# THE RELATIONSHIP BETWEEN LEG DOMINANCE AND KNEE MECHANICS DURING THE CUTTING MANEUVER

A THESIS SUBMITTED TO THE GRADUATE SCHOOL IN PARTIAL
FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE

MASTER OF SCIENCE

BY

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BALL STATE UNIVERSITY

MUNCIE, INDIANA

JULY 2012

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MASTER OF EXERCISE SCIENCE

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BALL STATE UNIVERSITY
MUNCIE, INDIANA
JULY 2012

# DECLARATION

The work presented in this thesis is, to the best of my knowledge and belief, original, except as acknowledged in the text, and the material has not been submitted, either in whole or in part, for a degree at this or any other university.

Scott R. Brown

Date

# ACKNOWLEDGMENTS

First and foremost I thank God for giving me the patience I needed to stay focused through times of adversity and frustration encountered in this process; I will always have faith in you!

A Special thanks to the two most important women in my life my mother Deborah Thiel and my girlfriend Erin Feldman; who no matter what, always had time to listen to me complain and always believed in me more than I did.

Keith Suttle, you are my colleague, my mentor, my best friend. Your innovative ideas and general outlook on life inspire me to always better myself in every aspect of my life. “The day we stop learning is the day we die.” – KDS

To Conrad Schubert, you are the greatest intern I have ever heard of. Your positive attitude and willingness to work hard always kept the moral high in the lab. I could not have done this alone.

My colleagues Brandi Mixell, Ryan Hubble and Kaitlyn Weiss who helped me with my data collection; without you, this would not have been physically possible!

The greatest advisor I ever could have hoped for Dr. Henry Wang. You were there for me the whole way. You gave me guidance when I needed it and encouragement when I did not have it. Thank you for all of the many hours that you have devoted to my life.

Thanks to my committee members Dr. Henry Wang, Dr. Clark Dickin, Dr. David Pearson and Dr. Stacey Walker who gave me guidance throughout this process.

To Head Women’s Soccer Coach Craig Roberts and Head Strength and Conditioning Coach Jason Roberson, thank you for all of the background support and for letting my use your athletes.

# ABSTRACT

**THESIS**: The Relationship Between Leg Dominance and Knee Mechanics During the Cutting Maneuver

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**DEGREE**: Master of Science

**DATE**: July 2012

**PAGES**: 80

The purpose of this study was to examine the relationship between leg dominance and knee mechanics to provide further information about the etiology of ACL injury. Sixteen healthy females between the ages of 18 and 22 who were NCAA Division I varsity soccer players participated in this study. Subjects were instructed to perform a cutting maneuver; where they sprinted full speed and then performed an evasive maneuver (planting on one leg and pushing off to the other leg in a new direction) at a 45° angle with their dominate leg (DL) and non-dominate leg (NDL). Subjects were required to perform five successful cuts on each side given in a random order. Bilateral kinematic and kinetic data were collected during the cutting trials. After the cutting trials, subjects performed bilateral isometric and isokinetic testing using a Cybex Norm dynamometer at a speed of 60°/sec to evaluate knee muscle strength. During the braking phase the NDL showed greater ($P=0.003$) power absorption, greater ($P=0.01$) peak internal rotation angle and greater ($P=0.005$) peak flexion velocity. During the propulsive phase the DL showed greater ($P=0.01$) power production, greater ($P=0.038$) peak internal adductor moment and greater ($P=0.02$) peak extension velocity. In addition, no differences ($P>0.05$) in knee extensor and flexor isometric and isokinetic torques between the two limbs were shown. The results of this study show that a difference in knee mechanics during cutting does exist between the DL and NDL. The findings of this study will increase the knowledge base of ACL injury in females and aid in the design of more appropriate neuromuscular, plyometric and strength training protocols for injury prevention.

# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

# NOMENCLATURE

**ACL** – Anterior cruciate ligament

**DL** – Dominant leg; preferred kicking leg

**NDL** – Non-dominant leg; preferred stance or support leg

**NC** – Non-contact

**NCAA** – National Collegiate Athletic Association

**IRB** – Institutional Review Board

**BSU** – Ball State University

**Title IX** – An addition to the Education Amendments in 1972 stating that no person shall be discriminated against on the basis of sex in all educational programs and activities receiving federal funds.

**Isometric** – Static action of a muscle against a stationary resistance without changing the joint angle or muscle length.

**Isokinetic** – Dynamic actions of muscles through a set range of motion set at a constant speed

# CHAPTER 1

## DEVELOPMENT OF THE PROBLEM

### INTRODUCTION

Soccer is the most popular and most played sport in the world consisting of over 265 million active footballers, 38 million of which are registered (those competing in youth, amateur or professional levels) (1). This population has continued to grow with an annual increase of 4.4 million participants from 2002 (1). In the United States alone, there are an estimated 24.5 million active footballers (4.2 million registered) which make up approximately 8.2% of the total population; roughly 7 million of which are female (1). These staggering numbers are largely due to the induction of title IX on the Education Amendments in 1972 which stated that no person shall be discriminated against on the basis of sex in all educational programs and activities receiving federal funds (67). Since that time, sports have seen a colossal increase in female participation in the U.S. In the 2010-11 season, the NCAA reported 193,232 female intercollegiate athletes comprising 9,827 teams (61). These numbers indicate a 260% increase in female footballers from the reported numbers in the 1981-82 season.

Coinciding with this large increase in female participation however has been an equally large number of sport related injuries. It has been noted that females who participate in sports that involve high risk jumping or cutting maneuvers have been shown to be at a higher risk for injury (3-9 times) when compared to males playing the same sport (11, 12, 52). The incidence of soccer related injuries for an individual player is estimated as much as 40 per 1000 match hours and has been seen to increase in younger and less experienced players (3, 11, 12, 37, 95). In addition, an estimated 60-80% of all soccer injuries occur to the lower extremities, specifically the ACL (4, 8, 15, 34). These ACL injuries have been examined in great detail and nearly 70% are non-contact (NC) in nature (6, 23, 24, 28, 45, 46, 48, 81, 89, 90, 98). These NC ACL injuries are shown to occur more frequently in field and court sports such as soccer, rugby and basketball and are classified as those reported to be caused by no apparent contact with a stationary object, contact with the ball, or contact with another player (3).

The mechanism breakdown for NC ACL injury can commonly involve a step-stop action, cutting task, sudden change of direction, landing from a jump with inadequate lower extremity mechanics or a lapse in concentration (23, 46, 48). Expanding on these findings, studies have reported the greatest loads in the knee to occur during a deceleration maneuver combined with a change of direction (10, 19, 32, 77, 78). During this maneuver, the foot is placed in a closed chain position and slightly pronated as the tibia internally rotates and the knee is at or near full extension. When the athlete attempts to change directions, the excessive torsional force can cause disruption to the ACL (104). During these maneuvers, extreme external loads induced by kinematic changes have been seen in the lower extremities. These changes have led to several different theories as to the exact mechanism of ACL injury. Such external loads occur during knee hyperextension or hyperflexion, excessive knee valgus or varus, internal or external tibial rotation and anterior tibial translation (19, 72, 74, 109).

Several studies examining the cutting maneuver as a possible mechanism for NC ACL injuries have noted the first half of the stance phase to be the most crucial; specifically the first 20% of stance (23, 96, 102, 103). It has been observed that during this time the foot is entering into a fixed location, the knee is near full extension (0-30°) and the tibia is internally or externally rotated as the body is preparing to be decelerate with or without a change of direction (23, 25, 65). These studies have also shown that females demonstrate increased knee valgus and a greater coronal plane moment during the first 20% of stance in the cutting maneuver when compared to males (70, 76, 78, 103). Additionally, Powers et al. showed that experienced players demonstrated greater coronal plane moments during the first 20% of stance when compared to novice players (102).

More recently, studies have begun to agree that the true mechanism for ACL injury occurs with multiple kinematic abnormalities. Video analyses of ACL injury mechanisms have found that multiplanar (defined as occurring in the sagittal, frontal and transverse plane) knee loadings are the primary mechanism of NC ACL injuries (5, 72, 101, 109). These findings are in agreement with similar studies that noted the knee incurs the highest ACL loading during knee valgus combined with either internal or external rotation and slight knee flexion or hyperextension (20, 74, 90, 94). *In vitro* and *in vivo* studies have reported the peak ACL loading force occurs between 15° and 40° of knee flexion and then diminish to zero beyond 40° (30, 62, 72, 73, 114). Also, similar studies have added that ACL injuries occur during weight-bearing conditions upon heel strike and weight acceptance.

Biomechanical evaluations of gender, cutting speed and cutting angle have been examined to great length. What has not been thoroughly evaluated however is the influence of leg dominance on ACL injury. Since soccer is a predominantly lower extremity sport, where-in athletes are required to run, cut and kick over a 90 minute match, it seems pertinent to include leg dominance to the etiology for ACL injury. Based on a number of studies that have looked at leg dominance in all soccer player injuries, the leg which the player prefers to kick the ball with or which they can kick the ball the furthest with has been noted as the preferred kicking leg or the dominant leg (DL) and the other leg has been noted as the preferred stance or support leg or non-dominant leg (NDL) (9, 39, 43, 44, 51, 111, 112).

To date, few studies have looked into the biomechanical role of leg dominance as a possible mechanism for NC ACL injuries in soccer players, especially in females. A cohort study in 2002 reviewed 80 subjects (44 male and 36 female) after they had received ACL reconstructive surgery. Together, the subjects were members of 16 different sport teams and activities during the time of injury. The authors reported no significant relationship between side of injury and arm or leg dominance, no significance between males and females in the association between the side of injury and the arm or leg dominance and no significance in side to side distribution of ACL tears between males and females (75). A reproduction of the same study in 2007 by Negrete et al. with 302 subjects (149 male and 153 female) again examined subjects with a mixture of sport backgrounds (84). Findings in this study agreed with Matava et al. with the exception of a side to side distribution of ACL tears. Females demonstrated a strong trend towards increased injury in the left lower extremity compared with the right (84). Both studies concluded that the side most likely to sustain a NC ACL tear cannot be predicted alone by the determination of leg dominance. However, both studies failed to incorporate a subject population comprised of the same sport making them both unable to adequately compare their results. Each sport places unique mechanical demands on an athlete during times of competition and therefore should be studied individually, not collectively.

A similar study examined 143 German national women's league soccer players across a season. Authors reported that the players significantly incurred more injuries to the DL (105) compared to the NDL (71) over the course of the season. Yet in the study's mechanism breakdown, of the 176 total injuries reported 59% were composed of an overuse or contact mechanism in the entire lower leg. NC injuries did not show any significance between sides (37 DL vs. 36 NDL) and specific NC ACL injuries were not even included (44). A more recent study by Brophy et al. has once again reopened the possibility of a relationship with leg dominance and an increased risk of ACL injury (28). Authors of this study took many of the limitations mentioned above in previous studies into account when examining 93 (41 male and 52 female) soccer players all with NC ACL injuries. Containing an identical subject population and injury mechanism, results showed that 74% of male subjects sustained an injury to the DL and 68% of female subjects sustained an injury to the NDL (28). This seems to be the first study of its kind that suggests leg dominance may play a gender based role in NC ACL injury specifically in soccer players. Unfortunately, this study was similar to previous studies in that it was a retrospective study reviewing ACL reconstructions in soccer players after the injury occurred. Because of this, any definitive answer of whether or not leg dominance has an effect on mechanical knee joint loading in healthy soccer players is still uncertain. A mutual agreement between these authors seems to be the possibility of lower extremity neuromuscular asymmetry, core and joint stabilization and proprioceptive deficits in the athlete. Authors further recommend prospective studies to look into the relationship between leg dominance and knee mechanics in healthy soccer players to confirm or refute the findings of these studies. The advancement of sport and player specific neuromuscular training protocols to improve these deficits has such become a necessity.

