

DIFFERENCES IN THE MECHANICS BETWEEN THE DOMINANT  
AND NON-DOMINANT PLANT LIMB DURING INSTEP SOCCER KICKING

by

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## ABSTRACT

**INTRODUCTION:** Over the past 15 years, participation in women's soccer has increased drastically and with that comes increased exposure to injury. When athletes perform deceleration tasks, such as planting the limb during a kick, there is an increased risk of anterior cruciate ligament (ACL) injury. Low knee flexion angles at contact, high posterior ground reaction force (GRF), increased lateral trunk lean, high knee abduction angle, and high knee external rotation of the knee have all been identified as potential mechanisms of ACL injury during deceleration tasks. At higher levels of competition, a soccer player becomes more valuable if they are able to produce quality kicks with both of their legs. While there is some evidence that plant limb mechanics differ between the dominant and non-dominant plant limb, there is little known about how these differences in mechanics relate to ACL injury risk through the previous specific variables (Clagg et al., 2009). The purpose of the current study is to determine the differences in the mechanics between the dominant and non-dominant plant limb during instep soccer kicking of competitive female soccer athletes. **METHODS:** 18 female participants were recruited for the current study (means and standard deviations were: age 20.7 +/- 2.4 years, height 1.7 +/- 0.1 meters, weight 61.5 +/- 8.2 kg, respectively). Each participant performed three instep soccer kicks at a 60° angle from the right side of the ball and the left side of the ball for a total of six kicks. Three dimensional coordinate locations of a standard full-body marker set were recorded during the kicking trials with a Vicon MX motion capture system (VICON, Denver, CO, USA). Plant foot ground reaction forces

were recorded with Kistler force plates. Three dimensional trajectories and force plate data were imported into Visual 3D (C-Motion, Inc.; Germantown, MD) for subsequent analyses of the kinematic and kinetic variables. Custom processing protocols developed in Visual 3D were used to determine posterior GRF, knee joint angles in the sagittal, transverse and frontal planes, and lateral trunk lean. All variables were calculated between initial plant foot contact (IC) and 200 ms after IC. **STATISTICAL ANALYSIS:** In order to test for significant differences across the non-dominant and dominant limbs, repeated measures MANOVA was used with significance set at  $p \leq 0.05$ . **RESULTS & CONCLUSION:** A repeated measures MANOVA was used with significance set at  $p \leq 0.05$  in order to test for significant differences between the non-dominant and dominant limbs. A non-significant multivariate main effect of limb was found (Wilks'  $\lambda = 0.873$ ,  $F(5,30) = .872$ ,  $p = 0.511$ ). The current study found insignificant differences between the dominant and non-dominant plant limb with respect to kinematics. Previous research on kinematics during a deceleration task has been inconsistent. The results of the current study are however consistent with previous research by Sigward and Powers (2006a) who found that kinematic differences within a deceleration task were non-significant between genders and also between experienced and novice female soccer players (Sigward and Powers, 2006a). Even with the lack of differences between genders and experienced and novice soccer athletes with respect to kinematics, Sigward and Powers did find significant differences when assessing kinetics. Further research on kinetic differences between the dominant and non-dominant plant limb would be beneficial to ACL injury risk research as it pertains to female soccer athletes. In conclusion, the non-significant differences in the current study and those

found in previous studies imply that kinematic differences vary dramatically within each individual athlete, perhaps suggesting that ACL injuries are a result of other types of mechanisms (Sigward and Powers, 2006a).

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## CHAPTER 1: INTRODUCTION

### **Introduction**

There is a 4- to 6-fold greater incidence of anterior cruciate ligament (ACL) injury in female compared to male athletes participating in the same sports or activities (Arendt and Dick, 1995). One reason for this may be that female athletes tend to place different mechanical stresses on the musculoskeletal system when performing movements such as cutting, landing, pivoting, and decelerating (Hewett et al., 2006a, Hewett et al., 2006b, Orloff et al., 2008). Researchers have assessed the mechanics of female athletes during specific sports tasks that are commonly linked to ACL injuries (Besier et al., 2001a, Hewett et al., 2006b, Orloff et al., 2008, Clagg et al., 2009). The following five factors are commonly associated with the increased risk of ACL injury in female athletes: lower knee flexion angles at impact, posterior ground reactions force (GRF), knee abduction, knee external rotation, and lateral trunk lean (Yu and Garrett, 2007, Besier et al., 2001b, Hewett et al., 2009, Hewett et al., 2005).

The first of the five factors is landing or planting the limb with decreased knee flexion angle less than 30° (Yu and Garrett, 2007, Beynnon et al., 1995, DeMorat et al., 2004, Duerselen et al., 1995). When an athlete performs a cutting or pivoting task they extend their knee in order to generate more braking force, which helps them decelerate and change directions quickly. When comparing knee extension and flexion, an athlete's hamstring muscles produce less force during extension for two reasons. The first reason

for less force production is that knee extension lengthens the hamstring muscles. When the muscle is placed in a lengthened position, the myosin and actin filaments are unable to produce a large number of cross bridges. With a lack of cross bridge formation, there is a decreased amount of tension in the muscle, which results in a decreased generation of force production. The second reason is that knee extension places the hamstring muscles at a difficult line of pull on the tibia. More specifically, when the knee is flexed at lower angles, the hamstring muscles run closer to parallel with the tibia making it more difficult to pull back on the bone and produce posterior tibial translation and unload the ACL. Li and colleagues investigated the effect of hamstring and quadriceps co-contraction on the kinematics of the knee joint and in-situ forces on the ACL during isometric extension of the knee. They found that a hamstring contraction is not as effective in reducing forces placed on the ACL at smaller angles of knee flexion (Li et al., 1999). An athlete's quadriceps muscles are a major contributor to the anterior shear force placed on the proximal end of the tibia during ACL tears. Duerselen et al. determined that applied quadriceps force from full extension to 30° of knee flexion caused the ACL to sustain a high level of strain. As knee flexion angles increased to more than 30°, the level of strain on the ACL started to decrease (Duerselen et al., 1995). Therefore, individuals who place their knee at a flexion angle of 30° or less during deceleration tasks may have a higher risk of sustaining non-contact ACL injuries.

A second factor related to the risk of ACL injury, during tasks such as pivoting or landing, is increased peak posterior GRF (Yu and Garrett, 2007, Yu et al., 2006). Increasing peak posterior GRF during sports tasks leads to higher levels of quadriceps activity (Yu and Garrett, 2007). This is because a posterior GRF creates a high flexion

moment relative to the knee, which is balanced by an extension moment generated by the quadriceps (Yu and Garrett, 2007). Higher levels of quadriceps muscle force cause anterior shear force on the proximal end of the tibia and promotes anterior tibial translations (Yu and Garrett, 2007). In a study performed by Yu et al., it was determined that peak posterior GRF correlated with peak proximal tibial anterior translation (Yu et al., 2006). Also, Yu and colleagues studied the peak posterior GRF produced by females and males during a stop-jump task. They concluded that females produced greater posterior GRF's during landing in a stop-jump task than did their male counterparts (Yu et al., 2006). In summary, the greater the posterior GRF is, the more the quadriceps muscle are engaged and the greater the ACL loading through anterior tibial translation (Yu and Garrett, 2007, Yu et al., 2006).

Higher knee abduction angle is a third factor related to ACL injury risk because it results in increased tension and strain on the ACL (Hewett et al., 2005, Hewett et al., 2009, Quatman and Hewett, 2009, McLean et al., 2005, Wascher et al., 1993). Hewett and colleagues studied neuromuscular control and abduction loading of the knee as a predictor of ACL injuries in female athletes. They determined that ACL-injured females produced knee abduction angles during a jump landing task that were significantly larger than knee abduction angles produced by uninjured females during the same task (Hewett et al., 2005). Also, Hewett et al. 2009 performed video analysis of females tearing their ACL. During the videos, the researchers observed higher knee abduction angles in females who tore their ACL's compared to both females whom did not tear their ACL's and males who did tear their ACL's. The increase in knee abduction angle produced by female athletes may be a result of their neuromuscular deficits in the hamstrings (Hewett

et al., 2005). In the study by Fukuda et al., they determined that quadriceps and hamstrings co-contraction contributed to most of the muscular support of the abduction and adduction loading. If there are neuromuscular deficits in the hamstring muscles, there may be less support and prevention of abduction loading. Therefore, higher abduction angles is a common risk factor related to ACL injury in female athletes who perform pivoting, cutting, and landing maneuvers (Hewett et al., 2005, Hewett et al., 2009, McLean et al., 2005).

The fourth factor related to ACL tears during pivoting and cutting tasks is knee external rotation (Besier et al., 2001b, Wascher et al., 1993). In a study using fresh frozen cadaver ligaments, combined loads were placed to the tibia throughout a range of motion. The researchers induced external rotation of the knee, tibia relative to femur, knee abduction, and knee extension. When external rotation of the knee was produced by the researchers, high loads were placed on the ACL. Also, when external rotation and knee extension motion was combined it produced the highest loads placed on the ACL (Wascher et al., 1993). In a study by Besier and colleagues, it was determined that athletes who performed a sidestepping or cutting maneuver produced significantly higher knee external rotation moments compared to moments produced by athletes during normal running. Also, in an additional study by Besier and colleagues, females who performed an unanticipated cutting task generated external rotation moments that were up to twice the magnitude of the moments generated by females during pre-planned cutting tasks. These studies provide support that an athlete who produces external rotation of the knee during cutting, pivoting, and decelerating maneuvers places high loads and strain on the ACL (Besier et al., 2001a, Wascher et al., 1993).

