

RESEARCHERS

Dr. James Oñate, Ph.D., ATC Assistant Professor, Responsible Project Investigator
Nelson Cortes, M.S. Ed, Doctoral Student, Human Movement Sciences Department
Roger Kollock, M.S. Ed., Doctoral Student, Human Movement Sciences Department
Jeffery Smith, Master Student, Human Movement Sciences Department

DESCRIPTION OF RESEARCH STUDY

There have been numerous studies that have analyzed the high occurrence of anterior cruciate ligament tears in non-contact sports. Most studies have looked at the knee joint and how it contributes to this type of injury. There is still a lack of knowledge on how these injuries occur in relation to the knee joint. Although there are numerous studies on anterior cruciate ligament tears, there is little evidence that shows how different foot positions while performing specific unanticipated athletic tasks affects the knee joint. There have been studies that have added other contributing factors while still analyzing the knee joint. Therefore there is a need to explain the effects of gender and how it affects hip and ankle motions in three athletic tasks based on different landing techniques, self-preferred, forefoot, and rearfoot. The purpose of this study is to analyze hip and ankle kinematics while performing three different athletic tasks.

If you decide to participate, then you will join a study involving research of different landing techniques that are related to hip and ankle kinematics during the stop-jump phase. The study will be collected in two sessions separated by one week. You will report to the Sports Medicine Research Lab, wearing spandex shorts, t-shirt or sports bra, and running shoes. You will fill out a questionnaire with questions about your history of injury and soccer experience.

- You will have a 10-minute warm-up period that will consist of cycling and/or self-directed stretching. After the warm-up period and stretching, thirty-seven (37) reflective markers will be placed on specific body landmarks. You will be requested to step on a scale in order for us to measure your weight and height. A caliper will be used to measure knee width, ankle width, elbow width, wrist width and hand thickness. A measurement tape will be used to measure your leg length. The measurement will be taken from your hip to your ankle.

- There will be a short period of time to familiarize yourself with the athletic tasks.
- The four athletic tasks that will be performed consist of a drop jump task, running pivoting task, a running side-step cutting task, and a running crossover-cutting task.
- To perform the drop jump task, you will be standing on a box, 30 cm height and 30 cm from the force plates, shift your weight forward to drop from the box and land on the force plates, followed by a jump straight back into the air and landing back on the force plates.
- When performing the running pivoting you will stand on the beginning of the platform, start running and planting onto the force plate with the dominant foot and pivoting 180 degrees and run to the opposite direction. You will use the designated landing technique by the researcher.
- The running side-step cutting task consists of you running towards the force plates and once you reach the force plate you will cut at an angle between 35°-55° either to the left or right as directed by image that will prompt on the screen depending on which leg is your dominant leg.
- The running-crossover-step cutting task consists of you running towards the force plates and once you reach the force plate you will plant and perform a crossover step while cutting at an angle between 35°-55° either to the left or right as directed by image that will prompt on the screen depending on which leg is your dominant leg.
- In both running tasks, you will be directed on which landing technique to perform as well. The landing techniques are forefoot (toes), rearfoot (heel), and self-preferred. The forefoot landing technique is performed by initially landing with your forefoot and then your rearfoot. The rearfoot landing technique is performed by initially landing with you rearfoot and then your forefoot.
- The self-preferred landing technique is how you would normally land whenever landing from a jump. If at any time while performing each task, you touch the ground with your hands or lose your balance and fall, the trial will not be analyzed.
- All athletic tasks will be randomly performed and 5 times each. The self preferred landing technique will be performed first in each task while the forefoot and rearfoot landing technique will be performed in a counterbalanced order.
- After performing the previous tasks you will perform one of two fatigue protocols (aerobic and anaerobic), with the other fatigue protocol being performed one week after the first session.
- The aerobic fatigue will consist of a VO2 maximal protocol, where you will run at 9 km/h with 1 km/h increments every two minutes until you cannot keep going. You will rest for five minutes followed by 30 minutes jogging, running, and sprinting. At the end of the protocol you will feel as if you have just finished a 5-kilometer race.
- The anaerobic fatigue will consist of performing a series of step-up and down movements on a 20-cm box for 30 seconds. Following you will perform a three-

cone drill, with the cones placed on an L shape separated by 5 yards. You will sprint 5 yards to one cone, sprint back to the starting cone, and head back to the second cone where you run around it and cut right to the third cone. You will then run in a circle around the third cone from the inside to the outside and run around the second cone before running to the first cone. Immediately following the three-cone drill, you will perform 5 consecutive counter-movement jumps staying within 25% of their max vertical jump. Immediately after, you will perform two different types of agility drills. On the 1st and 3rd set of the anaerobic fatigue protocol, the subjects will run over the ladder touching both feet in each ladder space. During the 2nd and 4th set of the fatigue protocol the subjects will face perpendicular to the ladder moving sideways along the ladder touching both foot in each space. You will repeat 4 times the entire protocol. At the end of the protocol, it will feel like as if you have just got done playing an intense game of basketball.

All athletic tasks will be videotaped, this will allow the investigator to insure the landing techniques and athletic tasks are performed correctly. If you do not consent to be videotaped you will be excluded from the test. You will also perform strength testing. The strength test involves using a load cell, which is a device similar to a dynamometer (strength measuring device) strength tester to measure hip, knee, and ankle strength. Two practice repetitions and three test trials will be conducted for each strength test. If you say YES, then your participation will last for approximately 60 minutes at the Sports Medicine Research Lab, Room 113, in Spong hall. Approximately 50 females and 50 males will be participating in this study.

EXCLUSIONARY CRITERIA

You will be excluded from the study in case you do not consent to be videotaped/photographed.