# PURPOSE

The purpose of this research is to investigate the effects of leg dominance on knee mechanics during the cutting maneuver. Kinematic and kinetic data will be compared between the DL and NDL during the cutting maneuver.

# SIGNIFICANCE

It is well established in the literature that elements such as gender and experience hold a biomechanical inference on knee mechanics during athletic maneuvers; possibly increasing the incidence of ACL injury in the individual. However, it still remains unclear if leg dominance plays a role in knee mechanics during these activities. Additionally, the effect that bilateral leg strength holds on knee mechanics has not been extensively researched. The findings of this study will increase the knowledge base of ACL injuries in females and may aid in the design of more appropriate neuromuscular, plyometric and strength training protocols aimed at injury prevention.

# SUMMARY

Cutting maneuvers are a frequent occurrence in field and court sports such as soccer, rugby and basketball. The increase in female participation in these sports in recent years has carried with it paralleled injury rates. In examining the mechanisms of these injuries technique, gender and experience have been studied repeatedly with little focus placed on leg dominance. The information attained from this study may be considered useful in understanding how leg dominance may affect the risk of injury during the cutting maneuver.

# CHAPTER 2

# REVIEW OF LITERATURE

## KNEE ANATOMY

The knee complex is the largest stabilizing hinge joint in the body (59, 104). The primary motions of the knee are flexion and extension in the sagittal plane. In addition, secondary motions include slight varus and valgus movements in the coronal plane as well as minor internal and external rotation in the transverse plane. The knee contains many articulating and biarticulating muscles including the quadriceps femoris muscle group (consisting of the vastus lateralis, vastus intermedius, vastus medialis, and rectus femoris), hamstring muscle group (consisting of the semitendinosus, semimembranosus, and biceps femoris), popliteus, gracilis, sartorius, and gastrocnemius muscles (107). These muscles hold together the four bones of the knee consisting of the femur, patella, tibia and fibula, listed proximal to distal and assemble into the tibiofemoral, tibiofibular and patellofemoral joints. Intertwined in these bones are many ligaments, tendons and soft tissue structures. These structures, listed superficial to deep, consist of the patellar tendon, iliotibial band, collateral ligaments (medial collateral ligament (MCL) and lateral collateral ligament (LCL)), fibrous capsule, synovial capsule, coronary ligament, transverse ligament, medial and lateral menisci, arcuate ligament, popliteofibular ligament, fabellofibular ligament, menisofemoral ligaments (ligaments of Humphrey and Wrisberg) and cruciate ligaments (posterior cruciate ligament (PCL) and anterior cruciate ligament (ACL)) (106). Of the many ligaments that are included in the knee structure, four ligaments in particular function as stabilizers in a multitude of directions which are divided into the extracapsular MCL and LCL, and the intracapsular PCL and ACL.

### *Collateral Ligaments*

Assisting the extracapsular ligaments, the MCL is located on the outer medial aspect of the knee and consists of two layers: the deep and superficial layers (106). The deep layer acts as a thickening of the joint capsule and attaches to the medial meniscus. Separated by a bursa, the superficial layer has a proximal attachment on the medial femoral epicondyle and travels a superoposterior to inferoanterior path across the joint line to a distal attachment on the medial tibial plateau (106). The primary stabilizing role of the MCL is to protect the knee against extreme valgus stress. On the opposite and lateral side of the knee is where the LCL is located. Attached proximally to the lateral femoral epicondyle, the LCL travels a superoanterior to inferoposterior path across the joint line and attaches distally on the proximal end of the fibular head (106). Unlike the MCL, the primary stabilizing role of the LCL is to prevent excessive varus forces that are placed on the knee as well as external tibial rotation.

### *Cruciate Ligaments*

Supporting the intracapsular structures, the cruciate ligaments help to control the knee in six degrees of freedom: three rotations (extension-flexion, external rotation-internal rotation, varus-valgus rotation) and three translations (anterposterior, mediolateral, and compression-distraction) (98). The PCL has been noted to be up to 1.5 times that of the ACL cross-sectional area and twice the tensile strength (63). Literature has also distinguished two functional components of the PCL; although three and four divisions have been described: the anterolateral and posteromedial bundles (71). Collectively, the PCL attaches proximally to the lateral portion of the femur's medial condyle and travels a inferoposterior path to distally attach to the posterior portion of the intercondylar eminence of the tibia (104). As a unit, the PCL's primary stabilizing role is to prevent posterior translation of the tibia relative to the femur (98).

The PCL functions in conjunction with the ACL to stabilize the knee during dynamic movements. However since the ACL is notably smaller and more fragile than the PCL, it has undergone more intense scrutiny. The ACL is housed in the intercondylar notch of the femur and also consists of two distinct bundles that twist in a medial spiral as they travel from the tibia to the femur: the anteromedial bundle and the posterolateral bundle. As a unit, the ACL inserts proximally to the posterior medial surface of the lateral femoral condyle, travel anteriorly, and passes laterally next to the PCL where it distally inserts to the anteromedial portion of the intercondylar eminence of the tibia (88). The ACL is known as one of the major static stabilizing ligaments of the knee and serves several functions in the protection of the knee joint (22, 49, 104, 106). The primary role of the ACL is to prevent excessive anterior subluxation of the tibia relative to the femur (59, 98). In addition, the ACL is also known to moderate internal and external rotation of the tibia on the femur as well as limit hyperextension of the tibiofemoral joint (106).

The knee is a very stable and functional complex when external loads are applied to the long lever arms in small amounts over short periods of time as commonly seen with walking. However, when these loads reach even a moderate level and are applied to the lever arms at relatively large distances from the knee, the torque generated within the joint can easily exceed the material properties of the ligaments and other capsular structures causing injury to the knee. These loads have been seen during *in vitro* structural stress tests and have demonstrated a direct relationship between an increase in force and likelihood of injury (74, 109).

## MECHANISM OF ACL INJURY

The knee complex is a sophisticated structure with an intricate anatomy. Due to the juxtaposition of the attachment sites, both ACL bundles are placed in a continually taut position while the knee joint moves through its normal range of motion (ROM). When the knee is fully extended, the posterolateral bundle becomes taut and when the knee is fully flexed, the anteromedial bundle becomes taut (59, 87, 106). This in turn places the ACL in a stressed position throughout multiple knee positions during events such a walking or squatting. On their own, these positions are typically harmless; consisting of normal movement patterns and ROM. However, when more advanced movements such as running, jumping or cutting, as commonly seen in sports, create additional forces in combination with the normal ROM of the knee, the ACL becomes more at risk for disruption. Thus, the true mechanism for ACL injury has been further divided into two categories: contact and noncontact.

### *Contact*

Injuries reported as occurring because of contact with an outside force such as another person or equipment are classified as contact injuries (3). With regard to contact ACL injuries, most are commonly seen in skiing accidents and involve a more complex breakdown of the mechanism. Three common causes of contact ACL injury have been discussed in literature (46, 47). The first is described as the “phantom-foot mechanism” where a skier falls back with a knee flexed past 90° and the tibia internally rotates as the quadriceps apply an excessive anterior force. The second mechanism involves a skier landing on the ski’s tail. The stiffness of the ski boot combined with a strong quadriceps contraction aid in anterior tibial translation. The third mechanism usually involves poor environmental conditions and\or increased speeds and involves the nose of the ski getting caught under the snow. The involved leg begins to abduct and externally rotate as the skier’s momentum carries them forward (17, 41).

Outside of skiing, contact injuries can occur in many different sporting activities or during a number of athletic tasks. These sporting activities include basketball, American football and soccer. During these activities, the most commonly seen contact scenarios include: a contact blow to the lateral aspect of the leg or knee causing valgus collapse, contact from a medial blow resulting in varus collapse or an anterior blow leading to hyperextension injury. Additionally, being contacted with another player during a change of direction has been noted as a possible scenario in contact ACL injury (23).

### *Noncontact (NC)*

Noncontact ACL injuries are shown to occur more frequently in field and court sports such as soccer, basketball and rugby. These injuries are classified as those reported to be caused by no apparent contact with another player, contact with the ball, or contact between the knee and the floor (3). Roughly 70% of all ACL injuries have been reported as NC in nature (6, 23, 24, 28, 45, 46, 48, 81, 89, 90, 98). The mechanism breakdown for NC ACL injury can commonly involve a step-stop action, cutting tasks, sudden changes in direction, landing from a jump with inadequate lower extremity mechanics or a lapse in concentration (23, 46, 48). In addition to these findings, studies have reported the greatest forces to occur during a deceleration maneuver combined with a change of direction (10, 19, 32, 77, 78). Here, the foot is placed in a closed chain position and slightly pronated as the tibia internally rotates and the knee is at or near full extension. When the athlete attempts to change directions, the excessive torsional force can cause disruption to the ACL (104).

## GENDER DIFFERENCES

In 1972 the Education Amendments were introduced to Title IX, stating that “No person in the United States shall, on the basis of sex, be excluded from participation in, be denied the benefits of, or be subjected to discrimination under any education program or activity receiving Federal financial assistance” (67). In the almost forty years since its passage, Title IX has become most famous for its impact on sports. Female participation in the National Collegiate Athletic Association (NCAA) began with roughly 74,239 players and has since grown to more than 182,503. Specific to women’s soccer, the NCAA reported 1,855 players and 80 teams in the 1981-1982 school year to over 24,671 participants in over 984 teams in the 2010-2011 school year (61).

This increase in number of female athletes has unfortunately been accompanied with a paralleled increase in female sport related injuries, predominantly to the ACL. Studies have shown that these ACL injuries occur more frequently (3-9 times) in female athletes when compared to their male equivalent. This injury is even more prevalent within females when a cutting maneuver is included as found in sports such as soccer, basketball and rugby.

A 13-year review by Agel et al. looked at ACL injuries in NCAA basketball and soccer players at 6176 individual schools, representing 15.6% of all schools sponsoring basketball and soccer programs for both men and women (3). In this study the authors demonstrated that the rates for all ACL injuries for female players were statistically higher than their male counterpart; concluding at roughly a 3:1 female to male injury rate. It was also noted that when comparing within gender by sport, female soccer players showed a higher rate of ACL injuries than did female basketball players (3).

## RISK FACTORS ASSOCIATED WITH ACL INJURY

### ***Anatomical and Structural***

When comparing female and male anatomy and structure of the knee there are several differences that can be observed: the female ACL have been noted to be smaller in length, cross-sectional area and volume compared to the male ACL, even after adjusting for body anthropometry (31). In addition, females possess a narrow A-shaped intercondylar notch with a larger height and smaller angle which may influence the notch-impingement theory whereas males possess a more U-Shaped notch (24). The typical female also demonstrates increased pelvic tilt, hip anteversion, excessive tibial torsion, excessive subtalar pronation and an increased Q angle. Also, greater magnitudes of joint laxity have been observed in females which create greater genu recurvatum and anterior knee laxity (57, 85).

### ***Hormonal***

Over the past decade, there has been a large interest in the menstrual cycle and sex steroid hormones as they have been related to risk factors for the occurrence of noncontact ACL injuries in female athletes (13, 21, 83, 105, 115). Typically, the menstrual cycle is subdivided into three distinct phases that are based on a mean cycle consisting of 28 days. The follicular phase (days 1-9) is characterized by low levels of both progesterone and estrogen until the late follicular phase, when estrogen levels spike. The ovulatory phase (days 10-14) acts as a continuation of the estrogen spike. Finally, the luteal phase (days 15-28) includes a rise in progesterone and, during the second half, a rise in relaxin as well (53).