A fifth factor related to ACL injuries, especially in females performing deceleration tasks, is lateral trunk lean (Hewett et al., 2009, Orloff et al., 2008, Alentorn-Geli et al., 2009). When an athlete moves their trunk laterally, the GRF vector moves laterally and creates a greater lever arm relative to the knee joint center (Hewett et al., 2009). When an athlete produces lateral trunk lean, it increases the potential for knee abduction loading (Hewett et al., 2009). When athletes generate greater knee abduction loading they produce greater knee abduction angles, which increases tension and strain on the ACL (Hewett et al., 2009, Wascher et al., 1993). In a video analysis study of ACL tears, Hewett et al. observed more lateral trunk lean and greater knee abduction angles during deceleration tasks in females as they tore their ACL. These results were significantly greater compared to males as they tore their ACL's and females who were uninjured performing the same task (Hewett et al., 2009). Lateral trunk lean is more prevalently produced by females performing similar sports tasks as males making it even more common in ACL injuries suffered by female athletes (Hewett et al., 2009, Orloff et al., 2008).

Due to the large amount of cutting, decelerating, and pivoting tasks during soccer, all of these risk factors are evident during a 90 minute game. One task that occurs often is planting the leg during a soccer kick. In fact, the act of kicking the ball during a soccer game accounts for roughly 51% of potential actions that may lead to injury (Rahnama et al., 2003). Since ACL injuries to female soccer athletes make up 23.6 % of all high school and collegiate injuries seen in the United States, kicking a soccer ball is a key task to focus on when considering injury risks in female athletes (Dick et al., 2007) .

At higher levels of competition a soccer player becomes more valuable if they are able to produce quality kicks with both of their legs. In fact in a research study by Starosta et al., the investigators determined that the most successful goal scorers are those players who can kick the ball with both feet (Starosta, 1988). However, most players display a dominance of kicking ability on one side because symmetry in kicking is difficult to develop. In a research study performed by Nunome and colleagues, it was determined that instep soccer kicking with the dominant kicking limb produces significantly greater knee muscle moments, intersegment velocities, and higher ball velocities than the non-dominant kicking limb. Similar results were reported in a study by Dorge et al. who determined that higher ball speeds were achieved with the dominant kicking limb compared to the non-dominant kicking limb due to higher foot speeds and a larger coefficient of restitution. These studies provide evidence that proper kinematics and symmetry between the kicking limbs is important to instep soccer kicking. However, there are only a few researchers that have studied plant leg kinematics and symmetry during instep soccer kicking (Clagg et al., 2009, Orloff et al., 2008).

Researchers who have studied plant leg mechanics during instep soccer kicking have assessed mechanical factors such as lateral trunk lean, knee extension, and knee external rotation (Clagg et al., 2009, Orloff et al., 2008). These two studies provide evidence that planting with the non-dominant limb is a less stable movement compared to planting with the dominant limb (Clagg et al., 2009, Orloff et al., 2008). Also, that plant leg mechanics of the non-dominant limb are consistent with the mechanical factors related to ACL injuries. Only one researcher has assessed the differences in dominant and non-dominant plant limb mechanics and its relationship with ACL injury (Clagg et al.,

2009). During this study, Clagg and colleagues assessed three mechanisms that they believed were causes of ACL injuries in female athletes. These three mechanisms were knee flexion torque, knee external torque, and knee abduction torque. All three moments were significantly higher in the non-dominant plant limb than the dominant plant limb. It was concluded in the Clagg et al. study that the non-dominant kicking limb is at a higher risk for ACL injury. However, unlike the current study, Clagg and colleagues were assessing the kinetics of the plant limb and not kinematics. Furthermore, there is no research assessing differences in female plant leg mechanics, between the dominant and non-dominant limb, using variables such as knee flexion angle, posterior ground reaction force, knee external rotation with the tibia relative to the femur, knee abduction angle, and lateral trunk lean. More research is needed in this area to help determine whether an athlete increases their risk of ACL injury while planting with their non-dominant plant limb.

### **Purpose**

The purpose of this study is to determine if there is a difference in the mechanics of the dominant and non-dominant plant leg during instep soccer kicking of competitive female soccer athletes. Furthermore, if there is a difference between limbs, to assess whether differences between the mechanics of the dominant and non-dominant plant limb are consistent with mechanisms related to the increase in ACL injury risk. The specific plant leg mechanics analyzed for the current study were as follows: frontal plane trunk angle, frontal plane knee angle, sagittal plane knee angle, knee external rotation, and posterior ground reaction force. It was hypothesized that there will be a difference between the non-dominant and dominant plant leg mechanics; specifically that at initial

ground contact the non-dominant plant limb will produce smaller angles of knee flexion, greater angles of knee abduction and external rotation, high posterior ground reaction force, and greater lateral trunk lean.

### **Significance**

Understanding the differences in dominant and non-dominant plant leg mechanics may help to provide more insight on the risk of ACL injury during a female instep soccer kick. The results may provide coaches with the knowledge that symmetry between the plant limbs is an important development during soccer practices for athletes who want to avoid ACL injuries. More specific variables have been chosen for this study because they are suggested by researchers to be potential risk factors leading to ACL injuries among female athletes who perform cutting, turning or planting maneuvers. If the results suggest that the non-dominant kicking leg exhibits the hypothesized mechanics, then there may be a link to potential ACL injury risk. Coaches may find this research beneficial in developing programs to prevent ACL injuries during soccer games and practices. Also, since there is limited data with regards to the asymmetry between the dominant and non-dominant plant limb during female soccer kicking, additional studies are needed to explore the nature of these potential differences (Clagg et al., 2009).

### **Limitations**

One potential limitation to this study is the number of participants included. The participant number may limit the scope of conclusions and the ability to generalize the results. The participants will need to have played soccer at a competitive level for one year previous to the study. Competitive soccer can be defined differently between

subjects and may result in a wide variety of skill levels. One participant may have more instep soccer kicking experience than another depending on the position in which they play on the field.

### **Delimitations**

The following delimitations were imposed in order to narrow the scope of the study. Eighteen participants volunteered for this study. All participants were competitive female soccer players with one year or more years of competitive soccer experience and were still currently playing. Participants were in the age range of 18 to 35. Any subjects with previous injuries to their ACL, as well as muscular skeletal injuries treated within the past six months, were not allowed to participate in the study. Although approach angles may vary considerably, participants were restricted to kick the soccer ball at a 60° angle of approach.

### **Summary**

When athletes perform deceleration tasks, there is an increased risk of ACL injury (Hewett et al., 2006b, Hewett et al., 2006a, Orloff et al., 2008). Soccer players use their plant limb to help them decelerate and stabilize their body before performing an instep soccer kick. Kicking the ball, during a soccer game, accounts for roughly 51% of potential actions that may lead to injury (Rahnama et al., 2003). The plant leg is important for instep soccer kicking performance, stabilization, and preparation of the body before the kick. Athletes who can produce symmetry between their plant limbs can perform quality soccer kicks with both legs while possibly decreasing their risk of injury due to less stabilization. Only one researcher has studied the differences in the non-

dominant and dominant plant limb mechanics during instep soccer kicking in female athletes (Clagg et al., 2009). Clagg and colleagues assessed a set of kinetic variables that they believed were determining mechanical factors that lead to increase ACL injury risk. In their research, they concluded that during an instep soccer kick the non-dominant plant limb produced significantly more braking torques in the knee than the torques that were measured in the dominant plant limb. Clagg et al. suggested that the non-dominant plant limb may be less stable and at greater risk for ACL injury. However, there is no research assessing differences in female plant leg mechanics, between the dominant and non-dominant limb, using variables such as knee flexion angle, posterior ground reaction force, knee external rotation with the tibia relative to the femur, knee abduction angle, and lateral trunk lean. More research is needed in this area to help determine whether an athlete increases their risk of ACL injury while planting with their non-dominant plant limb.

## CHAPTER 2: LITERATURE REVIEW

### **Introduction**

Females have a greater incidence of ACL injury compared to male athletes participating in the same sports or activities (Arendt and Dick, 1995). A proposed reason for this is that female athletes tend to place different mechanical stresses on the musculoskeletal system when performing movements such as cutting, landing, pivoting, and decelerating (Hewett et al., 2006a, Hewett et al., 2006b, Orloff et al., 2008). Researchers have assessed the mechanics of female athletes during specific sports tasks that are commonly performed during ACL injuries (Besier et al., 2001a, Hewett et al., 2006b, Orloff et al., 2008, Clagg et al., 2009). Through this combination of research, some common mechanical factors related to ACL injuries in female athletes have been determined.