RISKS AND BENEFITS

RISKS: If you decide to participate in this study, then you may face a risk of ankle sprain, knee injury, muscle pain, and muscle soreness. Ankle sprains can be compared as stepping off the curb, muscle pain and muscle soreness can be compared as the same sensation you might have after workout. The researcher tried to reduce these risks by provided clear directions on how to perform each athletic task and landing technique. And, as with any research, there is some possibility that you may be subject to risks that have not yet been identified.

BENEFITS: There are no direct benefits for the subject for participating in this study.

COSTS AND PAYMENTS

The researchers want your decision about participating in this study to be absolutely voluntary. Yet they recognize that your participation may pose some inconvenience with travel time to and from the testing site. Unfortunately at this time, the researchers are unable to give you any payment for participating in this study.

NEW INFORMATION

If the researchers find new information during this study that would reasonably change your decision about participating, then they will give it to you.

CONFIDENTIALITY

All information obtained about you in this study is strictly confidential unless disclosure is required by law. The researchers will take reasonable steps to insure confidentiality is upheld. The researchers will store all questionnaires, videotapes, and laboratory findings in a locked file cabinet prior to processing. The results of this study may be used in reports, presentations and publications, but the researcher will not identify you.

WITHDRAWAL PRIVILEGE

It is OK for you to say NO. Even if you say YES now, you are free to say NO later, and walk away or withdraw from the study -- at any time. Your decision will not affect your relationship with Old Dominion University, or otherwise cause a loss of benefits to which you might otherwise be entitled. The researchers reserve the right to withdraw your participation in this study, at any time, if they observe potential problems with your continued participation.

COMPENSATION FOR ILLNESS AND INJURY

If you say YES, then your consent in this document does not waive any of your legal rights. However, in the event of harm and/or injury arising from this study, neither Old Dominion University nor the researchers are able to give you any money, insurance coverage, free medical care, or any other compensation for such injury. In the event that you suffer injury as a result of participation in this research project, you may contact Dr. James Oñate at 757-683-4351, Nelson Cortes at 757-683-5676, or Dr. George Maihafer, the current IRB chair, at 757- 683-4520 at Old Dominion University, who will be glad to review the matter with you.

VOLUNTARY CONSENT

By signing this form, you are saying several things. You are saying that you have read this form or have had it read to you, that you are satisfied that you understand this form, the research study, and its risks and benefits. The researchers should have answered any questions you may have had about the research. If you have any questions later on, then the researchers should be able to answer them: Dr. James Oñate at 757-683-4351 or Nelson Cortes at 757-683-5676.

If at any time you feel pressured to participate, or if you have any questions about your rights or this form, then you should call Dr. George Maihafer, the current IRB chair, at 757- 683-4520, or the Old Dominion University Office of Research, at 757-683-3460.

And importantly, by signing below, you are telling the researcher YES, that you agree to participate in this study. The researcher should give you a copy of this form for your records.

Subject's Printed Name & Signature	Date

INVESTIGATOR'S STATEMENT

I certify that I have explained to this subject the nature and purpose of this research, including benefits, risks, costs, and any experimental procedures. I have described the rights and protections afforded to human subjects and have done nothing to pressure, coerce, or falsely entice this subject into participating. I am aware of my obligations under state and federal laws, and promise compliance. I have answered the subject's questions and have encouraged him/her to ask additional questions at any time during the course of this study. I have witnessed the above signature(s) on this consent form.

Investigator's Printed Name & Signature	Date

APPENDIX 2

INFORMED CONSENT

FOR USE OF PHOTO/VIDEO MATERIALS

STUDY TITLE: Lower Extremity Biomechanical Evaluation During Various Foot Landing Patterns and Athletic Tasks – A Gender Comparison

DESCRIPTION:

The researchers would also like to take photographs or videotapes of you performing a variety of athletic tasks in order to illustrate the research in teaching, presentations, and/or or publications.

CONFIDENTIALITY:

The tapes used during the study will be stored in a locked file cabinet in the Motion Analysis Laboratory (Room 1007, Student Recreation Center). These tapes will be stored in the Motion Analysis Laboratory. You would not be identified by name in any use of the photographs or videotapes. Even if you agree to be in the study, no photographs or videotapes will be taken of you unless you specifically agree to this.