It is well established that select sex hormone (E.g., estrogen, testosterone and relaxin) receptors are present on the ACL as well as others (E.g., estrogen and testosterone) on skeletal muscle (36, 42, 69). This suggests that estrogen may have an effect on fibroelastic function, collagen remodeling and even alter the structural, material and mechanical properties of the ACL (108).

Several studies have shown that there is a greater risk of ACL disruption at the onset of menses during the preovulatory phase at which point estrogen and progesterone levels are at their lowest (13, 83, 105). However not all studies support this view and suggest that more ACL injuries were reported to occur during the late follicular phase coinciding with the spike in estrogen (21, 115). Other studies maintain that the possibility of incurring an ACL injury during the menstrual cycle is not evenly distributed (12, 13, 21, 83, 105, 115). Unfortunately, these opposing studies make it difficult to establish the exact roll of the menstrual cycle and sex steroid hormones on ACL injury risk; and as a result, no conclusive evidence has been linked to the increase of ACL injuries to any predictable time within the menstrual cycle (104).

### *Environmental*

There are several environmental risk factors or extrinsic factors that must be considered when recognizing a risk for sport movement. These factors include but are not limited to footwear, playing surface and weather or climate. Footwear for instance, holds a direct connection with ACL injury as it relates to the rotational friction experienced by the player. An optimal range of a minimized rotational friction to avoid injury and optimize transitional friction to allow for peak performance was suggested by Ekstrand and Nigg (40). In addition, specific cleat position has been examined as a possible contributing factor. One study noted a higher rate of ACL injuries to occur in cleats with a more peripheral placement as the cleat arrangement resulted in higher torsional resistance (66).

Playing surface has also been noted as a possible contributing factor to ACL injuries.

Boden et al. reported a common mechanism shown for ACL injury was landing or stepping on an irregular playing surface at the time of the accident (23). They also included a fairly similar distribution across multiple playing surface types which included indoor hard court (35%), synthetic surface (35%) and natural grass (30%) (23); showing no apparent correlation between playing surface and an increased risk of ACL injury.

The interaction between climate and injury risk has also been studied as it can extrinsically affect a player's performance. A prospective study in 1999 from the Australian Football League found that low water evaporation and high rainfall significantly lowered the risk for NC ACL injuries as the soft ground lowered traction (91). The same author found similar results in a more resent study involving the National Football League which included a decrease in injury rate in natural grass stadiums compared with indoor domes (AstroTurf) as well a decrease in injury rate in cold weather compared to hot weather, regardless of field type (92).

### ***Biomechanical and Neuromuscular***

During these high risk maneuvers, external loads induced by kinematic changes have been seen in the lower extremities. These changes have led to several different theories as to the exact mechanism of ACL injury. Such external loads occur during knee hyperextension or hyperflexion, excessive knee valgus or varus, internal or external tibial rotation and anterior tibial translation (19, 72, 74, 109). More recently, studies have begun to agree that the true mechanism for ACL injury occurs with multiple kinematic abnormalities. Video analyses of ACL injury mechanisms found that multiplanar (defined as occurring in the sagittal, frontal and transverse plane) knee loadings were the primary mechanism of noncontact ACL injuries (5, 72, 101, 109).

These findings are in agreement with similar studies that noted the knee incurs the highest ACL loading during knee valgus combined with either internal or external rotation and slight knee flexion or hyperextension (20, 74, 90, 94). *In vitro* and *in vivo* studies have reported peak ACL loading force occurs between 15° and 40° of knee flexion and then diminish to zero beyond 40° (30, 62, 72, 73, 114). Also, similar studies have added that many ACL injuries occur during weight-bearing conditions upon heel strike and weight acceptance.

Proper neuromuscular control of the knee involves a complex interplay between the afferent and efferent neurological system as well as the musculature surrounding a joint and consists of proprioceptive and kinesthesia elements to optimize motor performance (58). During movement, neuromuscular control is known to stabilize and guide body segments and provide mechanical restraint to abnormal joint motion. Neuromuscular control has been defined as the body's unconscious efferent response to an afferent signal regarding dynamic joint stability (104). Kinesthesia interprets the sensation of joint motion or acceleration of the body and limbs during active movement through internal or external forces and aids in collecting proprioceptive information (50). Proprioception is the ability to detect body and limb position by interpreting afferent information through proprioceptors located in joints, muscles and tendons (50, 68).

The afferent proprioceptive signals that elicit motor control can be distinguished by their role: feedback or feedforward. Feedback signals are a result of afferent input where they continually regulate muscle activity through reflexive pathways and respond directly to potentially destabilizing events. Feedforward signals plan movements based on sensory information from past experiences and initiate a motor response in anticipation of a load or activity (68).

Many studies have shown that additional factors can greatly influence neuromuscular and biomechanical control. Sigward and Powers recently showed that experience had a large influence on knee mechanics during a cutting maneuver. Their study of 30 female soccer players (15 with 8 or more years of experience) showed the novice players to demonstrate smaller peak knee flexor, adductor and internal rotator moments when compared to their experienced counterparts (102). The disparity in knee kinetics between groups suggests that the experienced and novice soccer players employ different neuromuscular control strategies during motor performance. A similar study looked at the effects of fatigue on a similar cutting maneuver in 10 male professional soccer players and showed that the amount of knee flexion decreased as a direct function of exercise duration or fatigue. These results are in agreement with others demonstrating that fatigue alters lower limb biomechanical and neuromuscular control (16, 80).

## INFLUENCE OF LEG DOMINANCE

Soccer is a predominately lower extremity sport that requires muscular strength and endurance, neuromuscular control and proprioception at the hip, knee and ankle. Like other sports though, soccer players also tend to have a dominant and non-dominant leg. The leg which the player prefers to kick the ball with or which they can kick the ball the furthest with has been noted as the preferred kicking leg or the dominant leg (DL) and the other leg has been noted as the preferred stance or support leg or non-dominant leg (NDL) based on a number of studies that have looked at leg dominance in soccer player injuries (9, 39, 43, 44, 51, 111, 112).

To date, few studies have looked into the role of leg dominance as a possible mechanism for NC ACL injuries in soccer players, especially in females. A cohort study in 2002 reviewed 80 subjects (44 male and 36 female) after they had received ACL reconstructive surgery. Together, the subjects were members of over 10 different sport teams and activities during the time of injury. The authors reported no significant relationship between side of injury and leg dominance, no significance between males and females in the association between the side of injury and the leg dominance and no significance in side to side distribution of ACL tears between males and females (75).

Later, in 2007, Negrete et al. reproduced the same study with 302 subjects (149 male and 153 female) also with a mixture of sport backgrounds (84). The study’s findings agreed with Matava et al. (75) with the exception of a side to side distribution of ACL tears. Of the 153 female subjects and 149 male subjects, 99% and 96% respectively preferred their right leg as their dominant leg. Although females demonstrated a strong trend (58%) of ACL injury in the NDL (left) compared with the DL (right) the study concluded that the side most likely to sustain a NC ACL tear cannot be predicted alone by the determination of leg dominance (84).

A similar study examined 143 German national women's league soccer players across a season. Authors reported that the players significantly incurred more injuries to the DL (105) compared to the NDL (71) over the course of the season. However, of the 176 total injuries reported 59% were composed of an overuse or contact mechanism in the entire lower limb. NC lower extremity injuries did not show any significance between sides and NC ACL injuries were not included in the mechanism breakdown (44).

A more recent study by Brophy et al. has once again reopened the possibility of a relationship with leg dominance and an increased risk of ACL injury (28). Authors of this study took many of the limitations mentioned above in previous studies in to account when examining 93 (41 male and 52 female) soccer players all with NC ACL injuries. Containing an identical subject population and injury mechanism, results showed that 74% of male subjects sustained an injury to the DL and 68% of female subjects sustained an injury to the NDL (28). This seems to be the first study of its kind that suggests leg dominance may play a gender based role in NC ACL injury specifically in soccer players. Unfortunately, this study was similar to previous studies in that it was a retrospective study reviewing ACL reconstructions in soccer players after the injury occurred. Because of this, any definitive answer of whether or not leg dominance has an effect on mechanical knee joint loading in healthy soccer players is still inconclusive. A mutual agreement between these authors seems to be the possibility of lower extremity neuromuscular asymmetry, core and joint stabilization and proprioceptive deficits in the athlete. Authors further recommend prospective studies to look into the relationship between leg dominance and knee mechanics in healthy soccer players to confirm or refute the findings of these studies. The advancement of sport and player specific neuromuscular training protocols to improve these deficits has such become a necessity.

## ELECTROMYOGRAPHY

Electromyography (EMG) has been utilized as a non-invasive means of analyzing and assessing the function of muscle activation during physical activity for a number of decades. Several authors have recently analyzed the muscle recruitment activity around the knee during cutting maneuvers to determine a relationship with an increased incidence of injury (26, 38, 55, 93). Stiffening a muscle through activation has been noted to augment joint stiffness which in turn enhances the functional stability of the joint (97). Precise motor acquisition and rapid reaction time are important in performing advanced sport maneuvers and having an altered interaction between the dynamic and passive stabilizers may predispose an athlete to an increased incidence of injury (56).

Cappellini et al. identified an increase in EMG activity of all lower extremity muscles that were studied during higher locomotive speeds and in general, were the most active at foot contact (29). Authors also inferred that during running, the major leg joints experienced substantial flexion and extension during stance in order to create a spring-like action (29). Literature is consistent in showing that females generally elicit greater muscle activation in the quadriceps compared to hamstrings whereas males are seen to produce the opposite (38, 55, 93). Knowing the timing and magnitude of lower extremity muscle activation during a cutting maneuver may aid in the exercise prescription for ACL injury prevention.

## KINETICS

When a force causes a rotation, the rotation must occur about an axis of rotation and must have a line of action from the pivot point. The product of that force and the perpendicular distance to its line of action is referred to as a torque or a moment. The equation is mathematically shown as $T = F * r$ where T is the torque represented in newton-meters (Nm), F is the applied force in newtons (N) and r is the perpendicular distance from the pivot point to the line of action in meters (m). The terms torque and moment are synonymous in literature but will be further limited to moments for the sake of consistency. By capturing the initial force applied into the ground, inverse dynamics are then applied at the most distal joint and then work systematically up the segment links (54, 113).

Similarly, the angular work done per unit of time is referred to as power. Power is mathematically represented as $P = T * \omega$ where P is the power represented in watts or newton-meters per second (Nm/s), T is again torque in Nm and $\omega$ is the angular velocity in radians per second (rad/s) (54). Since the equation for power includes the result of the moment, powers are dependent on moments. Power is described as the rate at which physical work is performed or the rate at which energy is expended (64). By examining the power of a joint during a movement, internal forces will be available for further analyzing.

Recent studies examining the influence of gender and experience on knee mechanics have found useful information from which to compare common movements to (96, 102, 103). Sigward and Powers found that females demonstrated smaller sagittal plane moments and greater coronal plane moments than did males during the early deceleration phase of a cutting maneuver (103). The results in the coronal plane had yet to be identified before this study but may have been caused by a decrease in knee muscular strength, joint stability or cutting mechanics. Sagittal plane results were possibly caused by larger quadriceps activity during the early deceleration phase (first 20% of stance) of the cutting maneuver. This increase in muscle activity for the quadriceps may have increased knee extensor activity resulting in a reduced knee flexor moment. In a similar study by Sigward and Powers, novice females demonstrated smaller peak knee flexor, adductor and internal rotator moments when compared to experienced females. In addition, authors found that the novice females showed a smaller net joint moment impulse in the transverse and coronal planes (102). Again, possible causes of these results may have been attributed to muscular strength and/or proper cutting mechanics. These results have led to possible explanations for an increased risk of ACL injury during the cutting maneuver.