Among the common mechanical factors that have been previously determined, there are four commonly cited kinematic biomechanical factors that are associated with increased risk of ACL injury. These four factors are: lower knee flexion angles at impact, knee abduction, knee external rotation, and lateral trunk lean (Yu and Garrett, 2007, Besier et al., 2001b, Hewett et al., 2009, Hewett et al., 2005). Also, there is the a kinetic variable of posterior ground reactions force (GRF) that has been commonly cited in research as a risk factor of ACL injury (Yu & Garrett, 2007). Unfortunately, there is little research assessing the differences in dominant and non-dominant plant leg mechanics in

female soccer players during instep soccer kicking. Thus, it is difficult to determine whether the non-dominant limb may be more at risk for ACL injury. This chapter outlines literature supporting the need for a study that assesses differences between the plant limbs in female soccer players during an instep soccer kick, and the importance in evaluating the previous mechanical variables related to ACL risk.

### **ACL Injuries**

Approximately 100,000 to 250,000 high school and collegiate female athletes tear their ACL each year (Toth and Cordasco, 2001, Myer et al., 2004). The USA spends \$650 million annually on ACL injuries in female high school and collegiate varsity sports (Myer et al., 2004). Soccer is one of the most high risk sports for ACL injuries in women's athletics today. In fact, a 15-year study by the NCAA Injury Surveillance System (ISS) noted that knee injuries from female soccer players accounted for 23.6% of all injuries sustained in American collegiate sports (Dick et al., 2007). Of these injuries, approximately 60-80% occur in the lower extremities and injuries to ACL are among the most serious and frequent (Kellis et al., 2004)

Athletes can incur an ACL injury during contact or non-contact situations. A non-contact ACL injury occurs when an athlete generates great forces or moments at the knee that apply excessive loading on the ACL (Yu and Garrett, 2007). Another example of a non-contact ACL injury is one that occurs in the absence of player to player or body to body contact (Myklebust et al., 1998). ACL injuries can be difficult to classify due to the different definitions used by researchers. Yet, researchers report that out of the total

amount of ACL injuries in all sports played in the United States, approximately 70% are non-contact and 30% are contact injuries (McNair et al., 1990, Boden et al., 2009).

### **Mechanisms of ACL Injuries**

There is a 4-to 6-fold greater incidence of ACL injury in female compared to male athletes participating in the same sports or activities (Arendt and Dick, 1995).

Researchers suggest that the differences in male and female ACL injury rate may be due to anatomical, anthropometric, neuromuscular, and hormonal differences between the two genders (Hewett et al., 2006b, Alentorn-Geli et al., 2009). Also, an additional reason for the ACL injury rate discrepancy between the two genders may be due to different mechanical stresses female athletes tend to place on the musculoskeletal system when performing sports tasks such as cutting, landing, pivoting, and deceleration (Hewett et al., 2006a, Hewett et al., 2006b, Orloff et al., 2008, Alentorn-Geli et al., 2009, Hewett et al., 2009).

Researchers have assessed the mechanics of female athletes during specific sports tasks that are commonly performed during ACL injuries (Besier et al., 2001a, Hewett et al., 2006b, Orloff et al., 2008, Clagg et al., 2009). From their research, they have determined a variety of mechanical variables, related to ACL injuries in female athletes exist. Within this variety of mechanical variables, there are four commonly cited kinematic factors and one kinetic factor associated with increased risk of ACL that will be studied here. These five factors are: lower knee flexion angles at impact, posterior ground reactions force (GRF), knee abduction, knee external rotation with the tibia

relative to the femur, and lateral trunk lean (Yu and Garrett, 2007, Besier et al., 2001b, Hewett et al., 2009, Hewett et al., 2005).

### **Knee Flexion Angle**

The first of the five factors is knee flexion angle less than 30° (Yu and Garrett, 2007, Beynnon et al., 1995, DeMorat et al., 2004, Duerselen et al., 1995). When an athlete performs a cutting or pivoting task, they often extend their knee in order to generate more braking force, which helps them decelerate and change directions quickly. When comparing knee extension and flexion, an athlete's hamstring muscles produce less force during extension for two reasons. The first is that knee extension lengthens the hamstrings making it more difficult to create tension and produce higher amounts of force. The second reason is that knee extension places the hamstring muscles at a difficult line of pull on the tibia (Yu and Garrett, 2007, Hewett et al., 2005). The hamstring muscles help protect the ACL by generating a posterior shear force on the tibia that reduces the anterior shear force from the patellar tendon and thus unloads the ACL (Yu and Garrett, 2007). Between the quadriceps and hamstring muscles, an unequal ratio of co-contraction almost always exists. However, when the hamstrings are placed at a difficult line of pull, this unequal ratio increases. More anterior tibial translation occurs when the hamstrings produce less force (Yu and Garrett, 2007).

Li and colleagues investigated the effect of hamstring and quadriceps co-contraction on the kinematics of the knee joint and in-situ forces on the ACL during isometric extension of the knee. The researchers placed an isolated 200 N load on the quadriceps as the knee underwent anterior tibial translation. Anterior tibial translation

increased when the knee was flexed from full extension to 30° of flexion. As the knee was placed at higher than 30° of flexion, the anterior tibial translation motion decreased (Li et al., 1999). In addition to the 200 N load on the quadriceps, the researchers placed an 80N load on the hamstrings, which resulted in a reduced anterior tibial translation. However, the reduction of anterior tibial translation produced by hamstrings loading was significantly less during full extension and flexion 30° or less. The in-situ forces on the ACL during quadriceps loading increased significantly as the knee was placed in and between full extension and 15°, of flexion. The in-situ forces placed on the ACL during hamstring loading significantly decreased as the knee was placed at higher than 15° to 30°. At flexion angles less than 30° to 15° the in-situ forces were not significantly altered by hamstring loading (Li et al., 1999). Li and colleagues concluded that hamstring loading is not as effective in reducing forces placed on the ACL at smaller angles of knee flexion (Li et al., 1999). Therefore, there may be an unequal ratio of co-contraction during flexion angles of 30° or less.

An athlete's quadriceps muscles are a major contributor to the anterior shear force placed on the proximal end of the tibia during ACL tears. In an additional study by Dueselen and colleagues, nine cadaveric knee joints were tested in an apparatus that allowed unconstrained knee joint motion and analysis of quadriceps muscle force simulation. The researchers determined that quadriceps muscle activation significantly strained the ACL at knee flexion angles less than 30°. As knee flexion angles increased to more than 30°, there was a decrease in quadriceps muscle activation strain on the ACL (Duerselen et al., 1995). The literature provided evidence that individuals who place their

knee at 30° of flexion or less during sports tasks have a high risk of sustaining non-contact ACL injuries.

### **Posterior Ground Reaction Force**

A second factor related to the risk of ACL injury is increased peak posterior GRF (Yu and Garrett, 2007, Yu et al., 2006). An increasing peak posterior GRF during an athletic task increases ACL injury by inducing a higher quadriceps muscle contraction (Yu and Garrett, 2007). This is because a posterior GRF creates a high flexion moment relative to the knee, which is balanced by an extension moment generated by the quadriceps (Yu and Garrett, 2007). The extension moment generates higher quadriceps muscle contraction, which induces anterior shear force on the proximal end of the tibia and promotes anterior tibial translations (Yu and Garrett, 2007).

In a study performed by Yu and colleagues, thirty healthy and active male and female college students performed a vertical stop-jump task frequently utilized during basketball, volleyball, and soccer games. The researchers recorded and assessed data on the proximal tibial anterior shear force and peak ground reaction values as each subject performed the stop-jump task. They determined from their findings that peak proximal tibial anterior shear force corresponded to posterior GRF. In addition, in this same study by Yu and colleagues, the researchers also assessed differences in peak posterior GRF and knee flexion angles between males and females during a stop-jump task. Their results indicated that peak posterior GRF was higher during a stop-jump task performed by females when compared to the peak posterior GRF produced by males performing the same task. Also, the peak posterior ground reaction force produced by females correlated

with lower angles of knee flexion (Yu et al., 2006). These results are helpful in understanding posterior GRF produced by females during a deceleration task, and how posterior GRF relates to lower angles of knee flexion, which is also a common ACL mechanical risk factor. Posterior GRF may generate lower angles of knee flexion due to higher extension moments produced by the quadriceps. One might postulate that increased posterior GRF is also related to possible unequal co-contraction between the quadriceps and hamstring muscles during lower flexion angles. In summary, the greater the posterior GRF is, the more the quadriceps muscle are engaged, and the greater the ACL loading through anterior tibial translation (Yu and Garrett, 2007, Yu et al., 2006)

### **Knee Abduction**

A third factor related to ACL injury is higher knee abduction angle (Hewett et al., 2005, Hewett et al., 2009, Quatman and Hewett, 2009, McLean et al., 2005). When an athlete produces higher knee abduction angles during sports maneuvers, it result in increased tension and strain on the ACL (Wascher et al., 1993, Hewett et al., 2009). In the study by Fukuda et al., the researchers measured ten human cadaveric knee specimens. They measured in-situ force in the ACL and anterior tibial translation in response to abduction torque. Knee abduction torques from 0 to 10 NM were applied to the cadaveric specimens throughout knee flexion angles of 0° to 90°. The researchers determined that as the knee was placed at lower degrees of flexion and at increased knee abduction torques, the forces produced at the knee increased anterior tibial translation and ACL strain (Fukuda et al., 2003).