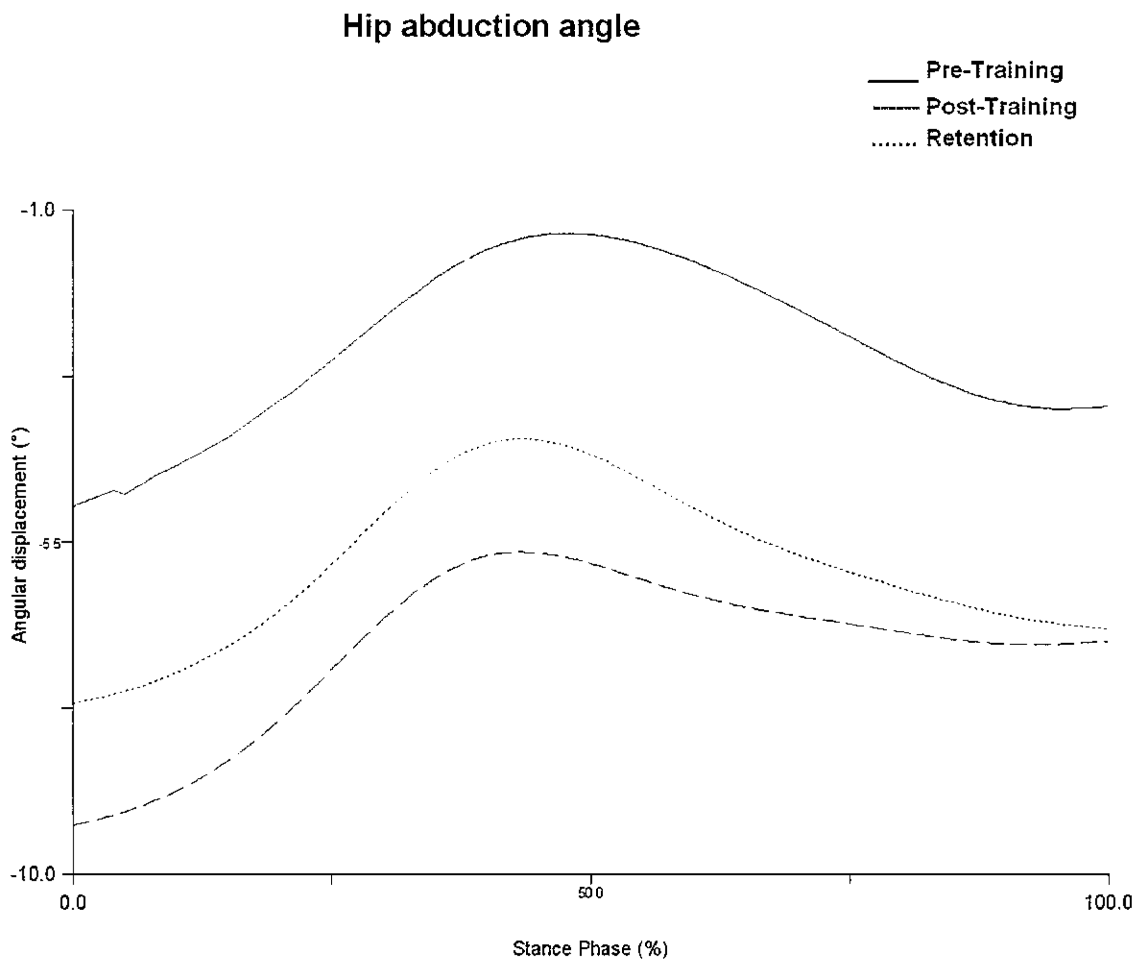
VOLUNTARY CONSENT

By signing below, you are granting to the researchers the right to use your likeness, image, appearance and performance - whether recorded on or transferred to videotape, film, slides, photographs - for presenting or publishing this research. No use of photos or video images will be made other than for professional presentations or publications. The researchers are unable to provide any monetary compensation for use of these materials. You can withdraw your voluntary consent at any time.

If you have any questions later on, then the researchers should be able to answer them: Dr. James Oñate 757-683-4351, or Nelson Cortes 757-683-5676. If at any time you feel pressured to participate, or if you have any questions about your rights or this form, then you should call Dr. George Maihafer, the current IRB chair, at 757-683-4520, or the Old Dominion University Office of Research, at 757-683-3460.

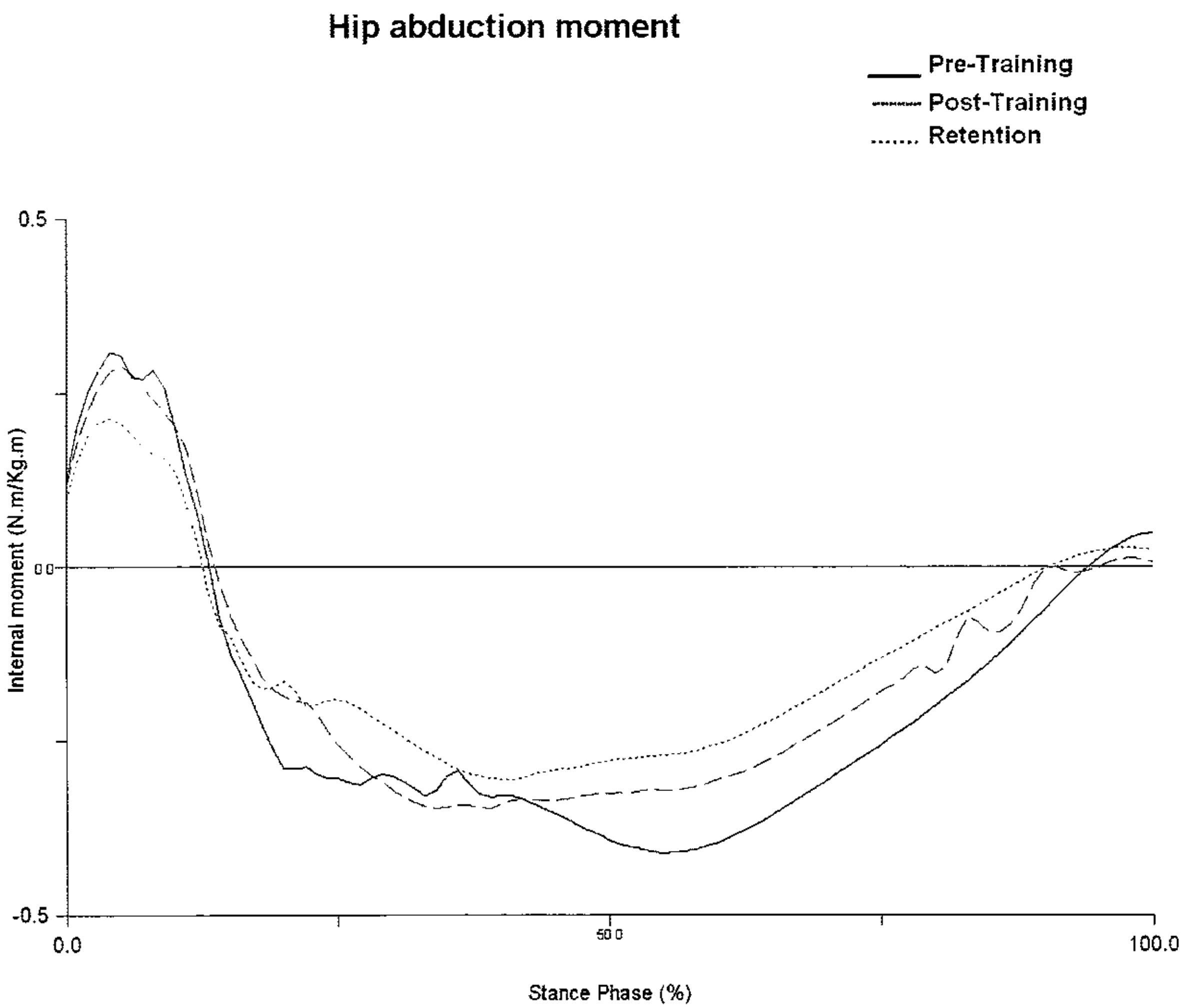
Subject's Printed Name & Signature	**Date**
Investigator's Printed Name & Signature	**Date**