## THE CUTTING MANEUVER

The cutting maneuver is an essential component of soccer. Lasting a minimum of 90 minutes, a soccer match requires its athletes to run, cut and kick within an area of 8250m squared. The mechanics of the cutting maneuver evolves with experience and exists as an evasive maneuver. Footballers will use this technique on both offensive and defensive sides of play and it may or may not include a ball.

The cutting maneuver itself is further broken down into two common phases: the braking or deceleration phase and the propulsive or change of direction phase. The braking phase begins at heel contact and consists roughly of the first half of the stance phase. It is during this phase where the body decelerates its forward velocity by supporting its weight on one leg and moving into hip, knee and ankle flexion. This is also the phase where the lower extremity joints elicit the highest amount of load to the soft tissue structures (30). The propulsion phase begins near mid stance and ends at toe off; comprising mostly the second half of the stance phase. This phase utilizes the elastic energy produced from the prior phase in addition to a change of direction to propel the body out of the cut.

As briefly referenced in the above ‘Mechanism of Injury’ chapter, the cutting maneuver has been shown to elicit the greatest forces in the knee of female athletes Early studies by Andrews et al. in 1977 were among the first to examine the cutting maneuver (10). Since this time, an abundance of supporting literature has been added to the topic. Each body of work has examined specific factors within the maneuver in hopes of replicating the injury and discovering underlying mechanisms of injury.

### *Cutting style*

Andrews et al. defined the sidestep cut by planting the foot opposite to the direction they wish to travel and using the opposite leg as the first step in the new direction (10). Conversely, the crossover cut was defined by planting the foot on the same side they wish to travel and then crossing the opposite leg in front as the first step in the new direction (10). Due to the difficulty as well as the internal demands (internal rotation of the femur) of the crossover cut, the sidestep cut has since been adopted as the most common cutting technique in sports like soccer, rugby and basketball (10, 77, 118).

### *Cutting angle*

Similar to cutting speed, cutting angle has also been widely examined by researchers. As the first to examine the cutting maneuver in 1977, Andrews et al. used a 90° angle with his subjects as he looked into two different types of cutting, the crossover and sidestep maneuvers (10). This particular angle was chosen as it was a common cutting mechanism performed among the study's subject population of eight collegiate football players. The study noted many variations within the two types of cutting and warranted further investigation into these differences. Similarly, Imwalle et al. examined the differences in hip and knee kinematics in both a 45° and 90° cut (60). It was shown that greater internal hip and internal knee rotations occurred in the 90° cut compared to the 45° angle and that hip adduction was significantly correlated to knee abduction positions during both angles (60). Greig looked into a 180° cut in order to replicate a competitive soccer maneuver and while temporal changes to the kinematics of the cutting maneuver were observed to occur, fatigue may have played a large part (51). In addition, subjects were required to perform "a reversal of direction" during trials whereas the cutting speed eventually fell to zero before the finishing acceleration (51). During this time foot placement at heel strike was nearly perpendicular with the entry path during the trials; subjects of this study created an entirely new cutting strategy at which to observe.

As a result of the limitations of the aforementioned studies (among others) and due to the refinement of ACL injury as it pertains to the cutting mechanism, a 45° angle is now commonly used for testing procedures. This angle has been reported as the most common cutting angle to occur during soccer showing no kinematic differences between gender; allowing subjects to maintain a match-like speed throughout testing trials and demonstrating a more realistic maneuver (78, 103).

### *Cutting seed*

The exact speed of an athlete at the time of a NC ACL injury has been the subject of debate for many years. A majority of authors have claimed that athletes do not typically perform a cutting maneuver at maximum speeds as the greater momentum is more difficult to control prior to a directional change. As a result, several studies have followed similar protocols throughout the years which account for a controlled cutting speed of 5.5 – 7.0 m\s to replicate this submaximal movement (77, 78, 96, 102, 103). Unfortunately, this speed have been assessed through unreliable observations, timing lights or photoelectric switch and force plate contact and seem to be unrealistically obtainable in most laboratory settings. As such, Sanna and O’Connor reduced the cutting speed of the athlete even further to 4.0 – 5.0 m\s as a percentage of the $VO_2$max in their 2008 study (99).

Until recently, the aforementioned cutting speed protocol has been unchallenged. Cross et al. were among the first pioneers to test subjects during a cutting maneuver at a subject determined “full speed” pace (32). Current studies have tested collegiate athletes during a full speed or maximal effort cutting maneuver as this speed was noted to be the most representative of the nature of competitive match-play (38, 51, 119, 120).

### *Cutting anticipation*

Many studies to date have examined the differences in the cutting maneuver as it relates to cutting angle, speed, gender and experience (10, 51, 77, 102, 103). However, newer insights into the effects of the neuromuscular system and the feedforward mechanism have seemed to once again shift the movement towards a more appropriate match-like situation. Common sport maneuvers, as noted by Besier et al. do not always occur in an anticipated manner during match-like situations (18). Instead, they commonly occur as a sudden reaction to an external stimulus such as in response to another player, reacting to the movement of a ball or to stay within the playing area (18).

A study performed by Besier et al. examined external loads applied to the knee joint in athletic individuals during a cutting maneuver performed at 30° and 60° under preplanned and unanticipated conditions (18). Authors of the study found qualitative differences in joint kinematics between preplanned and unanticipated conditions in their subjects. These differences included changes in foot placement on the ground and trunk lean toward the direction of travel during the cutting maneuver. It was also concluded that unanticipated cutting conditions altered (increased valgus\varus and flexion\extension) the external moments applied to the knee by up to twice the magnitude (18).

In match play situations, there would appear to be a lack of time between a forthcoming maneuver and its neuromuscular planning strategy. During these unanticipated movements, muscles crossing the knee joint may be activated before the required task or at a greater magnitude in order to counter such intense external loads and to further protect the integrity of the knee complex.

# CHAPTER 3

# METHODOLOGY

*Subjects*

Sixteen healthy females (mean ± SD: age = 19.6 ± 1.3 yrs, body mass = 62.4 ± 6.1 kg, height = 168.0 ± 4.3 cm) volunteered as subjects for this study. All subjects were NCAA Division I varsity soccer players and had a minimum of twelve years of soccer experience (14.1 ± 0.8 yrs) and at least one year of collegiate experience (1.9 ± 1.0 yrs). All subjects were currently under the supervision of the singular head strength and conditioning coach and followed identical Olympic lifting training protocols (see Training Protocol in Appendix A). Additionally all subjects were healthy and had no current complaints of lower extremity injuries. Subjects were excluded from the study if they reported any of the following: (1) any history of ACL injury to either leg (2) any history of knee joint injury to either leg (3) any physical or neurological condition that would impair their ability to perform the required cutting maneuver.

### *Experimental Protocol*

All testing was performed at the Biomechanics Laboratory at Ball State University. Prior to participation, all aspects of the research study were explained to each subject and a written informed consent was obtained in accordance with the Institutional Review Board (see Informed Consent in Appendix B). All subjects were fitted with identical size appropriate compression tops, bottoms and socks (Nike Pro Compression, Nike, Inc., Beaverton, OR, USA) and indoor soccer shoes (Esito Finale IT, Puma, Boston, MA, USA). After which, subject height and mass was measured as well as additional bilateral anthropometric measurements using standard and commonly practiced techniques (33). The leg which the player prefers to kick the ball with or which they can kick the ball the furthest with was noted as the preferred kicking leg or the dominant leg (DL) and the other leg was noted as the preferred stance or support leg or non-dominant leg (NDL). This criteria was based on a number of studies that have looked at leg dominance in soccer player injuries (9, 39, 43, 44, 51, 111, 112).

Three dimensional kinematics and kinetics data were collected using a 12-camera motion capture system (240 Hz) (VICON Inc., Denver, CO, USA) where cameras were positioned so that each marker can be detected by at least three cameras for both static standing (model calibration) and dynamic cutting maneuvers (see Figure 2 in Appendix C). Ground reaction forces were collected using two calibrated and leveled AMTI force platforms (Model ORG-7-2000, Advanced Mechanical Technologies Inc., Watertown, MA, USA) embedded within the testing floor sampling at 2400 Hz. Spherical retro-reflective markers (14mm) were placed bilaterally on the following anatomical locations: acromion, superior border of the manubrium, cervical 7 vertebrae, thoracic 10 vertebrae, posterior superior iliac spines, anterior superior iliac spines, lateral femoral condyle, medial femoral condyle, lateral malleolus, medial malleolus, posterior calcaneus, base of second metatarsal, and base of fifth metatarsal. In addition, cluster marker sets consisting of four markers were placed on the lateral thigh and shank.

Prior to testing, a static standing trial was collected in order to build the three dimensional model. Range of motion trials were then collected, during which the knee joints performed flexion/extension within 30 degrees of range of motion and the hip joints performed flexion/extension, 45 degrees diagonal flexion/extension, and abduction within a range of 30 degrees. The range of motion trials were used to determine the locations of knee and hip joint centers (100).

Subjects then performed a general warm-up by jogging at a self-selected pace on a treadmill for five minutes followed by a general self-selected lower extremity dynamic warm-up as this protocol was identical to the team's weight training, practice and game warm up procedures. Next, subjects were instructed to perform a side-step cutting maneuver as previously described by McLean et al. (77). The cutting maneuver consisted of sprinting full speed and then performing an evasive maneuver (planting on one leg and pushing off to the other leg in a new direction) at a 45° angle with their DL and NDL. Tape lines were provided to direct subjects through the protocol as well as to ensure that a distinct change of direction occurred and not a "rounding". Subjects were required to perform five successful cuts on each side given in a random order. A successful trial consisted of the subject staying within the tape lines, having the plant foot land completely on the force platform and entering and exiting the cut at full speed.

Following the cutting trials, each subject performed unilateral maximal voluntary isometric contraction (MVIC) to assess muscular leg strength for the quadriceps and hamstring muscle groups using a Cybex Norm dynamometer (Lumex, Ronkonkoma, NY, USA) sampling at 100Hz. Subjects were positioned using a standardized protocol described by Montgomery and Shultz (82); where straps were used to stabilize the chest, hips, thighs and distal shank. The lateral femoral epicondyle was aligned with the dynamometer axis of rotation and the distal shank was secured at 2 finger's breadth proximal to the lateral malleolus. Gravity adjustments were made by determining the combined effects of leg mass and the passive muscle tension using the HUMAC software provided. Unilateral MVIC testing of the quadriceps was conducted with the subject seated with hip and knee flexion at 90° and 60°, respectively and pushing against a fixed resistance (7, 110). Unilateral MVIC testing of the hamstrings was conducted with the subject seated and hip and knee flexion at 90° and 30°, respectively and pulling against a fixed resistance (110). Subjects performed three 3-second MVICs for each muscle group with a 60-second rest between each trial (82). Following the MVIC testing, subjects performed isokinetic testing, in the same seated position, consisting of a limited ROM (0-90 degrees; 0 degrees being full knee extension) at a fixed speed of 60°/sec for three extension and three flexion actions (117). Once completed, subjects were tested on their other leg using the identical aforementioned protocol. Consistent with similar protocols, investigators provided strong verbal encouragement during each trial to maximize the subjects' consistent effort across trials (2, 82, 110).