Hewett and colleagues studied neuromuscular control and abduction loading of the knee as a predictor of ACL injuries in female athletes. They recruited a total of 205 female athletes in high-risk sports of soccer, basketball, and volleyball. Out of all 205 participants, nine female athletes had a previous ACL injury. All participants performed a jump-landing task and the results suggested that the nine previously injured athletes had significantly different knee posture compared to the non-injured athletes. Knee abduction angles in the previously injured participants were 8° greater during the jump-landing task (Hewett et al., 2005). Hewett and colleagues performed a follow up study with video analysis of female athletes tearing their ACL. Videos of the following 3 groups of athletes performing similar tasks were analyzed: females tearing their ACL, males tearing their ACL and females performing the same task that did not injury tear. All videos were recorded in the sagittal and coronal plane. During video analysis, researchers observed higher knee abduction angles in females who tore their ACL's compared to males who tore their ACL and females who did not tear their ACL (Hewett et al., 2009).

One reason for the increase in knee abduction angle produced by female athletes during sports tasks may be a result of their neuromuscular deficits in the quadriceps and hamstrings (Hewett et al., 2005). Fukuda et al. determined that quadriceps and hamstrings co-contraction contributed to most of the muscular support of the abduction and adduction loading. If there are neuromuscular deficits in the hamstring muscles, there may be less support and prevention of abduction loading. The literature supports higher abduction angles as a common risk factor related to ACL injury in female athletes (Fukuda et al., 2003, Hewett et al., 2005, Hewett et al., 2009).

### **Knee External Rotations**

The fourth factor related to ACL tears is knee external rotation (Besier et al., 2001b, Wascher et al., 1993). A study by Besier and colleagues investigated the external loads applied to the knee joint during different deceleration tasks and assessed the potential risk for ACL loading. The researchers recruited 11 healthy male soccer players and collected their lower limb kinetics during running, sidestepping, and crossover cutting. The purpose of the study was to compare the kinetics of cutting and sidestepping deceleration tasks to those of a running task. These types of tasks are popular during soccer games alongside planting the limb during a soccer kick. The results suggested that external/internal rotation moments were greater at the knee during the sidestepping and crossover cutting when compared to the running task. Specifically, higher external rotation moments were placed on the knee during the cutting maneuver and higher internal rotation moments were placed on the knee during the sidestepping maneuver. The high internal/external rotation moments of the knee during these deceleration tasks may be a result of a lack of stability in the knee preventing it from joint internal/external movement. The researchers concluded that compared with running, a potential for increased ACL loading during cutting and sidestepping tasks is a result of the large increase in knee internal/external rotation moments (Besier et al. 2001b).

According to Besier and colleagues, knee joint loading was assessed during unanticipated and preplanned running and cutting maneuvers in female soccer players (Besier et al., 2001a). The researchers assessed knee joint angles and the production of moments in knee flexion/extension, abduction/adduction, and internal/external rotation. The results of the study determined that during unanticipated running and cutting

maneuvers, subjects produced knee internal/external rotation moments up to twice the magnitude of the moments measured during pre-planned running and cutting maneuvers. Besier and colleagues concluded that running and cutting maneuvers performed without anticipation increases knee internal/external rotation and generates high moments applied to the knee, which may result in a risk of non-contact knee ligament injury. Both of the Beisers et al. studies provide support that an athlete who produces external rotation of the knee generates higher external rotation moments during cutting, pivoting, and decelerating maneuvers and therefore may place high loads and strain on the ACL (Besier et al., 2001b, Besier et al., 2001, Wascher et al., 1993).

### **Lateral Trunk Lean**

A fifth factor related to ACL injuries especially in females is lateral trunk lean (Hewett et al., 2009, Orloff et al., 2008, Alentorn-Geli et al., 2009). When an athlete moves their trunk laterally, the GRF vector moves laterally and creates a greater lever arm relative to the knee joint center (Hewett et al., 2009). In a study by Orloff and colleagues, differences in kinematics of plant leg position during instep soccer kicking between male and female soccer players were assessed. Researchers determined significant differences in female and male lateral trunk lean. Female soccer players produce greater lateral trunk lean as well as higher lateral GRF during instep soccer kicking compared to male soccer players (Orloff et al., 2008).

Athletes who produce lateral trunk lean also increase their potential for knee abduction loading (Hewett et al., 2009). In a video analysis of ACL tears, Hewett and colleagues collected, over a 12-year period, 23 injury videos: 10 female and seven male

ACL injured athletes, and six female controls performing similar landing and cutting tasks. The results of the video analysis suggested that lateral trunk lean and knee abduction angles were higher in female compared to male athletes during the time of their ACL injury. Females who injured their ACL produced greater lateral trunk lean motion and knee abduction during ACL injury compared to control females during similar tasks (Hewett et al., 2009). These videos suggest that as females produce lateral trunk lean movements they also produce greater knee abduction angles. When athletes generate a greater knee abduction angle, they produce greater loading and tension on the ACL (Hewett et al., 2009, Wascher et al., 1993).

### **Soccer Kick Symmetry**

Mechanical variables related to ACL risk have been studied during tasks of cutting, decelerating, jump-landing, and pivoting (Hewett et al., 2009, Hewett et al., 2006a, Besier et al., 2003, Besier et al., 2001, Orloff et al., 2008). All of these tasks mentioned previously are evident during a 90 minute soccer game. Another common task during a soccer game is an instep soccer kick. An instep soccer kick accounts for roughly 51% of potential actions that may lead to injury (Rahnama et al., 2003). Often during a soccer kick, the plant leg is used to decelerate and properly position the body in preparation for the kick (Clagg et al., 2009). This makes the plant leg during an instep soccer kick a key area of focus when assessing injury risks in female soccer players.

At higher levels of competition, a soccer player becomes more valuable if they are able to produce quality instep soccer kicks with both of their legs. In fact, researchers have determined that the most successful goal scorers are those players who can kick the

ball with both feet (Starosta, 1988). Yet, most players display a dominance of kicking ability in one of their legs because symmetry in kicking is difficult to develop. Nunome and colleagues examined five highly skilled club soccer players, participating in an under-17 international competition, while performing instep soccer kicks with their preferred and non-preferred leg. As the kicking motions were captured, the researchers reported data that suggested significantly greater knee muscle moments, intersegment velocities, and higher ball velocities in the dominant limb compared to the non-dominant kicking limb. Similar results were reported in a study by Dorge et al. who randomly selected 30 skilled soccer players to perform an instep soccer kick with the dominant and non-dominant leg while the researchers measured ball speed with a radar gun. The researchers concluded the higher ball speeds were achieved with the dominant kicking limb compared to the non-dominant kicking limb due to higher foot speeds and a larger coefficient of restitution. The researchers of these two studies also provide evidence that proper kinematics, kinetics, and symmetry between the kicking limbs are important to instep soccer kicking (Nunome et al., 2006, Dorge et al., 2002). However, there are only a few researchers that have studied the differences between the plant legs during instep soccer kicking (Clagg et al., 2009, Orloff et al., 2008).

### **Plant Leg Symmetry**

Researchers who studied symmetry between the plant legs during instep soccer kicking found common mechanical factors they believe to be risks of ACL injury. Among these mechanical factors are lateral trunk lean, and knee joint moments in all three planes (Clagg et al., 2009, Orloff et al., 2008). These two studies provided evidence that planting with the non-dominant limb is a less stable movement compared to planting

with the dominant limb (Clagg et al., 2009, Orloff et al., 2008). Also, plant leg mechanics of the non-dominant limb more closely resemble mechanics related to ACL injuries in comparison to the dominant limb. Specifically in females, differences in the dominant and non-dominant plant leg mechanics and their relationship with ACL injury risk have been assessed by Clagg et al. (Clagg et al., 2009). During this study, Clagg and colleagues studied nine female collegiate soccer players as they performed a series of kicking tasks from three different approach conditions. Kinetic data was assessed on the hip, knee, and ankle and joint moments of the plant leg were recorded. The results suggested that the non-dominant plant leg produced greater extension, external rotation, and abduction moments at the knee compared to the dominant plant leg during instep soccer kicking.

Clagg et al. indicate that the non-dominant plant leg produced greater braking forces than the dominant plant leg. The mechanical variables chosen in their study were believed to be causes of ACL injuries in female athletes. The differences between the dominant and non-dominant limb mechanics during this study suggest that the non-dominant plant limb is at a higher risk for ACL injury. Clagg and colleagues were assessing the knee joint moments in all three planes of the plant limb during each kick. A study that assesses differences in the kinematics of plant limb has not been performed. If knee joint moments are seen more readily during a deceleration task, it might be that the knee is less stable during such a maneuver and therefore joint movement is a result. Furthermore, a research study that assesses the differences in dominant and non-dominant plant leg mechanics in relation to knee flexion angle, knee external rotation angle, knee

abduction angle, posterior ground reaction force, and lateral trunk lean has never been studied.