Appendix 3

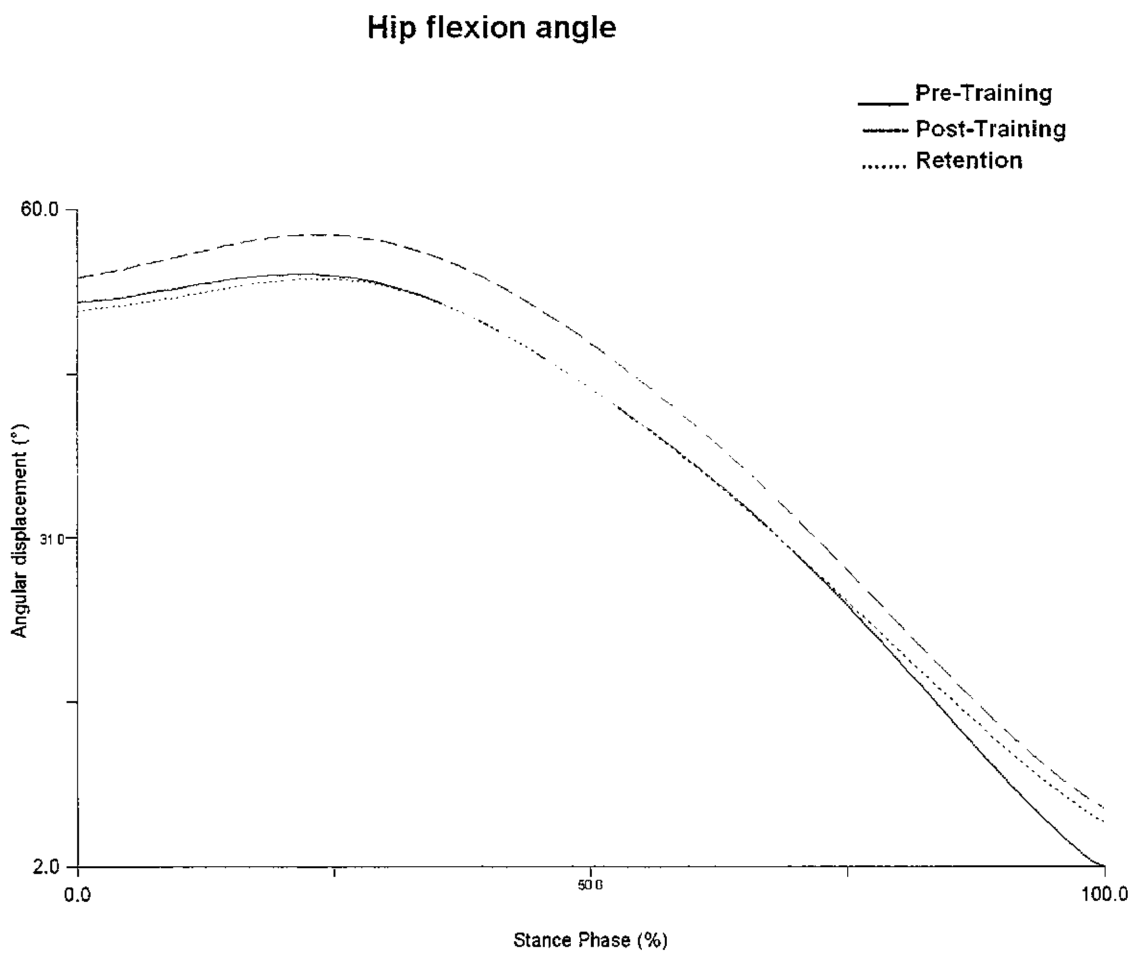


Hip abduction angle
Pre-Training
Post-Training
Retention
-1.0
-5.5
-10.0
0.0
50.0
100.0
Angular displacement (°)
Stance Phase (%)