### *Data Reduction*

The raw marker trajectory data was reconstructed in Nexus (Version 1.7, VICON Inc., Denver, CO, USA) and then processed in Visual3D (Version 4.9, C-Motion, Germantown, MD, USA) with the use of standard segment and joint definitions. Net joint moments were calculated using standard inverse dynamics equations (113). All data was normalized to body mass and cut cycle (identified as the period from initial contact of the foot to toe off, as determined by the force platform readings) to facilitate comparison between subjects. Specifically, the stance of cutting was divided into two distinct phases, the braking phase and propulsive phase. The braking phase is from initial foot contact to zero knee flexion velocity. The propulsive phase is from zero knee flexion velocity to toe-off.

### *Statistical Analysis*

Statistical analysis was performed using SPSS (Version 19.0 for Windows, SPSS Inc., Chicago, IL, USA). Dependent variables were grouped into primary and secondary variables.

Primary variables included peak knee power, peak knee flexion/extension velocity, peak knee adductor moment, and peak knee internal/external rotation during braking and propulsive phases. Secondary variables included approach speed, peak knee extensor moment, knee flexion at foot contact, peak knee flexion angle, peak knee abduction angle at stance of cutting, and peak isometric and isokinetic torques of knee flexor and extensor. One-way repeated measure multiple analysis of variance (MANOVA) was used to examine differences in knee mechanics between legs. In particular, repeated measure MANOVAs were performed to examine differences in primary variables between legs during braking and propulsive phases, respectively. Repeated measure MANOVAs were also performed to examine differences in secondary variables between legs during stance of cutting and dynamometry testing, respectively. In addition, approach speed was examined using Paired Student t-test. All significant levels were set at 0.05.

## LIMITATIONS

The subject population of this study was comprised of females only. As such, we were unable to examine any gender differences that may have occurred had males been included in the population. In addition, the subjects were informed of the direction of the cutting maneuver prior to its initiation; creating an anticipated cutting maneuver. Because of this, the internal loads placed on the knee joint may not have been as high as with unanticipated cutting maneuvers.

## DELIMITATIONS

All participants involved in this research were recruited from the Ball State University woman’s varsity soccer team and reflect the demographics of that population.

# CHAPTER 4

## RESEARCH ARTICLE

The following paper was written with the expectation that it would be submitted to Medicine & Science in Sport & Exercise for review following completion of this thesis process.

# The Relationship Between Leg Dominance and Knee Mechanics During the Cutting Maneuver

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# ABSTRACT

SCOTT R. BROWN, CLARK DICKIN, DAVID PEARSON, STACY WALKER, AND HENRY WANG. The Relationship Between Leg Dominance and Knee Mechanics During the Cutting Maneuver. Females have shown a 3-9 times greater risk for non-contact (NC) anterior cruciate ligament (ACL) disruption compared to their male counterpart while participating in sports that involve high risk jumping or cutting maneuvers such as soccer, rugby and basketball. Female soccer players have shown close to a 70% greater chance of sustaining an ACL disruption to their non-dominant leg (NDL) when compared to their dominant leg (DL). **Purpose**: To examine the relationship between leg dominance and knee mechanics during the cutting maneuver. **Methods**: Sixteen healthy female (19.6 ± 1.3 yrs, 62.4 ± 6.1 kg, 168.0 ± 4.3 cm) NCAA Division I varsity soccer players volunteered as subjects for this study. Subjects were instructed to perform a cutting maneuver; where they sprinted full speed and then performed an evasive maneuver (planting on one leg and pushing off to the other leg in a new direction) at a 45° angle with their DL and NDL. **Results**: During the braking phase of the cut the NDL showed greater ($P=0.003$) power absorption, greater ($P=0.010$) peak internal rotation angle and greater ($P=0.005$) peak flexion velocity. During the propulsive phase the DL showed greater ($P=0.010$) power production, greater ($P=0.038$) peak internal adductor moment and greater ($P=0.020$) peak extension velocity. In addition, no differences ($P>0.05$) in knee extensor and flexor isometric and isokinetic torques between the two legs were shown. **Conclusions**: The results of this study show that a difference in knee mechanics during cutting does exist between the dominant and non-dominant leg. The findings of this study will increase the knowledge base of ACL injury in females and could aid in the design of more appropriate neuromuscular, plyometric and strength training protocols for injury prevention. **Key Words**: ACL, injury, soccer, female, isometric, isokinetic

## INTRODUCTION

***Paragraph Number 1*** Soccer is the most popular and most played sport in the world involving over 265 million active footballers, 38 million of which are registered (those competing in youth, amateur or professional levels) and has continued to grow with an annual increase of 4.4 million participants since 2002 (1). In the United States alone, there are an estimated 24.5 million active footballers (4.2 million registered) which make up approximately 8.2% of the total population; roughly 7 million of which are female (1). This large number of female participants is largely due to the induction of title IX on the Education Amendments in 1972 which stated that no person shall be discriminated against on the basis of sex in all educational programs and activities receiving federal funds (22). Since that time, all sports have seen a colossal increase in female participation in the U.S. In the 2010-11 season, the NCAA reported a 260% increase in female footballers from that reported in the 1981-82 season. (21).

***Paragraph Number 2*** Coinciding with this large increase in female participation has been an equally large number of sport related injuries. It has been noted that females who participate in sports that involve high risk jumping or cutting maneuvers have been shown to be at a higher risk (3-9 times) when compared to males playing the same sport (6, 20). The incidence rate of soccer related injuries for individual female players is estimated as much as 40 per 1000 match hours and has been seen to increase in younger and less experienced players (2, 6). In addition, an estimated 60-80% of all soccer injuries occur to the lower extremities, specifically the ACL (3, 13). These ACL injuries have been examined in great detail and nearly 70% are non-contact (NC) in nature (4, 11, 31). These NC ACL injuries are classified as those reported to be caused by no apparent contact with a stationary object, contact with the ball, or contact with another player (2).

***Paragraph Number 3*** The mechanism breakdown for NC ACL injury has been shown to involve a step-stop action, cutting task, sudden change of direction, landing from a jump with inadequate lower extremity mechanics or a lapse in concentration (8, 17, 18). Expanding on these findings, studies have reported the greatest loads in the knee to occur during a deceleration maneuver combined with a change of direction (7, 25, 26). When the athlete attempts to change directions, the excessive torsional force can cause disruption to the ACL (33). During these maneuvers, extreme external loads induced by kinematic changes have been seen in the lower extremities (12). These changes have led to several different theories as to the exact mechanism of ACL injury. Such external loads occur during knee hyperextension or hyperflexion, excessive knee valgus or varus, internal or external tibial rotation and anterior tibial translation (7, 23, 34, 36).

***Paragraph Number 4*** Biomechanical evaluations of gender, cutting speed and cutting angle have been examined to great length. What has not been thoroughly evaluated however is the influence of leg dominance on ACL injury. Since soccer is a predominantly lower extremity sport, where-in athletes are required to run, cut and kick over a 90 minute match, it seems pertinent to include leg dominance to the etiology for ACL injury. Based on a number of studies that have looked at leg dominance in all soccer player injuries, the leg which the player prefers to kick the ball with or which they can kick the ball the furthest with has been noted as the preferred kicking leg or the dominant leg (DL) and the other leg has been noted as the preferred stance or support leg or non-dominant leg (NDL) (15, 16, 19).

***Paragraph Number 5*** Several retrospective studies have attempted to look into the role of leg dominance on ACL injury but have failed to standardize sport background and injury mechanism (16, 24, 29). A recent study by Brophy et al. took these limitations into account when examining soccer players all with NC ACL injuries (11). Containing an identical subject population and injury mechanism, results showed that 74% of male subjects sustained an injury to the DL and 68% of female subjects sustained an injury to the NDL; suggesting that leg dominance may play a gender based role in NC ACL injury specifically in soccer players (11). Authors further recommend prospective studies to look into the relationship between leg dominance and knee mechanics in healthy soccer players to confirm these findings.

*Paragraph Number 6* Therefore, the purpose of this research is to investigate the effects of leg dominance on knee mechanics during the cutting maneuver. It was surmised that there would be differences in knee mechanics between the DL and NDL during the cutting maneuver.

## METHODS

*Paragraph Number 7* **Subjects**. Sixteen healthy females (mean ± SD: age = 19.6 ± 1.3 yrs, body mass = 62.4 ± 6.1 kg, height = 168.0 ± 4.3 cm) volunteered as subjects for this study (Table 1). All subjects were NCAA Division I varsity soccer players and had a minimum of twelve years of soccer experience (14.1 ± 0.8 yrs) and at least one year of collegiate experience (1.9 ± 1.0 yrs). All subjects were currently under the supervision of the singular head strength and conditioning coach and followed an identical Olympic lifting strength training protocol. Additionally all subjects were healthy and had no current history of lower extremity injuries. Subjects were excluded from the study if they reported any of the following: (1) any history of ACL injury to either leg; (2) any history of injury to the knee joint of either leg; or (3) any physical or neurological condition that would impair their ability to perform the required cutting maneuver.

*Paragraph Number 8* **Experimental Protocol**. The research protocol was approved by the Institutional Review Board at Ball State University. Prior to participation, all aspects of the research study were explained to each subject and written informed consent was obtained. All subjects were fitted with identical, size appropriate compression, tops, bottoms and socks (Nike Pro Compression, Nike, Inc., Beaverton, OR, USA) and indoor soccer shoes (Esito Finale IT, Puma, Boston, MA, USA). The leg which the player prefers to kick the ball with or which they can kick the ball the furthest with was noted as the preferred kicking leg or the dominant leg (DL) and the other leg was noted as the preferred stance or support leg or non-dominant leg (NDL). This criteria was based on a number of studies that have looked at leg dominance in soccer player injuries (15, 16, 19).

***Paragraph Number 9*** A 12-camera (MX 40) motion capture system (240 Hz) (VICON Inc. Denver, CO, USA) was used to track the three dimensional (3D) trajectories of reflective markers placed on the body during cutting maneuvers. Two embedded AMTI force platforms (Model OR6-7-2000, Advanced Mechanical Technologies Inc., Watertown, MA, USA) were used to collect ground reaction forces at 2400 Hz. VICON NEXUS (Version 1.7, VICON Inc. Denver, CO, USA) was used to reconstruct and process the raw 3D trajectory data and ground reaction force data. A Cybex Norm dynamometer (Lumex, Ronkonkoma, NY, USA) was used to assess knee extensor and flexor isometric and isokinetic strength at 100 Hz.

***Paragraph Number 10*** Spherical retro-reflective markers (14mm) were placed bilaterally on the following anatomical locations: superior border of the acromion, superior border of the manubrium, cervical 7 vertebrae, thoracic 10 vertebrae, posterior superior iliac spines, anterior superior iliac spine, lateral femoral condyle, medial femoral condyle, lateral malleolus, medial malleolus, posterior calcaneus, base of second metatarsal, and base of fifth metatarsal. In addition, cluster marker sets consisting of four markers were placed on the lateral thigh and shank.

***Paragraph Number 11*** Subjects then performed a general warm-up by jogging at a self-selected pace on a treadmill for five minutes followed by a general self-selected lower extremity dynamic warm-up as this protocol was identical to the team’s weight training, practice and game warm up procedures. Next, subjects were instructed to perform a side-step cutting maneuver as previously described by McLean et al. (25). The cutting maneuver consisted of sprinting full speed and then performing an evasive maneuver (planting on one leg and pushing off to the other leg in a new direction) at a 45° angle with their DL and NDL. Tape lines were provided to direct subjects through the protocol as well as to ensure that a distinct change of direction occurred and not a “rounding” maneuver. Subjects were required to perform five successful cuts on each side given in a random order. A successful trial consisted of the subject staying within the tape lines, having the plant foot land completely on the force platform and entering and exiting the cut at maximal speed to simulate a match situation (40).