### **Summary**

When athletes perform deceleration tasks, there is an increased risk of ACL injury (Hewett et al., 2006b, Hewett et al., 2006a, Orloff et al., 2008). One deceleration task is the act of kicking a ball during a soccer game, which accounts for roughly 51% of potential actions that may lead to injury (Rahnama et al., 2003). Soccer players use their plant limb to help decelerate and stabilize their body before performing an instep soccer kick. Plant leg mechanics are important for instep soccer kicking performance, stabilization, and preparation of the body before the kick. Athletes who can produce symmetry between their plant limbs can perform quality soccer kicks with both legs while possibly decreasing their risk of injury due to less stabilization. Only one researcher has studied the differences in the non-dominant and dominant plant limb mechanics during instep soccer kicking in female athletes (Clagg et al., 2009). Clagg and colleagues assessed a set of kinetic variables that they believed were determining mechanical factors leading to increased ACL injury risk. In their research, they concluded that during an instep soccer kick the non-dominant plant limb produced significantly more braking moments in the knee than the moments that were measured in the dominant plant limb. Clagg et al. suggested that the non-dominant plant limb may be less stable and at greater risk for ACL injury. However, there is no research assessing differences in female plant leg mechanics, between the dominant and non-dominant limb, using variables such as knee joint angles in all three planes, posterior GRF, and lateral

trunk lean. More research is needed in this area to help determine whether an athlete increases their risk of ACL injury while planting with their non-dominant plant limb.

## CHAPTER 3: METHODS

### **Introduction**

This chapter provides a description of the methods used to assess whether differences exist in the mechanics of the dominant and non-dominant plant limb during an instep soccer kick in female soccer players. The participants in this study performed six total soccer kicks, three from the dominant limb and three from the non-dominant limb. Kinematic and kinetic variables during each soccer kick were collected. Five specific variables, chosen based on their potential relationship to ACL injury, were analyzed to determine whether differences exist between the dominant and non-dominant plant limb during instep soccer kicking. This chapter outlines the participant inclusion and exclusion criteria, recruitment policies, testing procedures, measurement instruments, data reduction, and statistical analysis that were used.

### **Participants**

Eighteen female participants were recruited for the current study (means and standard deviations were: age 20.7 +/- 2.4 years, height 65.3 +/- 2.2 inches, weight 135 +/- 17.9 lbs, respectively). All participants had one year of previous experience in competitive soccer and are still currently playing. Competitive soccer was defined as soccer at the level of high school, club, and collegiate or Olympic Development Program (ODP). Any participants who had played over half of their soccer career as a goal keeper were excluded from the study. Participants who had received treatment from a physician

or doctor concerning a musculoskeletal injury in the past six months were excluded from the study. Such an injury could affect the ability of the participant to perform the instep soccer kick and possibly alter the mechanics of the previously injured plant leg. Also, any participant with a previously injured ACL was excluded from the study.

Women's collegiate and competitive high school and club soccer has become a popular sport in the United States. Within the Boise, Idaho area, there are a variety of high school teams, club programs, collegiate soccer programs, and ODP. Thus, the participants were recruited from this population. The participants were recruited through announcements at local soccer indoor facilities, the Boise State University recreation centers, and outdoor soccer parks in and around the Boise school district. The participants were also recruited through flyers and by word of mouth. An effort was made through personal recruitment of colleagues, friends, and acquaintances to enlist participants from and around the Boise, Idaho area. All participation was voluntary.

### **Procedure**

The study consisted of one data collection session. Within this session, participants were given a brief introduction of the study, including the purpose, requirements, and procedures that were to take place during testing. Anyone who was interested in volunteering to be a part of the study was asked to sign a written consent form approved by the University's Institutional Review Board. Once the participant had signed the consent form, she then filled out the eligibility form. This form included the participants inclusion and exclusion criteria such as age, soccer experience, position the participant played on the soccer field, which limb the participant considered their

dominant kicking leg, history of previous musculoskeletal injuries within the past six months, and note of any previous ACL injuries. All responses were treated with confidentiality. If the participant was eligible, they could continue on to the testing portion of the study.

Participants were asked to change into tight fitting clothing that did not have any reflective material and their indoor soccer shoes. The first procedure was to take the participants height and weight with a stadiometer and scale. All measurements performed on the participants were made by female members of the research team. A total of 53 reflective markers were applied to the participants in preparation for the motion capture protocol. The marker set consisted of reflective spherical markers that were fixed securely onto the lateral and medial side of the right and left lower extremity limbs. One cluster of markers was placed on the right and left lateral side of the thigh, shank and foot, one marker each on the right and left anterior superior iliac spine, posterior superior iliac spine, lateral and medial epicondyle of the knee, and lateral and medial malleoli of the ankle. The marker set also included upper body markers with one on the left and right medial and lateral wrist, lateral forearm, lateral left and right upper arm, lateral left and right shoulder, clavicle, manubrium, xiphoid process, right scapula, C7, T10, and right and left side of the anterior head and right and left side of the posterior head (Kellis et al., 2004, Besier et al. 2001b).

Participants were then asked to perform a series of calibration trials in order to calculate functional joint centers of the right and left knee and the right and left hip (Schwartz and Rozumalski, 2005). Participants then warmed up on a treadmill for 3

minutes. The treadmill started off at a speed of 1.5 miles/hour and continually increased its speed 0.10 miles/hour every 10 seconds. A familiarization period was performed next in which the participants could practice their approach of the kick without kicking the ball. This was done to help the participant familiarize themselves with the boundaries and the number of approach steps allotted to them during their kick. Participants had to stay within a two foot wide boundary, which was at a 60° angle from the right and left side of the ball. They were only allowed three approach steps towards the ball before the kick. Once the participant felt comfortable, they were allotted several practice trials to warm up and familiarize themselves with kicking a soccer ball in the laboratory. The ball was placed in a position on the side of the force plate that assured their plant foot would make contact with the force plate. Participants were told to strike the ball with as much force as possible while aiming at a marked target in the shape of an X on a net hanging eight feet in front of the ball. This net was placed perpendicular to the y-axis of the global coordinate system. Each participant performed three instep soccer kicks at the 60° angle from the lateral side of the ball with their dominant limb first. They then repeated the steps of the familiarization period and three practice kicks from a 60° angle from the lateral side of the ball with the non-dominant limb. Then they took their three instep soccer kicks with the non-dominant kicking limb. A kick that did not result in full placement of the foot on the force plate was excluded from data analysis and a redo of the kick was allotted.

Three dimensional coordinate locations of a standard full-body marker set were captured at 240Hz (Kernozek and Ragan, 2008, Lin et al., 2009) during the kicking trials with an 8 camera Vicon MX motion capture system (VICON, Denver, CO, USA). These

data were later used to calculate joint and segmental angles. The plant foot GRF was recorded with Kistler force platform (Kistler, Amherst, MA, USA). Force plate data were later used to determine the posterior GRF during the instep soccer kick.

### **Data Analysis**

Labeled 3D trajectory and force plate data were imported into Visual 3D (C-Motion, Inc. Germantown, MD) for analysis of the kinematic and kinetic variables. The kinematic and kinetic data were filtered in Visual 3D using a Butterworth low pass filter at a cutoff frequency of 6 Hz for the kinematic data and 40 Hz for the kinetic data (Lin et al., 2009). Custom processing protocols developed in Visual 3D were used to determine the minimum knee flexion angle, peak posterior GRF, peak knee abduction angle, peak knee external rotation angle tibia relative to femur, and peak lateral trunk lean. All variables were calculated between the time of initial plant foot contact (IC) to 200 ms after IC (Yu et al., 2006, Hewett et al., 2009). The force plate data collected during each kicking trial were used to determine IC and the data was manually cropped at 200 ms after IC (Orloff et al., 2008). The average of the minimum knee flexion angle, peak knee abduction angle, peak knee external rotation angle, peak lateral trunk lean, and peak posterior ground reaction force was calculated over all three trials for the dominant and non-dominant plant limbs, respectively. The averages of the five mechanical variables were calculated and used in the statistical analysis to determine if any significant differences existed between the limbs.

### **Statistical Analysis**

In order to test for significant differences across the non-dominant and dominant limbs, Repeated Measures MANOVA was used with significance set at  $p \leq 0.05$ . If the Repeated Measures MANOVA indicated significant differences existed in the mechanics of the plant limbs, a discriminate analysis would be used as a post-hoc test to determine how each individual variable contributed to the difference.

## CHAPTER 4: RESULTS

### **Introduction**

In the current study, five mechanical variables were assessed to determine whether there was a difference between the dominant and non-dominant plant limb during instep soccer kicking. These five variables were minimum knee flexion angle, peak posterior GRF, peak knee abduction angle, peak external rotation angle, and peak lateral trunk lean. An average of these minimum and peak values was calculated over the three kicking trials from both the dominant and non-dominant side. Therefore, for each participant, the mean value for each variable was calculated for the dominant and the non-dominant plant limbs, respectively. In order to test for significant differences across the non-dominant and dominant limbs, a Repeated Measures MANOVA was used with significance set at  $p \leq 0.05$ . If the Repeated Measures MANOVA indicated significant differences existed in the mechanics of the plant limbs, a discriminate analysis would be used as a post-hoc test to determine how each individual variable contributed to the difference. This chapter contains the descriptive statistics and the results of the Repeated Measures MANOVA for the variables of interest.

## Descriptive Statistics

**Table 1.1 The Means and Standard Deviations of Each Variable Within the Dominant and Non-Dominant Plant Limb.**

Variable	DL Mean (SD)	NDL Mean (SD)
AP GRF (N)	154.19 (22.04)	118.39 (22.04)
Sagittal Knee Angles	21.87 (1.12)	20.78 (1.12)
Frontal Knee Angles	-3.68 (1.37)	-1.63 (1.37)
Transvers Knee Angles	-0.74 (0.01)	0.94 (1.94)
Trunk Lean (deg)	-2.63 (.659)	-4.07 (0.66)

## Repeated Measures MANOVA

A non-significant multivariate main effect of limb was found during the deceleration task (Wilks'  $\lambda = 0.873$ ,  $F(5,30) = .872$ ,  $p = 0.511$ ). Therefore, a discriminant analysis was not performed due to the non-significant difference between the dominant and non-dominant plant limb.