Appendix 4

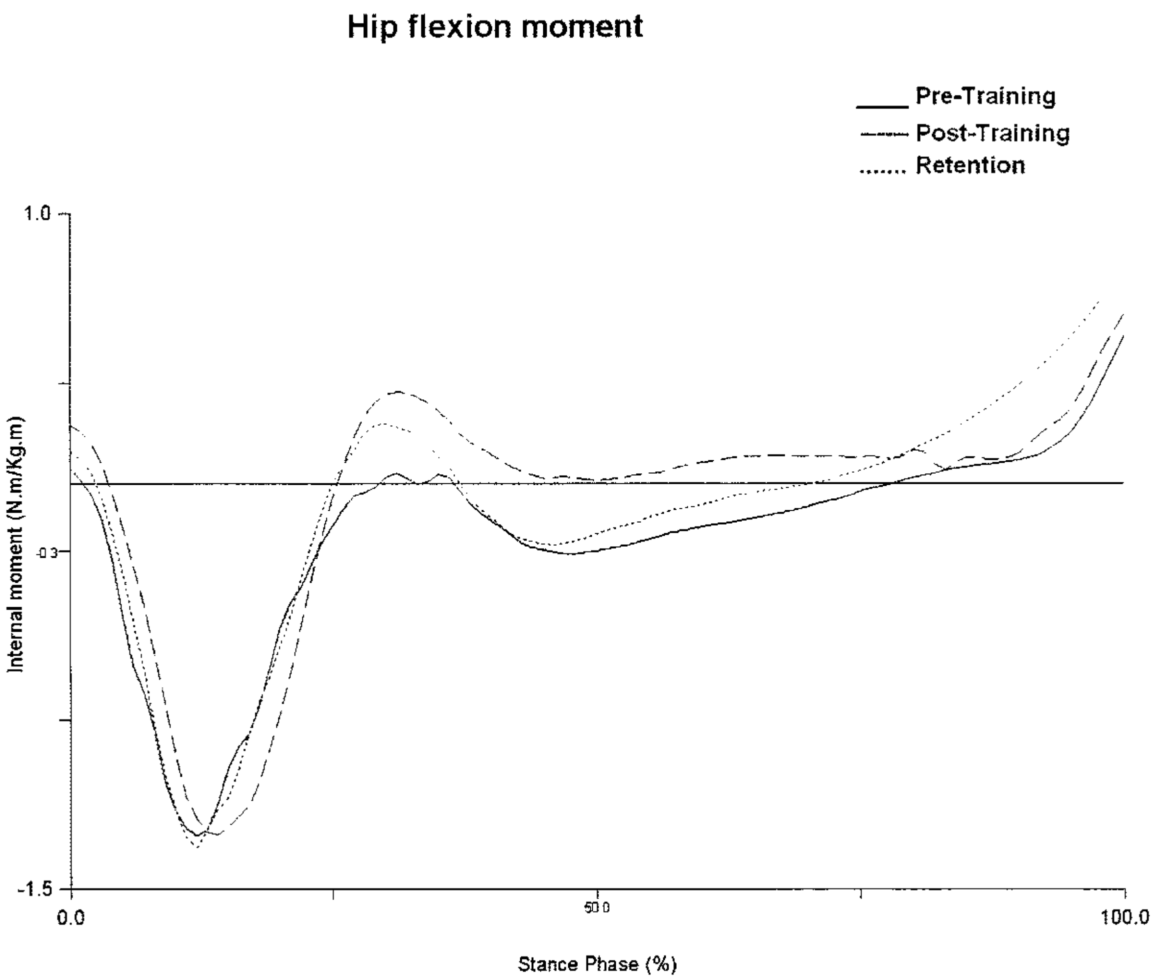

Hip abduction moment
Pre-Training
Post-Training
Retention
0.5
0.0
-0.5
Internal moment (N.m/Kg.m)
0.0
50.0
100.0
Stance Phase (%)

Appendix 5



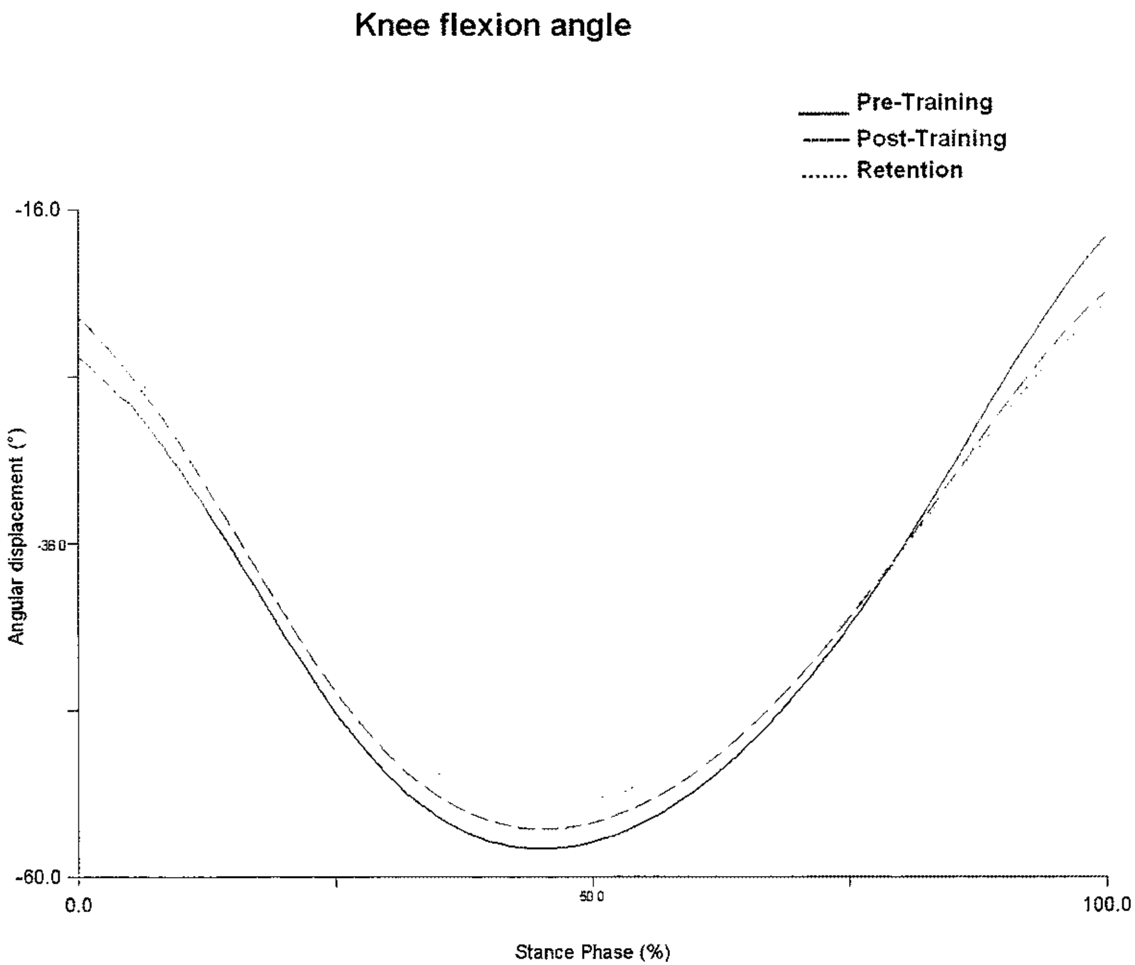
Hip flexion angle
Pre-Training
Post-Training
Retention
60.0
31.0
2.0
Angular displacement (°)
0.0
50.0
100.0
Stance Phase (%)