*Paragraph Number 12* Following the cutting trials, each subject performed unilateral maximal voluntary isometric contraction (MVIC) to assess muscular leg strength for the quadriceps and hamstring muscle groups using a Cybex Norm dynamometer (Lumex, Ronkonkoma, NY, USA). The order of the tested leg was randomly determined. Subjects were positioned using a standardized protocol described by Montgomery and Shultz (28); where straps were used to stabilize the chest, hips, thighs and distal shank. The lateral femoral epicondyle was aligned with the dynamometer axis of rotation and the distal shank was secured at 2 finger's breadth proximal to the lateral malleolus. Gravity adjustments were made by determining the combined effects of leg mass and the passive muscle tension using the HUMAC software (Lumex, Ronkonkoma, NY, USA). Unilateral MVIC testing of the quadriceps was conducted with the subject seated with hip and knee flexion at 90° and 60°, respectively and pushing against a fixed resistance (5, 35). Unilateral MVIC testing of the hamstrings was conducted with the subject seated and hip and knee flexion at 90° and 30°, respectively and pulling against a fixed resistance (35). Subjects performed three 3-second MVICs for each muscle group with a 60-second rest between each trial (28). Following the MVIC testing, subjects performed isokinetic testing, in the same seated position, consisting of a limited ROM (0-90 degrees; 0 degrees being full knee extension) at a fixed speed of 60°/sec for three extension and three flexion actions (39). Once completed, subjects were tested on their other leg using the identical aforementioned protocol. Consistent with similar protocols, investigators provided strong verbal encouragement during each trial to maximize the subjects' consistent effort across trials (28, 35).

*Paragraph Number 13* **Data Reduction and Analysis**. Visual 3D (Version 4.90, C-Motion, Germantown, MD, USA) was used to perform link model based computations on lower extremity joints. Hip and knee joint centers were defined by using a functional joint procedure (49). Net joint moments were calculated using standard inverse dynamics equations (37). All data was normalized to body mass and cut cycle (identified as the period from initial contact of the foot to toe off, as determined by the force platform readings) to facilitate comparison between subjects. Specifically, the stance of cutting was divided into two distinct phases, the braking phase and propulsive phase. The braking phase was from initial foot contact to zero knee flexion velocity. The propulsive phase was from zero knee flexion velocity to toe-off.

***Paragraph Number 14*** **Statistical Analysis**. Statistical analysis was performed using SPSS (Version 19.0 for Windows, SPSS Inc., Chicago, IL, USA). Dependent variables were grouped into primary and secondary variables. Primary variables included peak knee power, peak knee flexion/extension velocity, peak knee adductor moment, and peak knee internal/external rotation during braking and propulsive phases. Secondary variables included approach speed, peak knee extensor moment, knee flexion at foot contact, peak knee flexion angle, peak knee abduction angle at stance of cutting, and peak isometric and isokinetic torques of knee flexor and extensor. One-way repeated measure multiple analyses of variance (MANOVA) were used to examine differences in knee mechanics between legs. In particular, repeated measure MANOVAs were performed to examine differences in primary variables between legs during braking and propulsive phases, respectively. Repeated measure MANOVAs were also performed to examine differences in secondary variables between legs during stance of cutting and dynamometry testing, respectively. In addition, approach speed was examined using Paired Student t-test. All significant levels were set at 0.05.

## RESULTS

***Paragraph Number 15*** The within-subject effect of the MANOVA test for secondary variables during stance of cutting was not significant (P=0.763). The within-subject effect of the MANOVA test for secondary variables during knee strength test was not significant (P=0.943). However, the within-subject effect of the MANOVA test for variables during braking phase of cutting was significant (P=0.002). Also, the within-subject effect of the MANOVA test for variables during the propulsive phase of cutting was significant (P=0.046). Further pair-wise comparisons were performed on the braking phase and propulsive phase to determine the differences in individual variables between the two legs.

***Paragraph Number 16*** Primary knee joint mechanics in the DL and NDL are presented in Table 2. During the braking phase, subjects produced greater peak power absorption (P=0.003), peak knee flexion velocity (P=0.005) and peak knee internal rotation (P=0.010) in the NDL than those in the DL. During the propulsive phase, subjects produced greater peak power production (P=0.010), peak knee extension velocity (P=0.020) and peak knee adductor moment (P=0.038) than those in the NDL. The average approach speed is presented in Figure 1 and did not differ between legs (P=0.07).

## DISCUSSION

***Paragraph Number 17*** The purpose of this study was to investigate the effects of leg dominance on knee mechanics during the cutting maneuver. Epidemiological studies performed by Brophy et al. showed nearly 70% of female ACL injuries occur to the NDL even after accounting for sport and injury mechanism (11). Based on these findings, it was surmised that there would be differences in knee mechanics between the DL and NDL when executing a cutting maneuver. The results of this study support the original hypothesis. Specifically, during the braking phase of the cutting movement, the NDL knee demonstrated greater power absorption, greater peak internal rotation angle and greater peak flexion velocity. During the propulsive phase of the cutting movement, the DL knee showed greater power production, greater peak internal adductor moment and greater knee extension velocity.

***Paragraph Number 18*** During the braking phase of cutting, the body is decelerating. The quadriceps is lengthening while the knee joint is flexing. This leads to energy absorption around the knee joint (29). Knee joint power absorption indicates kinetic energy is absorbed by the knee musculature and connective tissues such as the ACL. In fact, ACL experiences high tension when the knee joint angle is within the first 0 to 40 degrees of flexion during cutting related activities (14, 38). In this study, during heel strike of cutting, the average knee flexion angle was approximately 26 degrees and increased to as much as 51 degrees through the stance phase; which indicates that the ACL is in a position of undergoing high tension. When compared to the DL knee, the NDL knee exhibited greater peak power absorption. When further examined, peak knee flexion velocity during the braking phase was shown to be greater in the NDL compared to the DL. An increased rate of knee flexion could result in increased rate of ACL lengthening. As tension developed in viscoelastic tissue, such as the ACL, is dependent on mechanical loading and loading rate (30), the ACL of the NDL may experience increased tensile loading during the braking phase of cutting than that of the DL. In addition, there is increased internal knee rotation in the NDL during the braking phase of cutting; increased internal knee rotation could also place the ACL under high tension (31, 34). Thus, the increased power absorption and higher knee flexion velocity coupled with greater internal knee rotation may place the NDL's ACL in higher tensile strain during braking phase of cutting. The possible higher tensile strain may result in increased risk of ACL injury in NDLs.

***Paragraph Number 19*** During the propulsive phase of cutting movement, the body is accelerating towards the direction of the cut. The quadriceps is shortening, the knee joint is extending. There is power production around the knee joint, which reflects energy flowing out the knee joint to increase the kinetic energy of the moving body. Interestingly, the DL knee demonstrated a significantly greater increase in power production than the NDL. In addition, an increase in peak knee extension velocity was seen to occur to the DL knee. It seems that the propulsive phase of the cutting movement is executed faster by the DL than the NDL. Studies have found that skill level holds an inference on cutting mechanics (32). If the DL should possess more skill than the NDL, than an increase in power production in the DL would be expected in the cutting maneuver. Since the DL is determined by the leg in which the subject would kick a soccer ball the furthest with, it is expected that the DL would be more skilled in hip flexion and knee extension; which are common components in a soccer kick (9, 10). However, as the knee extension velocity increases, the ACL lengthening also increases at a fast rate. Increasing lengthening velocity in soft tissue results in pronounced tension development (30). Thus, the ACL may experience an increase in tension. In addition, there is greater peak knee adductor moment in the DL when compared to the NDL. It has been noted in previous studies that during the stance phase of cutting, individuals exhibited increased knee joint adduction moments when pivoting on the plant leg to initiate the change of direction (7, 27). Therefore, increasing power production with increased knee extension velocity coupled with increased knee adductor moment may expose the ACL of the DL knee to high tension. An increased risk of ACL injury associated with the DL may be possible during the propulsive phase of the cutting maneuver.

***Paragraph Number 20*** In this study, we also evaluated subject's knee extensor and flexor strength by using dynamometry as shown in Table 3. Interestingly, both legs demonstrated similar knee extensor and flexor isometric and isokinetic torques. Findings from the dynamometry evaluation may help explain that the knee extensor moment between the two legs were not significantly different during cutting. The similar knee strength between legs may be a result of the Olympic lifting strength training protocol established by the head strength and conditioning coach. Also the subject's experience at the collegiate level may have further established similar leg strength. Having equivalent strength in the DL and NDL could potentially decrease the variability in knee moments by stabilizing and strengthening the rigidity of the joint complex.

***Paragraph Number 21*** In summary, although the DL and NDL possessed similar knee extensor and flexor strength through proper training programs, there were mechanical differences between the DL and NDL knees during the cutting maneuver. The NDL knee demonstrated greater power absorption, knee flexion velocity, and internal rotation than the DL knee during braking phase of cutting. However, the DL knee exhibited greater power production, knee extension velocity, and adduction moment than the NDL during the propulsive phase of cutting. It appears that the NDL could be more prompted to increased risk of ACL injury during the braking phase while the DL may face increased risk of ACL injury during the propulsive phase.

## CONCLUSIONS

***Paragraph Number 22*** In addition to the long-standing mechanism of NC ACL injury where the knee experiences multiplanar loadings during the deceleration phase of a cutting maneuver; there now seems to be two possible injury mechanisms. The first mechanism involves a combination of increased power absorption and internal rotation in the NDL during the braking phase. The second mechanism involves a combination of increased power production and increased knee abductor moment in the DL during the propulsive phase.

***Paragraph Number 23*** The direct causes of the increased knee flexion velocity in the NDL and the increased knee extension velocity in the DL in the current study are unknown. It is necessary to discover whether the knee mechanics shown in this study were influenced by adjacent joint mechanics, trunk kinematics or lower extremity muscle activation patterns during the cutting maneuver. After further investigations, more appropriate injury prevention strategies and prescriptions may be made to improve on proper landing techniques, body position, joint stability and awareness and the appropriate utilization of lower extremity power.

## ACKNOWLEDGMENTS

***Paragraph Number 24*** This study was funded, in part, by a Ball State University ASPiRE grant I513-12.

***Paragraph Number 25*** The authors have no conflict of interest.

***Paragraph Number 26*** The authors thank all the players, coaches and strength and conditioning staff on the Ball State University woman’s soccer team for their participation in this study.

***Paragraph Number 27*** The results of the present study do not constitute endorsement by the American College of Sports Medicine.

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**Table 1:** Subject Characteristics [mean (standard deviation)].

| | **Female soccer players** |
|---|---|
| Subjects (n) | 16 |
| Age (yr) | 19.69 (1.40) |
| Height (cm) | 168.25 (4.23) |
| Mass (kg) | 62.24 (5.73) |
| Collegiate experience (yr) | 1.94 (1.00) |
| Soccer experience (yr) | 13.94 (0.93) |
| Dominant leg | Right = 16, Left = 0 |
| Position | Goalkeeper = 1, Defender = 7<br>Midfielder = 5, Forward = 3 |

**Table 2:** Primary knee joint mechanics in the DL and NDL during the braking phase and propulsive phase of the cutting maneuver [mean (standard deviation)].

| **Dependent variables** | **Conditions** | | |
|---|---|---|---|
| | **DL** | **NDL** | **P value** |
| **Braking phase** | | | |
| Peak power absorption (W/kg) | 16.35 (3.70) | 19.43 (6.04) | 0.003* |
| Peak adductor moment (Nm/kg) | - 1.03 (0.47) | - 0.93 (0.28) | 0.328 |
| Peak internal rotation angle (°) | 18.8 (5.4) | 22.1 (5.1) | 0.010* |
| Peak knee flexion velocity (°/s) | - 484.5 (152.4) | - 565.8 (178.8) | 0.005* |
| **Propulsive phase** | | | |
| Peak power production (W/kg) | 13.51 (2.94) | 11.55 (2.49) | 0.010* |
| Peak adductor moment (Nm/kg) | - 1.44 (0.76) | - 1.01 (0.43) | 0.038* |
| Peak knee extension velocity (°/s) | 553.0 (121.8) | 504.1 (114.6) | 0.020* |

* Denotes a significant difference (P=0.05) between DL and NDL.