When visually inspecting the means of the variables, it seems that the dominant plant limb produced greater posterior GRF in comparison to the non-dominant plant limb (dominant  $154.19N \pm 22.04N$ , non-dominant  $118.39 \pm 22.04$ ). The non-dominant plant limb produced a smaller knee flexion angle (non-dominant  $20.78 \pm 1.12$  dominant  $21.87 \pm 1.12$ ), greater abduction angle (non-dominant  $-1.63 \pm 1.37$  dominant  $-3.68 \pm 1.37$ ), greater external rotation angle (non-dominant  $0.94 \pm 1.94$  dominant  $-0.74$ ), and lateral trunk lean (non-dominant  $-4.07 \pm 0.66$  dominant  $-2.63 \pm .659$ ) all in comparison to the dominant plant limb. However, potentially due to the variability of the data, these results

do not lead to the conclusion that there is a significant difference in the plant leg mechanics of the dominant and non-dominant limbs.

## CHAPTER 5: DISCUSSION AND CONCLUSION

### **Discussion**

The results of the current study indicate that there was a non-significant difference in the mechanics between the dominant and non-dominant plant limb of female soccer players while performing an instep soccer kick. The lack of difference between the dominant and non-dominant plant limb found in the current study is contrary to our original hypothesis

One reason for the non-significant difference between the dominant and non-dominant limb may be the methodology used in the current study with respect to event time and the assessment of only minimums and maximums within each variables event. Designating a specific time frame to assess the five mechanical variables in the current study was difficult due to the inconsistent research on timing of ACL tears (Clagg et al., 2009, Kellis et al., 2004, Orloff et al., 2008, Hashemi, 2011). In previous research, mechanical variables related to ACL injury risk have been assessed between IC and ball contact (Clagg et al., 2009, Kellis et al., 2004). However, in a study by Orloff et al., mechanical risk factors were assessed at initial contact and ball contact yet not in between. Park et al. and colleagues assessed mechanical risk factors between IC and 150 ms. The event chosen for the current study was used in previous research as these previous researchers believed ACL injuries occurred sometime between IC and 200 ms (Yu et al., 2006, Hewett et al., 2009).

Within the current research study, after the participants performed IC with the plant limb, they were able to kick the ball before reaching 200 ms. The time frame in the current study may have been too long for valid assessment of the specific kinematic variables due to the speed of the movement. During the instep soccer kick, soccer players use their plant limb to stabilize themselves as they swing through the ball with their kicking limb. Stabilization of the knee requires an athlete's ability to receive feedback from the body and in turn balance and coordinate themselves accordingly to the task (Myer et al., 2006, McLeod et al., 2009). The act of stabilization is not necessarily one smooth and fluid motion, and so the athlete could potentially be adjusting their knee joint back and forth within each plane in order to balance through-out the entire kick. If assessment of mechanics is within a longer event time it may be difficult to determine the exact kinematics as they are constantly changing in order to adjust for balance during the kick. In this case, a more accurate way to look at joint angle kinematics would be to split the plant limb motion into phases or to only look at an exact point in time during the deceleration task (Hewett et al., 2009).

In a survey on the mechanisms of ACL injury, a majority of the 89 athletes whom had previously torn their ACL recalled hearing a loud popping sound and believed their injury occurred at IC (Boden et al., 2000). The athletes who fulfilled the survey were performing deceleration tasks at the time of their injury within sports such as basketball, football, and soccer. The recall of the exact time of their personal ACL injury, which for most was at IC, may be supported by the belief that athletes performing a deceleration task have a delay of adequate co-activation in the quadriceps and hamstring muscles milliseconds prior to foot contact (Hashemi, 2011). The quadriceps and hamstrings

provide a sense of “active control” to stabilize that knee. If there is a delay in “active control” just prior to IC, the athlete may be using the support of ligaments and tendons, or “passive control,” at IC to make up for the difference. However, this lack of muscular protection is only over a short duration of time (Hashemi, 2011). Therefore, IC and possibly a few milliseconds may be a more relevant time frame to assess mechanisms of ACL injury. This thought is supported by investigators who suggest ACL injury occurs between 17 and 50 ms after IC (Krosshaug et al., 2007). In addition, the values for each variable were calculated as an average of minimum knee flexion, peak knee abduction, peak knee external rotation, peak lateral trunk lean and peak posterior GRF over all three trials from the dominant and non-dominant side. Considering that the event time frame may have been too long, a better method used to match this time frame would be to calculate an average of the entirety of the movement throughout the entire event time over all three trials. Since the variability of movement within each participant was more apparent during the longer time frame, it was difficult to determine that the limb was in only one position throughout IC to 200 ms.

The lack of significant kinematic differences between the dominant and non-dominant limb is not entirely surprising given previous investigations evaluating knee joint kinematics related to ACL injury are somewhat inconsistent (Sigward and Powers, 2006a, McLean et al., 2004a, Yu et al., 2006, Yu and Garrett, 2007). There is much debate as to whether knee sagittal plane biomechanics are more or less relevant to ACL injury when compared to knee frontal and transverse plane biomechanics (McLean et al., 2004a, Yu and Garrett, 2007). The debate as to which knee plane biomechanics put the ACL at greater risk has given rise to research articles supporting significant and non-

significant kinematical values from both perspectives. Therefore, in the current study, we chose to look at knee biomechanical kinematics in all three planes. Even more so, investigations on differences between gender biomechanics in relation to ACL injury have also revealed non-significant results (Malinzak et al., 2001, McLean et al., 2004b). While it is believed that females may produce more knee abduction during a deceleration tasks when compared to their male counterparts, it is under debate as to whether females also produce lower knee flexion angles (Malinzak et al., 2001, McLean et al., 2004b).

To add to this inconsistency, individuals in the current study demonstrated inconsistent kinematics while performing the three kicking trials. The types of kicks produced could be divided into two categories. One category of kick may be defined as a “breaking kick” in which the GRF was directed in the posterior direction as the participant planted the limb at IC. The other type of kick could be categorized a “run through” kick in which the GRF was pointed in the anterior direction for the entire duration of the kick. This variation within a participant’s plant limb mechanics made it difficult to determine the exact type of kinematics that each subject utilized even within one of their limbs. Further research could investigate the mechanics of these two types of kicks to determine if any differences exist and to look deeper into an athlete’s risk of ACL injury based on the type of kick.

The current study has some limitations with regards to data collection and analysis. Within the data collections, every effort was made to minimize marker movement were performed by taping the markers firmly to their landmarks and strapping them down for extra security. Error of marker placement could have affected the

kinematic values although the markers were placed on each participant consistently by the same researcher. With respect to data analysis, the time frame in the current study may have been too long for valid assessment of the specific kinematic variables due to the speed of the movement. The long event time may have hindered the ability to narrow in the specific kinematic values that are relevant to ACL injury. Previous research suggests a smaller event time would be more appropriate when calculating kinematic variables related to ACL injury (Krosshaug et al., 2007). Another limitation to the study was the assessment of only minimum and maximum values of each variable. It's possible that calculating an average of each variable over the entire event time would be a better representation of kinematics than only assessing differences between minimum and peak values.

Even with these limitations, current study mirrors that of a similar investigation by Sigward and Powers (Sigward and Powers, 2006a). They found non-significant differences between kinematics of experienced and novice female soccer players performing a deceleration task. Sigward and Powers also contributed the lack of differences in kinematics between experienced and novice soccer athletes to the inconsistent results supported by previous research. However, these investigators also assessed kinetics and found significant differences between the experienced and novice athletes with respect to knee frontal and transverse moments and impulse. The differences suggested that the experienced athletes were at more risk of ACL injury as they were producing greater moments and more impulse potentially placing a greater load on the ACL. Sigward and Powers suggested that even with the disparity in kinetics, the fact that there were non-significant differences between the kinematics might suggested

that experienced and novice athletes engaged different neuromuscular control strategies to complete the task (Sigward and Powers, 2006a). Sigward and Powers concluded in their study that experienced female soccer athletes may be at a greater risk of ACL injury when compared to the novice soccer athletes due to kinetic differences. This study is similar to the current study that assessed differences between the experienced and non-experienced plant limb yet only through kinematic differences.

The current study assessed differences between the dominant and non-dominant plant limb with respect to four kinematic variables and one kinetic variable. The specific variables were chosen as a representation of ACL injury risk factors provided by previous research and included posterior GRF, knee joint angles in all three planes, and lateral trunk lean (Hewett et al., 2006b, Besier et al., 2001, Orloff et al., 2008, Clagg et al., 2009). However, differences between the dominant and non-dominant plant limb were non-significant in the current study while using these specific variables. Therefore, it is difficult to know whether the dominant or non-dominant plant limb is at more risk of ACL injury. The results of the current research study are consistent with the results of a previous research study in which non-significant differences in similar kinematic variables between experienced and novice soccer athletes are present (Sigward and Powers, 2006a). However, the study performed by Sigward and Powers did find differences between the experienced and novice female soccer athletes while assessing kinetic variables such as knee joint moments and impulses. In light of this study, it would be beneficial to perform further research on the differences between the dominant and non-dominant plant limb while assessing these same kinetic variables that are related to ACL injury. Therefore, as a follow-up to the current study, the kinetic differences

between the dominant and non-dominant plant limb were investigated. A description of the follow-up study can be found in Appendix C.