Appendix 6



Hip flexion moment
Pre-Training
Post-Training
Retention
1.0
-0.3
-1.5
Internal moment (N.m/Kg.m)
0.0
50.0
100.0
Stance Phase (%)

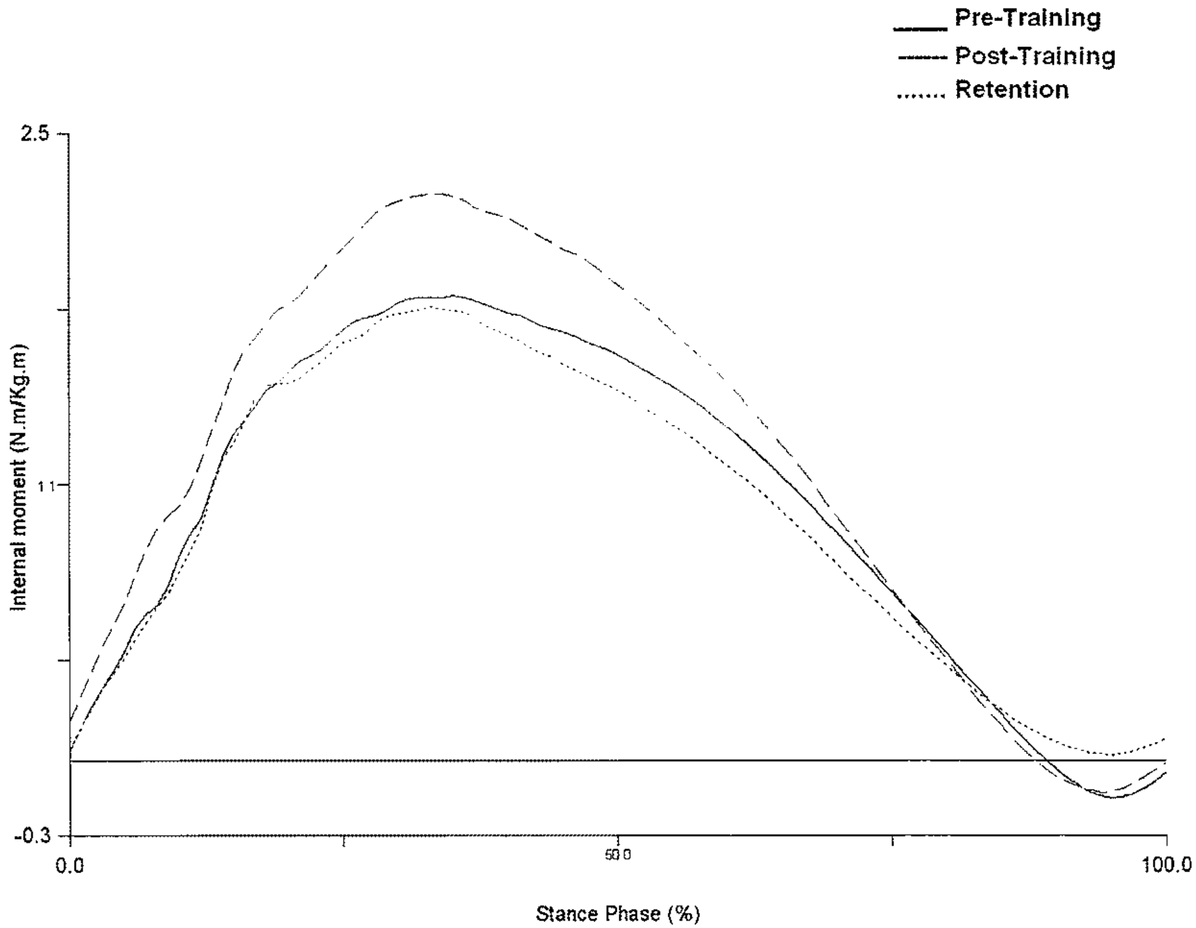
Appendix 7



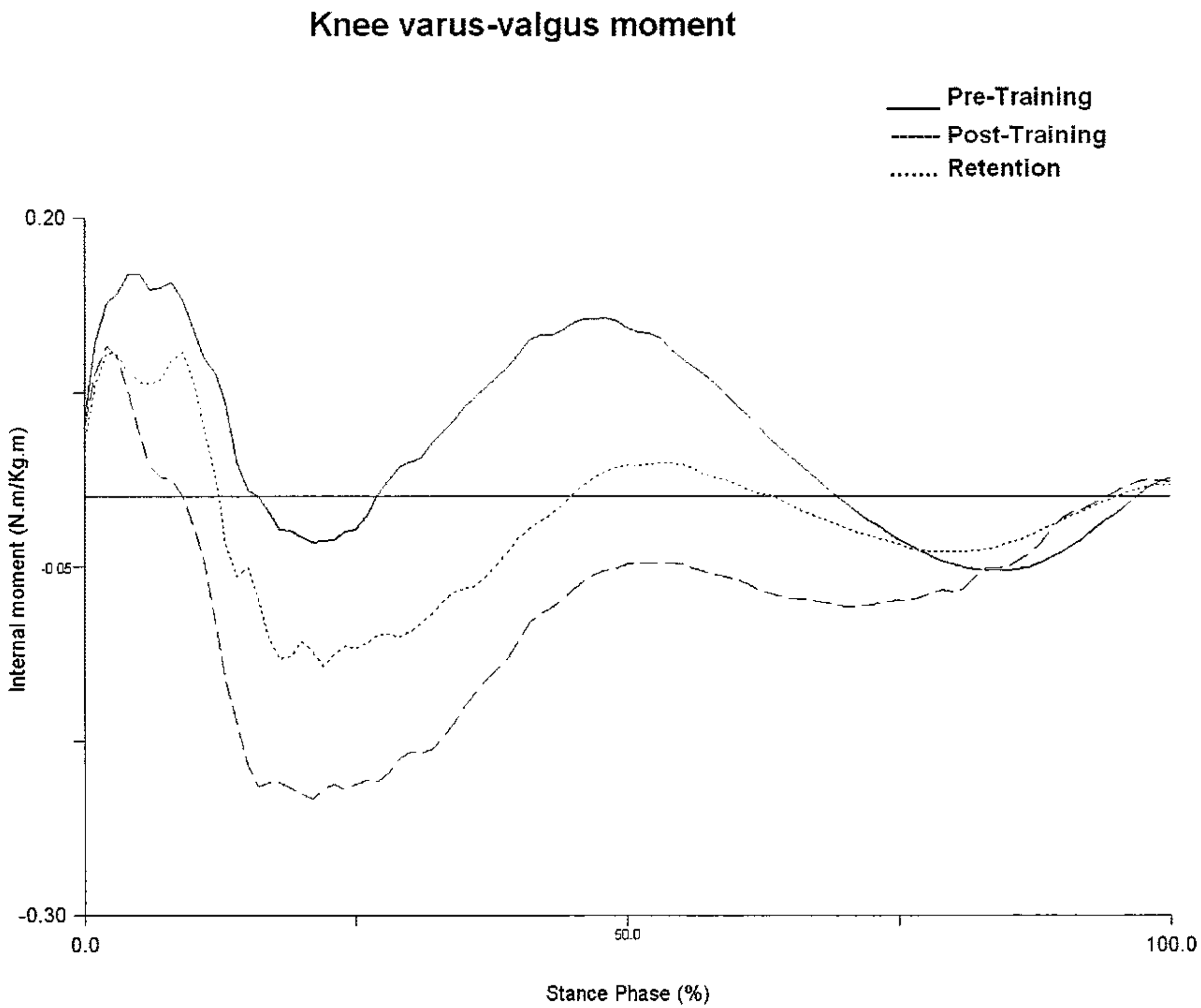
Knee flexion angle
Pre-Training
Post-Training
Retention
-16.0
-38.0
-60.0
Angular displacement (°)
0.0
50.0
100.0
Stance Phase (%)