**Table 3:** Secondary knee joint mechanics in the DL and NDL during the stance phase of the cutting maneuver and during knee strength testing [mean (standard deviation)].

| **Dependent variables** | **Conditions** | |
|---|---|---|
| | **DL** | **NDL** |
| **Stance Phase** | | |
| Peak extensor moment (Nm/kg) | 2.82 (0.41) | 2.68 (0.36) |
| Flexion angle at foot contact (°) | 27.0 (6.1) | 25.8 (7.2) |
| Peak flexion angle (°) | 52.0 (4.7) | 51.1 (5.0) |
| Peak abduction angle (°) | - 12.4 (6.4) | - 12.9 (4.7) |
| **Knee joint torques** | | |
| Peak isometric extensor torque (Nm) | 185.72 (53.51) | 184.55 (46.46) |
| Peak isometric flexor torque (Nm) | 96.32 (22.81) | 94.67 (21.65) |
| Peak isokinetic extensor torque (Nm) | 163.29 (36.10) | 164.77 (30.16) |
| Peak isokinetic flexor torque (Nm) | 83.85 (17.26) | 85.30 (15.19) |

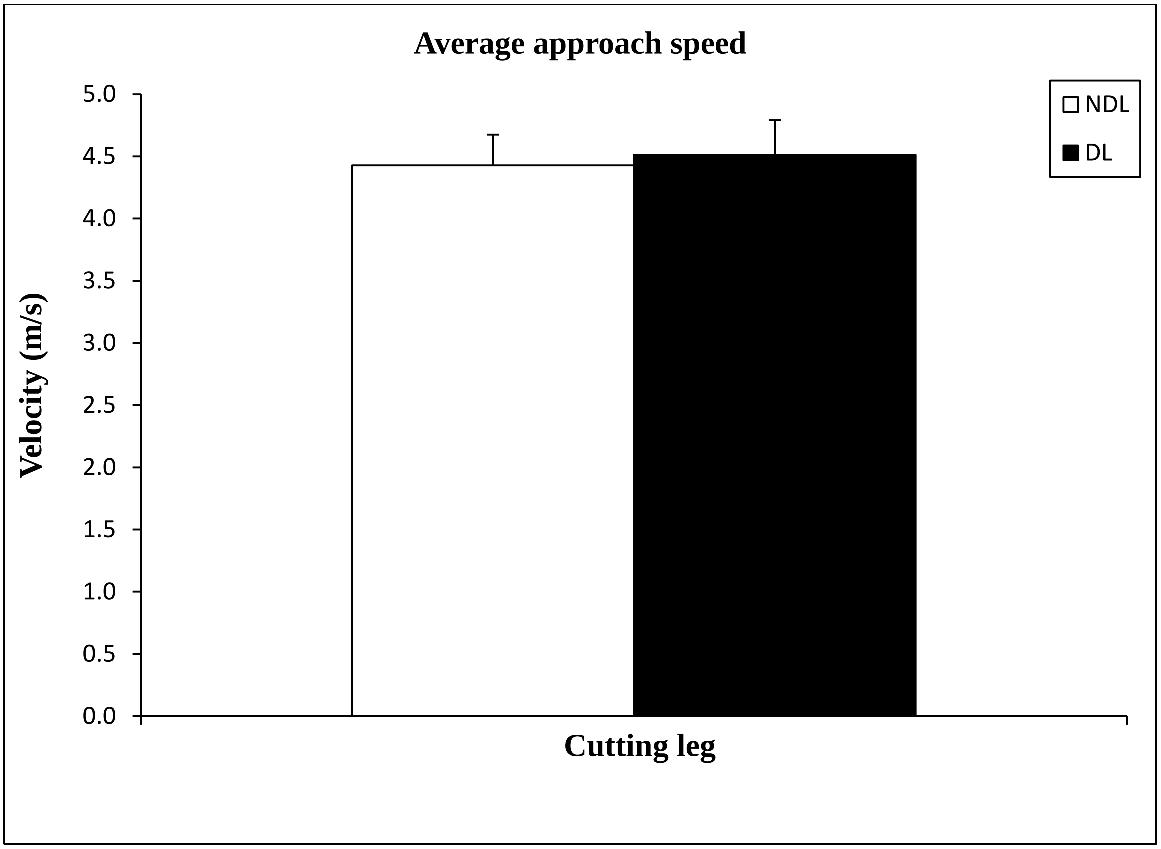

**Fig. 1** Average approach speed during the cutting maneuver between legs. (P=0.07)

# CHAPTER 5

# SUMMARY AND CONCLUSIONS

## SUMMARY

The purpose of this study was to investigate the effects of leg dominance on knee mechanics during the cutting maneuver. Epidemiological studies performed by Brophy et al. showed nearly 70% of female ACL injuries occur to the NDL even after accounting for sport and injury mechanism (28). Based on these findings, it was surmised that there would be differences in knee mechanics between the DL and NDL when executing a cutting maneuver. The results of this study support the original hypothesis. Specifically, during the braking phase of the cutting movement, the NDL knee demonstrated greater power absorption, greater peak internal rotation angle and greater peak flexion velocity. During the propulsive phase of the cutting movement, the

DL knee showed greater power production, greater peak internal adductor moment and greater knee extension velocity.

During the braking phase of cutting, the body is decelerating. The quadriceps is lengthening while the knee joint is flexing. This leads to energy absorption around the knee joint (29). Knee joint power absorption indicates kinetic energy is absorbed by the knee musculature and connective tissues such as the ACL. In fact, the ACL experiences high tension when the knee joint angle is within the first 0 to 40 degrees of flexion during cutting related activities (14, 35, 116). In this study, during heel strike of cutting, the average knee flexion angle was found to be 26 degrees and increased to as much as 51 degrees through the stance phase; which indicates that the ACL is in a position of undergoing high tension. When compared to the DL knee, the NDL knee exhibited greater peak power absorption. When further examined, peak knee flexion velocity during the braking phase was shown to be greater in the NDL compared to the DL. Increased rate of knee flexion could result in increased rate of ACL lengthening. As tension developed in viscoelastic tissue, such as the ACL, is dependent on mechanical loading and loading rate (86), the ACL of the NDL may experience increased tensile loading during braking phase of cutting than that of the DL. In addition, there is increased internal knee rotation in the NDL during braking phase of cutting; increased internal knee rotation could also place the ACL under high tension (90, 109). Thus, the increased power absorption and higher knee flexion velocity coupled with greater internal knee rotation may place the NDL's ACL in higher tensile strain during braking phase of cutting. The possible higher tensile strain may result in increased risk of ACL injury in NDLs.

During the propulsive phase of cutting movement, the body is accelerating towards the direction of the cut. The quadriceps is shortening, the knee joint is extending. There is power production around the knee joint, which reflects energy flowing out the knee joint to increase the kinetic energy of the moving body. Interestingly, the DL knee demonstrated a significant increase in power production. In addition, an increase in peak knee extension velocity was seen to occur to the DL knee. It seems that the propulsive phase of the cutting movement is executed faster by the DL than the NDL. Studies have found that skill level holds an inference on cutting mechanics (97). If the DL should possess more skill than the NDL, than an increase in power production in the DL would be expected in the cutting maneuver. Since the DL is determined by the leg in which the subject would kick a soccer ball the furthest, it is expected that the DL would exhibit higher levels of control in hip flexion and knee extension; which are common components in a soccer kick (26, 27). However, as knee extension velocity increases, the ACL lengthening also increases at a fast rate. Increasing lengthening velocity in soft tissue results in pronounced tension development (86). Thus, the ACL may experience an increase in tension. In addition, there is greater peak knee adductor moment in the DL when compared to the NDL. It has been noted in previous studies that during the propulsive phase, individuals exhibited increased knee joint adduction moment when pivoting the plant leg to initiate the change of direction (19, 79). Therefore, increasing power production with increased knee extension velocity coupled with increased knee adductor moment may expose the ACL of the DL knee to high tension. An increased risk of ACL injury associated with the DL may be possible during the propulsive phase of the cutting maneuver.

In this study, we also evaluated individual’s knee extensor and flexor strength by using dynamometry. Interestingly, both legs demonstrated similar knee extensor and flexor isometric and isokinetic torques. Findings from the dynamometry evaluation may help explain that the knee extensor moment between the two legs were not significantly different during cutting. The similar knee strength between legs may be a result of the Olympic lifting strength training protocol established by the head strength and conditioning coach. Also the subject’s experience at the collegiate level may have further established similar leg strength. Having equivalent leg strength in the DL and NDL could potentially decrease the variability in knee moments by stabilizing and strengthening the rigidity of the joint complex.

In summary, although the DL and NDL possessed similar knee extensor and flexor strength potentially through proper training programs, there were mechanical differences between the DL and NDL knees during the cutting maneuver. The NDL knee demonstrates greater power absorption, knee flexion velocity, and internal rotation than the DL knee during braking phase of cutting. However, the DL knee exhibited greater power production, knee extension velocity, and adduction moment than the NDL during propulsive phase of cutting. It appears that the NDL could be at an increased risk of ACL injury during the braking phase while the DL may be at an increased risk of ACL injury during the propulsive phase.

# CONCLUSIONS

In addition to the long-standing mechanism of NC ACL injury where the knee experiences multiplanar loadings during the deceleration phase of a cutting maneuver; there now seems to be two possible injury mechanisms. The first mechanism involves a combination of increased power absorption and internal rotation in the NDL during first half of stance. The second mechanism involves a combination of increased power production and increased knee abductor moment in the DL during the second half of stance.

The direct causes of the increased knee flexion velocity in the NDL and the increased knee extension velocity in the DL in the current study are unknown. It is necessary to discover whether the knee mechanics shown in this study were influenced by adjacent joint mechanics, trunk kinematics or lower extremity muscle activation patterns during the cutting maneuver. After further investigations, more appropriate injury prevention strategies and prescriptions may be made to improve on proper landing techniques, body position, joint stability and awareness and the appropriate utilization of lower extremity power.