### **Conclusion**

In conclusion, the current study found non-significant differences between the dominant and non-dominant plant limb with respect to the assessment of specific kinematics and kinetic variable. There was a trend towards a significant difference. The reason for the lack of differences between the limbs with respect to kinematics is difficult to say due to inconsistent research (Sigward and Powers, 2006a, McLean et al., 2004a, Yu et al., 2006, Yu and Garrett, 2007). The results of the current study are however supported by previous research performed by Sigward and Powers who also found a trend that fell short of statistically significant differences in kinematics. In previous research, kinematic differences within a deceleration task were non-significant between genders, and experienced and novice female soccer players (Sigward and Powers, 2006a). In conclusion, the non-significant differences in the current study and those found in previous studies imply that kinematic differences may vary dramatically within each individual athlete, perhaps suggesting that ACL injuries are a result of other types of mechanisms.

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## APPENDIX A

**Questionnaire**

## Eligibility Form

Name: \_\_\_\_\_

Age: \_\_\_\_\_

Which leg do you consider your dominant kicking leg?

<b>Leg</b>	
------------	--

How many years have you participated in competitive soccer?

<b>Years</b>	
--------------	--

Check the level you participate in soccer and the time you have spent playing at that level.

Type	Check	Time
Recreational		
High school		
Club		
ODP		
Other		

What position do you play on the soccer field and how long have you played in that position. List more than one position if you have played in multiple positions.

Position	Time

Have you ever had an ACL injury? Circle Yes or No.

Have you had any previous injuries within the past 6 months that required a visit to the doctor or physician? Circle Yes or No.

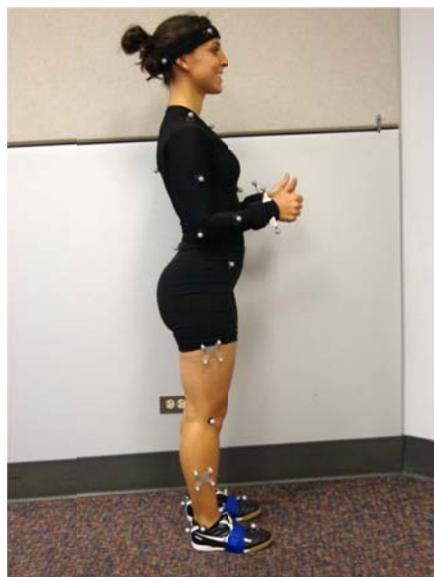
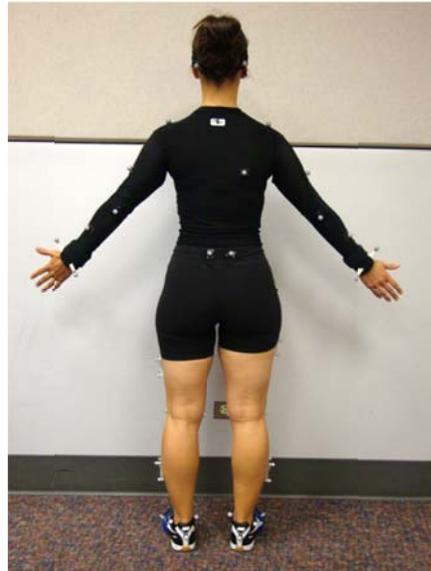
If yes list the injuries and the date of your last visit.

<b>Injuries</b>	<b>Day/Month/Year</b>

APPENDIX B

**Reflective Marker Photos**

Reflective Marker Photos



APPENDIX C

**Clinical Biomechanics Manuscript**

DIFFERENCES IN THE MECHANICS BETWEEN THE DOMINANT AND NON-  
DOMINANT PLANT LIMB DURING INSTEP SOCCER KICKING

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Abstract: 234

Main Text: 2,640

Tables: 1

## Abstract

*Background.* While there is some evidence that plant limb mechanics differ between the dominant and non-dominant plant limb during soccer kicking, there is little known about how these differences in mechanics relate to ACL injury risk. The purpose of this study was to determine the differences in the mechanics between the dominant and non-dominant plant limb during instep soccer kicking of competitive female soccer athletes.

*Methods.* Three dimensional kinetics and ground reaction force were recorded during early deceleration phase of the plant limb during instep soccer kicking of 18 female soccer players. Plant limb differences in anterior-posterior GRF impulse, knee joint impulse in all three planes, and lateral trunk lean were evaluated.

*Findings.* A significant multivariate main effect of limb was found ( $p=0.00$ ). A discriminant analysis was performed to determine which variables were most responsible for the difference between limbs. This analysis revealed that the net frontal plane knee moment impulse, AP GRF impulse, and knee sagittal plane knee moment impulse were the main contributors to the difference between conditions.

*Interpretation.* While there were significant differences between DL and NDL, these differences did not support our original hypotheses. Rather, these results suggest that there is increased loading of the DL, which may place it at greater risk for ACL injury. These findings are similar to previous evidence suggesting that athletes may conform to a more protective strategy while performing a less familiar task.

## 1. Introduction

Over the past 15 years, the increase in women's participation in soccer has led to increased injury rates, specifically at the knee (Dick et al., 2007). Knee injuries in female soccer players alone account for 23.6% of all injuries sustained in American collegiate sports (Dick et al., 2007). Of the different actions that could lead to injury during a soccer game, kicking accounts for approximately half of the potential injuries during a 90 minute soccer game (Rahnama et al., 2003). These statistics viewed in the context of the 4- to 6-fold greater incidence of anterior cruciate ligament (ACL) injury in female compared to male athletes provide a strong rationale for examining potential injury mechanisms/risks during kicking tasks in soccer (Arendt and Dick, 1995).

During a kicking task, the plant limb is responsible for decelerating the body in preparation for the kicking motion of the opposite limb. This is relevant to the study of ACL injury mechanisms because it is generally accepted that ACL injuries occur during deceleration tasks such as cutting, landing, and pivoting (Hewett et al., 2006a, Hewett et al., 2006b, Orloff et al., 2008). However, the question of how limb dominance affects the risk of injury in female athletes has received little attention, especially in the context of soccer. Even though soccer players are expected to be proficient at kicking with both limbs, most soccer players display a dominance of kicking ability on one side because symmetry in kicking is difficult to develop (Starosta, 1988). This asymmetry in kicking mechanics may have injury implications. For example, Brophy and colleagues reported that female soccer players were more likely to injure their dominant support limb (Brophy et al., 2010). However, this study was a retrospective analysis of injury rates and did not provide insight about differences in lower extremity biomechanics.

On the other hand, the results reported by Brophy and colleagues are inconsistent with previous research on the differences between the dominant and non-dominant plant limb mechanics as they pertain to ACL injury risk during soccer kicking tasks. To date, Clagg et al. have published the only study on the differences in plant limb mechanics and their potential relationship to ACL injuries in female soccer players. Clagg and colleagues found that female soccer players exhibited greater knee extension, abduction, and external rotation joint moments in their non-dominant plant limb. This led to the conclusion that the non-dominant plant limb is at higher risk for ACL injury compared to the dominant plant limb (Clagg et al., 2009). Although previous research supports the conclusion that greater knee extension, abduction and external rotation moments are consistent with an increased risk of ACL injury (Sigward and Powers, 2006a, McLean et al., 2004b, Yu and Garrett, 2007), the results of Clagg et al. are inconsistent with those of Brophy and colleagues. Due to these inconsistencies, there is still a question as to whether the dominant or non-dominant plant limb is more susceptible to ACL injury during instep soccer kicking of female soccer players.

The opposing results may be a product of several experimental limitations in the Clagg et al. study where maximum knee joint moments were used as indicators of ACL injury risk (Clagg et al., 2009). However, these variables were calculated during a time frame that spanned from initial contact (IC) to maximum hip extension. This time frame is quite long considering that ACL injury likely occurs in the first 50 ms following initial foot contact (Krosshaug et al., 2007). Therefore, it is possible that the maximum joint moments in the study by Clagg et al. did not occur in the time frame most critical to ACL injury.

Therefore, the purpose of this study is to determine differences in the mechanics of the dominant and non-dominant plant limb in competitive female soccer players during a kicking task. This will be accomplished by evaluating the net anterior/posterior (AP) GRF impulse, knee joint moment impulse in all three planes, and lateral trunk lean during the initial 50ms after foot contact as a way of focusing in on ACL risk factors during the a critical time of injury.

## **2. Methods**

### *2.1 Participants*

18 female participants were recruited for the current study (age 20.7 +/- 2.4 years, height 1.7 +/- 0.1m, weight 61.5 +/- 8.2 kg). All participants had at least one year of previous experience in competitive soccer and are still currently playing. Competitive soccer was defined as soccer at the level of high school, club, collegiate or Olympic Development Program (ODP). Within this year, participants needed to have played soccer at least two times per week. Any participants who had played over half of their soccer career as a goal keeper were excluded from the study. All participants were healthy with no current complaints of lower extremity injury. Participants who received treatment from a physician or doctor concerning a musculoskeletal injury in the past six months were excluded from the study. Such an injury could affect the ability of the participant to perform the instep soccer kick and possibly alter the mechanics of the previously injured plant limb. Also, any participant with a previously injured ACL was excluded from the study. All participants reported that their right limb was their dominant

kicking limb. This means that the left limb of all the participants in the current study was the dominant plant limb.