Appendix 8

Knee flexion moment



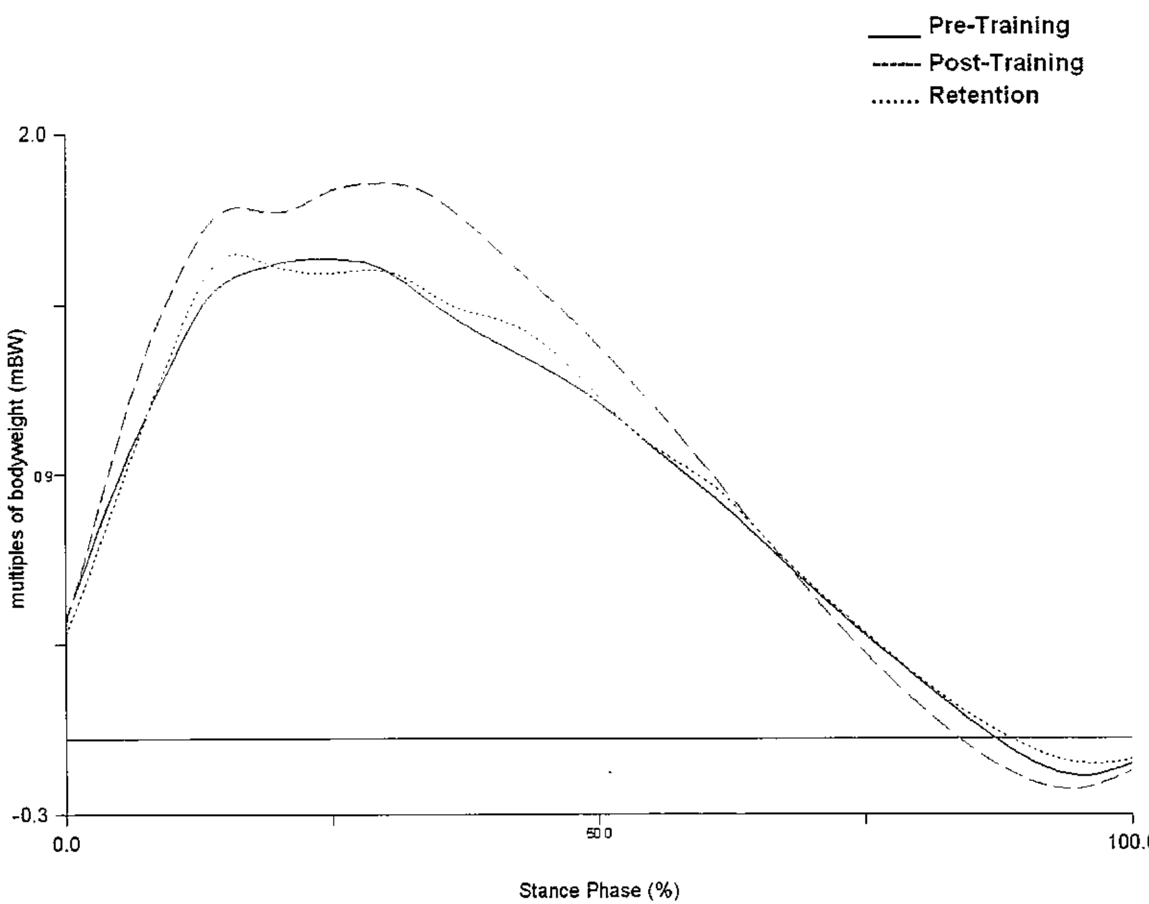
Appendix 9



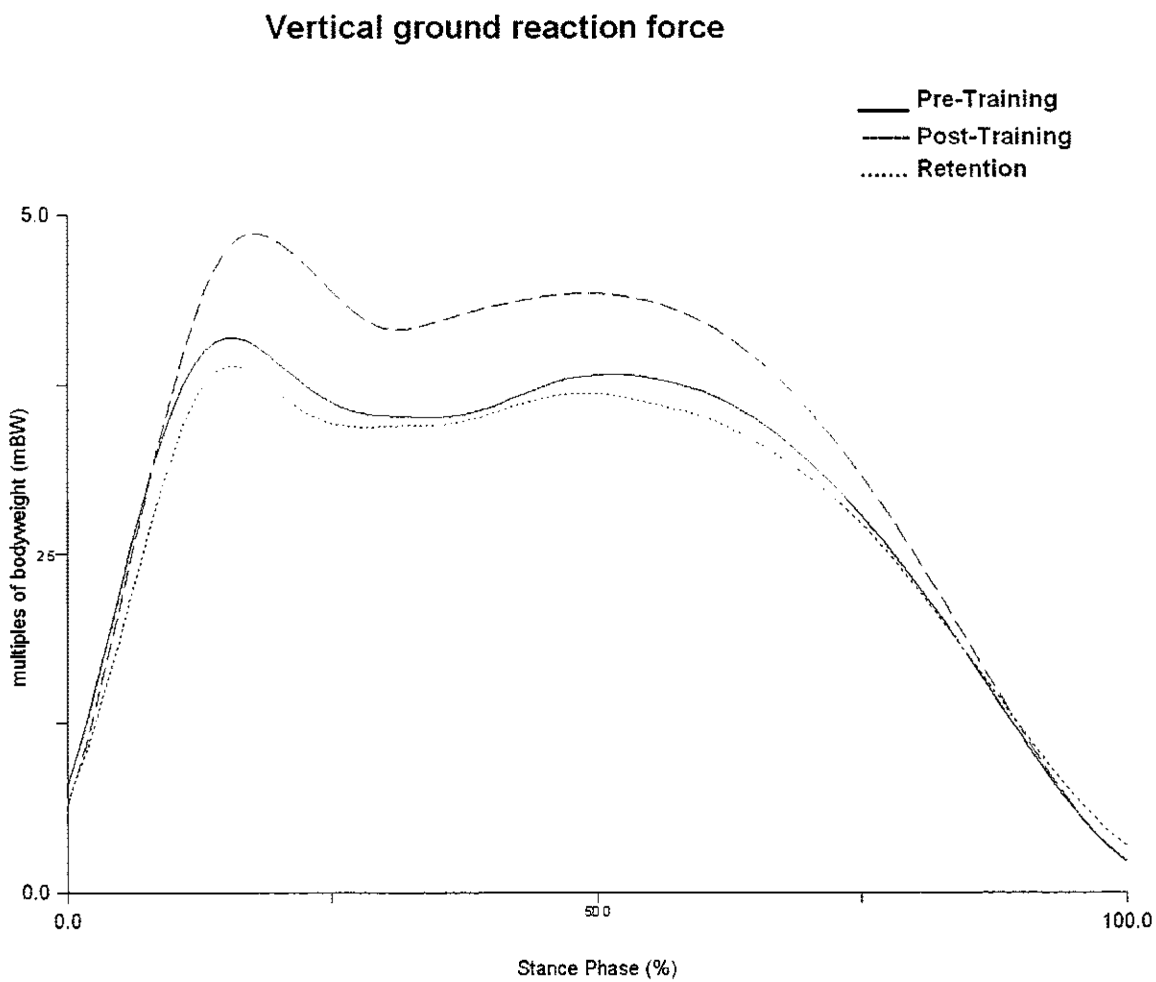
Knee varus-valgus moment
Pre-Training
Post-Training
Retention
0.20
-0.05
-0.30
Internal moment (N.m/Kg.m)
0.0
50.0
100.0
Stance Phase (%)

Appendix 10

Posterior ground reaction force



Appendix 11



Vertical ground reaction force
Pre-Training
Post-Training
Retention
5.0
2.5
0.0
multiples of bodyweight (mBW)
0.0
50.0
100.0
Stance Phase (%)

VITA
Ryan S. McCann

Department of Study

Old Dominion University
Human Movement Sciences Department
Student Recreation Center
Norfolk, VA 23529

Education

May 2010 Master of Science in Education
Post-Professional Athletic Training Education Program
Old Dominion University
Norfolk, Virginia

May 2008 Bachelor of Science
Athletic Training
Minor: Health Care
Northern Kentucky University
Highland Heights, Kentucky

Professional Experience

01/10 - 05/10 Old Dominion University; Norfolk, VA
Co-Instructor: Advanced First Aid and CPR (HE224, 3 credits)
- Designed lessons plans, lectured class, supervised lab activities, and designed and administered tests and quizzes following the curriculum of the American Red Cross

8/08 – 5/10 Old Dominion University; Norfolk VA
Graduate Assistant Athletic Trainer
- Certified athletic trainer with varsity athletes during Athletic Training Room coverage; rotations with Women's Varsity Soccer, Wrestling, Men's Varsity Baseball, Football, and Women's Basketball; practice and game coverage of Men's and Women's Varsity Tennis
- Performed evaluations of athletic injuries, created and supervised treatment and rehabilitative protocols for athletes, and assisted staff ATCs with administrative duties.