## *2.2 Procedures*

A standard full body marker set was applied to each participant in preparation for the motion capture protocol. Lower body markers included a cluster of markers on the right and left lateral side of the thigh, shank and foot, one marker each on the right and left anterior superior iliac spine, posterior superior iliac spine, lateral and medial epicondyle of the knee, and lateral and medial malleoli of the ankle. The upper body markers included one on the left and right medial and lateral wrist, lateral forearm, lateral left and right upper arm, lateral left and right shoulder, clavicle, manubrium, xiphoid process, right scapula, C7, T10, and right and left side of the anterior head and right and left side of the posterior head (Kellis et al., 2004, Besier et al. 2001b).

Participants were then asked to perform a series of calibration trials in order to calculate functional joint centers of the right and left knee and the right and left hip (Schwartz and Rozumalski, 2005). Participants then warmed up on a treadmill for 3 minutes. The treadmill started off at a speed of 1.5 miles/hour and continually increased its speed 1.0 miles/hour every 10 seconds. Participants were allotted several practice trials to warm up and familiarize themselves with kicking a soccer ball in the laboratory. The participants were aligned at a 60° angle from the direct approach of the ball and were allowed three preparation steps towards the soccer ball. Each participant performed three instep soccer kicks at a 60° angle from the right side of the ball and the left side of the ball for a total of six kicks. Participants were told to strike the ball with as much force as

possible while aiming at a marked target in the shape of an X on the net along the y-axis of the coordinate system. A kick that did not result in full placement of the foot on the force plate was excluded from data analysis.

### *2.3 Data Analysis*

Labeled 3D trajectory and force plate data were imported into Visual 3D (C-Motion, Inc. Germantown, MD) for analysis of the kinematic and kinetic variables. The kinematic and kinetic data were filtered in Visual 3D using a Butterworth low pass filter at a cutoff frequency of 6 Hz for the kinematic data and 40 Hz for the kinetic data (Lin et al., 2009). Custom processing protocols developed in Visual 3D were used to determine AP GRF impulse, knee joint impulse in all three planes, and lateral trunk lean. All variables were calculated between the times of initial plant foot contact (IC) to 50 ms after IC. The force plate data collected during each kicking trial was used to determine IC and the trial was manually cropped to 50 ms thereafter. The average of the net AP GRF impulse, knee joint impulse in all three planes, and lateral trunk lean was calculated over all three trials for the dominant and non-dominant limbs. These average values for each limb were used in the statistical analysis to determine if any significant differences existed between the limbs.

### *2.4 Statistical Analysis*

In order to test for significant differences across the non-dominant and dominant limbs Repeated Measures MANOVA was used with significance set at  $p \leq 0.05$ . A

discriminate analysis was used as a post-hoc test to determine how the individual variables contributed to the difference between limbs.

### 3. Results

The RM MANOVA revealed a significant multivariate main effect for limb (Wilks'  $\lambda = 0.348$ ,  $F(5,30) = 11.25$ ,  $p = 0.000$ ). A discriminant analysis was performed to determine which variables were most responsible for the difference between limbs. This analysis revealed that the net frontal plane knee moment impulse, AP GRF impulse and knee sagittal plane knee moment impulse were the main contributors to the difference between conditions. The structure coefficients for these variables were 0.538, 0.493, and 0.424, respectively.

**Table C.1 The Means and Standard Deviation of Each Variable Within the Dominant and Non-Dominant Plant Limb.**

Variables	DL	NDL
AP GRF Impulse (Nms)	4.11	-1.24
Net Sagittal Knee Moment Impulse	0.00	-0.03
Net Frontal Knee Moment Impulse	0.05	0.02
Net Transvers Knee Moment Impulse	-0.02	-0.02
Trunk Lean (deg)	-2 (3)	-4 (3)

### 4. Discussion

The purpose of the current study was to determine if biomechanical differences exist between the dominant and non-dominant plant limbs during an instep soccer kicking task. A significant difference was found between the dominant and non-dominant plant limb of female soccer players during this task. The net frontal plane knee moment

impulse, AP GRF impulse, and knee sagittal plane knee moment impulse were the primary contributors to this difference between limbs. Values in all three of these variables were higher for the dominant plant limb compared to the non-dominant plant limb.

The association between large frontal knee moments and ACL injury risk is supported by previous research on female athletes performing deceleration tasks (McLean et al., 2005, Sigward and Powers, 2006a, Besier et al., 2001b). Females have demonstrated greater knee moments in the frontal plane compared to their male counterparts while performing a cutting task (McLean et al., 2005, Sigward and Powers, 2006b). Also, compared with running, the potential for increased ligament loading during deceleration tasks such as sidestepping and crossover cutting maneuvers are partially the result of the large abduction/adduction moments (Besier et al., 2001b). In-situ studies have determined that an increase in knee abduction moment increases the anterior tibial translation and ACL strain (Fukuda et al., 2003). The larger net moment impulse values found in the current study for the dominant plant limb suggest that athletes are potentially placing themselves at greater risk of ACL injury while kicking from the dominant side.

Greater net posterior GRF impulse creates larger knee flexion moments, which are countered by greater quadriceps activation and therefore increased ACL loading (Yu and Garrett, 2007). An increase in GRF tends to fall hand-in-hand with greater knee moment impulse generation in the sagittal plane (Yu and Garrett, 2007). Female recreational athletes have greater knee joint resultant extension moment during landing in stop-jump tasks than male recreational athletes (Yu et al., 2006). Also, those females

demonstrate greater posterior ground reaction force during landing in a stop-jump task when compared with males even with the constraint of a knee brace designed to decrease knee extension during a deceleration tasks. Given that a greater posterior GRF impulse leads to increased quadriceps activation and a greater extension moment, this may explain why greater net posterior GRF impulse and greater knee moment impulse in the sagittal plane were both generated in the same plant limb

We found that the dominant plant limb demonstrated greater values in the mechanics associated with increased ACL injury risk when compared to the non-dominant plant limb. These results are consistent with the study of Brophy et al. in which it was concluded that female soccer players are statistically more likely to injury their dominant plant limb (Brophy et al., 2010). On the other hand, our results are contrary to the results of Clagg et al., who found greater “at risk” values in the non-dominant plant limb (Clagg et al., 2009). The results of the current study may have differed from those of Clagg et al. for several reasons, including differences in kicking approach, time frame of data analysis, and choice of variables. In the current study we chose to assess Net GRF and moment impulses during the time frame of IC to 50 ms after for what is believed to be a more narrowed and focused perspective of ACL injuries (Park et al., 2009).

The difference in mechanics between the non-dominant and dominant plant limb in the current study suggest that the dominant plant limb is experiencing larger moments for a longer period of time possibly putting that plant limb at greater risk of ACL injury. The results of the current study are similar to previous evidence suggesting that athletes may conform to a more protective strategy while performing a less familiar task. Females

with more soccer experiences demonstrated larger knee moments than those exhibited by novice female soccer players (Sigward and Powers, 2006a). Another possible reason for the decrease in joint moment impulse in the frontal and sagittal plane of the non-dominant plant limb may be due to an increase muscle co-contraction of the quadriceps and hamstrings. It has been found that these females who demonstrated greater knee moments also exhibited reduced co-contraction when compared to novice female soccer players during the same cutting maneuver. Muscle co-contraction activation of inexperienced athletes during a cutting and jumping maneuver have been seen to have higher ratios than those of experienced athletes (Sigward and Powers, 2006a, V, 2003, Eloranta, 2003). The previous study is similar to the current study in that differences were assessed between the experienced and novice plant limb of female soccer players. Since the quadriceps and hamstring muscles act to control the knee in all three planes of movement, an increase in co-contraction between these muscles will help to stabilize the knee joint possibly causing less motion and joint moment impulse (Lloyd and Buchanan, 2001). These results are consistent with previous research studying the “principle of skill acquisition,” helping to explain that as athletes become more familiar with a task they produce less co-activation of musculature during their performance, therefore reducing their stabilization mechanisms (Thoroughman and Shadmehr, 1999).

## **5. Summary**

The results of the current study suggest that there is a difference between the dominant and non-dominant plant limb during instep soccer kicking of competitive female soccer players. The dominant limb produced greater “at risk” values with respect

to the dominant limb. These results are inconsistent with previous research that determined the non-dominant plant limb is at more risk of ACL injury due to greater “at risk” values when compared to the dominant plant limb (Clagg et al., 2009). However, the current results are consistent with previous research suggesting females are more susceptible to injuring their dominant plant limb and experienced soccer athletes demonstrating more “at risk” patterns for ACL injury than novice soccer athletes (Sigward and Powers, 2006a, Brophy et al., 2010). This suggests that as a female soccer player becomes more experienced with kicking from one limb they may use more aggressive mechanics when executing that task and therefore place themselves at a higher of ACL injury (Sigward and Powers, 2006a). In conclusion, female soccer players may place their dominant plant limb at a higher risk of ACL injury.

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