# CHAPTER 6

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# APPENDIX A

## TRAINING PROTOCOL

# BALL STATE UNIVERSITY PHASE 1 Weeks 1-4

## WOMEN'S SOCCER

| DAY 1 | WEEK 1 | WEEK 2 | WEEK 3 | WEEK 4 |
|---|---|---|---|---|
| **1a) Barbell Complex** | *2x5* | *2x5* | *2x5* | *2x5* |
| Bent Row/RDL/Front Squat/Push Press | *Bar* | *Bar* | *Bar* | *Bar* |
| **1b) Squat Jump** | *3x5* | *3x5* | *3x6* | *3x6* |
| (Stick Landings) | | | | |
| **2) Snatch Pull** (WK 1-2 Power Position) | *5x2* | *5x2* | *6x2* | *6x2* |
| (WK 3-4 Hang Position) | | | | |
| **3a) Concentric Rack Pull** | *3x4* | *3x4* | *3x4* | *3x4* |
| | | | | |
| **3b) TRX Inverted Row** | *3x8* | *3x8* | *3x8* | *3x8* |
| | | | | |
| **4a) DB Split Squat** | *3x4/side* | *3x4/side* | *3x4/side* | *3x4/side* |
| | | | | |
| **4b)Side Plank w/:02sec holds** | *2x5/side* | *2x5/side* | *2x6/side* | *2x6/side* |
| | | | | |

| DAY 2 | WEEK 1 | WEEK 2 | WEEK 3 | WEEK 4 |
|---|---|---|---|---|
| **1a) Barbell Complex** | *2x5* | *2x5* | *2x5* | *2x5* |
| Bent Row/RDL/Front Squat/Push Press | *Bar* | *Bar* | *Bar* | *Bar* |
| **1b) Lateral Bound** | *3x3/side* | *3x3/side* | *3x4/side* | *3x4/side* |
| (Stick Landings on Two Feet) | | | | |
| **2) Snatch Pull** (WK 1-2 Hang Position) | *5x2* | *5x2* | *6x2* | *6x2* |
| (WK 3-4 Below Knee) | | | | |
| **3a) Goblet Squat** | 3x5 | 3x5 | 3x5 | 3x5 |
| | | | | |
| **3b) DB Push Press** | 3x6 | 3x6 | 3x6 | 3x6 |
| | | | | |
| **4a) Lateral Push Back Lunge** | *3x4/side* | *3x4/side* | *3x4/side* | *3x4/side* |
| | | | | |
| **4b) Plank w/:03sec holds** | *2x5/side* | *2x5/side* | *2x6/side* | *2x6/side* |
| | | | | |

# BALL STATE UNIVERSITY PHASE 2 Weeks 5-8

WOMEN'S SOCCER

| DAY 1 | WEEK 5 | WEEK 6 | WEEK 7 | WEEK 8 |
|---|---|---|---|---|
| **1a) Barbell Complex** | *2x5* | *2x5* | *2x5* | *2x5* |
| RDL, Snatch Pull, BN Push Press, OH Squat | *Bar* | *Bar* | *Bar* | *Bar* |
| **1b) Lateral Bound + Stick** | *3x3e* | *3x3e* | *3x3e* | *3x3e* |
| (Land on 1 foot) | | | | |
| **2) Snatch Pull** | *6x2* | *6x2* | *6x2* | *6x2* |
| SL SQ Jump (Land on 2 feet) 3x3, 3x2 | | | | |
| **3a) Speed Front SQ** ( > 1.0 m/s) | *5x2* | *5x2* | *5x2* | *5x2* |
| | | | | |
| **3b) One Arm DB Row (Supported)** | *3x5e* | *3x5e* | *3x5e* | *3x5e* |
| | | | | |
| **4a) DB Reverse Lunge** | *3x4/side* | *3x4/side* | *3x4/side* | *3x4/side* |
| | | | | |
| **4b) Shovel Twist w/ Plate** | *2x8/side* | *2x8/side* | *2x8/side* | *2x8/side* |
| | | | | |

| DAY 2 | WEEK 5 | WEEK 6 | WEEK 7 | WEEK 8 |
|---|---|---|---|---|
| **1a) Barbell Complex** | *2x5* | *2x5* | *2x5* | *2x5* |
| RDL, Snatch Pull, BN Push Press, OH Squat | *Bar* | *Bar* | *Bar* | *Bar* |
| **1b) Lateral Bound+Stick** | *3x3/side* | *3x3/side* | *3x4/side* | *3x4/side* |
| (Stick Landings on One Foot) | | | | |
| **2) Snatch Pull** (WK 1-2 Floor Up) | *6x2* | *6x2* | *6x2* | *6x2* |
| (WK 3-4 Floor Up, Catch) | | | | |
| **3a) Concentric Rack Pull** | 4x3 | 4x3 | 4x3 | 4x3 |
| | | | | |
| **3b) DB Push Jerk** | 3x6 | 3x6 | 3x6 | 3x6 |
| | | | | |
| **4a) Single Leg SQ to Bench** | *3x4/side* | *3x4/side* | *3x4/side* | *3x4/side* |
| | | | | |
| **4b) Renegade Row** | *2x10* | *2x10* | *2x12* | *2x12* |
| | | | | |

# APPENDIX B

## INFORMED CONSENT

Ball State University
Muncie, Indiana 47306

**Informed Consent**

# The Relationship Between Leg Dominance and Knee Mechanics During the Cutting Maneuver

**Why am I being invited to take part in this research?**
You are being invited to partake in this research study because you meet the requirements. If you volunteer, you will be one of about twenty people to do so.

**Who is conducting the study?**
This is a scientific research study conducted by Ball State University Biomechanics Laboratory personnel. Biomechanics Graduate Assistant Scott Brown will be the principal investigator for this study and Assistant Professor of Exercise Science Dr. Henry Wang will oversee the study.

**What is the purpose of this study?**
The purpose of this study is to determine whether females exhibit greater forces in the knee joint in their non-dominant leg when compared to their dominant leg. The validation of such information would infer that a female’s non-dominant leg is more susceptible to injury as compared to their dominant leg. Finally, the examination of the relationship between leg dominance and knee mechanics would provide further information about anterior cruciate ligament injury in females.

**Where is the study going to take place and how long will it last?**
The study will take in the Biomechanics Laboratory at Ball State University and will take approximately 2.5 hours.

**What criteria must be met for me to participate in this study?**

- Female 18-23 years of age
- A minimum of four years of experience playing organized soccer
- Healthy with no current complaints of lower extremity injuries
- No history of knee injury to either leg that may have resulted in knee joint laxity
- No history of anterior cruciate ligament injury or surgery to either leg
- No lower extremity musculoskeletal injury within the past twelve months
- No physical or neurological condition that would impair their ability to perform the required task

**What will I be asked to do?**
Prior to participation, you will be verbally informed of all procedures of the study. You will be asked to sign an informed consent as requested by the Institutional Review Board for Ball State University. You will then be fitted in athletic gear consisting of a compression top and bottom, socks and athletic shoes. The following measurements will be taken: height, weight, joint girths, and leg length. You will then be asked to perform a general warm-up at a self-selected pace on the treadmill for five minutes followed by a general self-selected lower extremity dynamic warm-up for five minutes. You will then be instructed to perform five cuts at a 45 degree angle to the right and five cuts at a 45 degree to the left. Finally, you will be asked to perform three maximal

voluntary isometric contractions and three maximal voluntary isokinetic contractions to measure leg muscle strength for each leg.

**What are the possible risks and discomforts?**
The risks associated with a cutting maneuver in a laboratory setting are minimal. It is very unlikely that you will be injured during the cutting maneuver as it is a common movement practiced by soccer players. The isometric and isokinetic testing may induce a small amount discomfort to lower extremity musculature which may result in muscle soreness. This discomfort will be minimal and is only temporary; lasting for only a day or two.

**Will I benefit from taking part in this study?**
There is no direct benefit to you if you volunteer for the study. If requested, a copy of the study abstract and/or manuscript can be shared with you.

**Do I have to take part in this study?**
You do not have to participate in this study. If you decide to take part in this study, it should be because you want to volunteer. You may end your participation at any time during the study.

**If I don’t want to take part in the study, are there other choices?**
If you choose not to participate in the study, or do not meet the study inclusion criteria, there are no other alternatives to participation at this time.

**What will it cost me to participate?**
There is no financial expense for you if you volunteer for the study. If requested, parking arrangements will be made at no expense.

**How will the data be stored and retained?**
All data will be collected by the study’s personnel. Data recorded on paper will be stored in a locked file cabinet and digital data will be stored in a hard drive of a password protected workstation computer in the Biomechanics Laboratory. Only the research staff will have access to the data. Files will be retained as indicated for five years and used for subsequent publication in peer-reviewed journals. After the five year period, paper files will be shredded and electronic files will be deleted or destroyed. If information learned from this study is published, participants will not be identified by name. Subject data collected on the computers will be confidential as they will be coded with corresponding subject numbers (for example, #001 means the first subject in the study). The number that is assigned to each subject will be used in all study-related communications as well any publications or presentations of the results. The subject numbers will be kept in a password protected computer housed in the lab which will be different from the main workstation computer used to store data. Access to the numbers will be maintained by the primary investigator of the project in a locked office separate from the data files.

**Who will see the information that I give?**
We will keep confidential all research records that identify you to the extent allowed by law. Your information will be combined with information from other people taking part in the study. When we write about the study to share it with other researchers, we will write about the combined information we have gathered. You will not be identified in these written materials. We may publish and/or present the results of this study; however, we will keep your name and other identifying information confidential. By signing this form, however, you allow the research

investigators to make your records available to the Institutional Review Board (IRB) Offices at Ball State University and regulatory agencies as required by law.

**Can my taking part in the study end early?**

Your participation in this study is completely voluntary and you are free to withdraw your permission at any time for any reason without penalty or prejudice from the investigator and coaches. Please feel free to ask any questions of the investigator before signing the informed consent and at any time during the study. The individuals conducting the study may need to withdraw you from the study which may occur if your condition changes such that you no longer meet the inclusion criteria.

**What happens if I get hurt or sick during this study?**

Emergency medical treatment is available if you become injured or ill during your participation in this research project. You will be responsible for the costs of any medical care that is provided. It is understood that in the unlikely event of an injury or illness of any kind as a result of your participation in this research project that Ball State University, its agents, and employees will assume whatever responsibility is required by law. If any injury or illness occurs in the course of your participation in this research project, please notify the principal investigator. In the case of an unexpected physical injury or illness, data collection will be terminated, and first aid will be provided. If it is needed, research investigators will follow Ball State University Guideline for Emergency Situations on Campus for Medical Emergencies as outlined on the attached handout or by visiting the following website: http://cms.bsu.edu/About/AdministrativeOffices/EmergencyPrepared/Guidelines/MedEmergencies.aspx.

**What if I have questions?**

Before you decide whether to accept this invitation to volunteer in the study, please ask any questions that might come to mind now. At any time during your involvement in this study, you may contact the primary investigator, Scott Brown at (805) 245-1433 or members of the research team at (765) 285-5126 to ask any questions you may have. If you have any questions about your rights as a volunteer in this research, please contact the Institutional Review Board Coordinator of Research Integrity at Ball State University (765) 285-5070. We will give you a copy of this consent form to take with you.

**Consent**

I, ___________________________________, agree to participate in this study. I have had the study explained to me and my questions have been answered to my satisfaction. I have read the description and give my consent to participate. I give my consent to use the data collected for the current study. I understand that I can withdraw my consent at any time during the study if I feel uncomfortable. I understand that I will receive a copy of this informed consent form for my own records.

To the best of my knowledge, I meet the inclusion criteria for participation in this study.

| | |
|---|---|
| ______________________________________________<br>Participant Signature | ___________________________<br>Date |
| ______________________________________________<br>Address | ___________________________<br>Phone |
| ______________________________________________<br>Participant Name (Printed) | |
| ______________________________________________<br>Name of Person Providing Information to the Participant | |
| ______________________________________________<br>Signature of Investigator | ___________________________<br>Date |

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### Guidelines for Emergency Situations on Campus

## Medical Emergencies

**If someone becomes ill or is injured and requires immediate assistance:**

1. Dial 911 or 765-285-1111. Provide detailed information on the location of the ill or injured person.
2. Unless trained, do not attempt to render any first aid before assistance arrives.
3. Do not attempt to move a person who has fallen and appears to be in pain.
4. Attempt to obtain the following information from the ill or injured person:
   - Name, if not known
   - Description of symptoms
   - Allergies
   - Medications
   - Major medical history (heart condition, asthma, diabetes, etc.)
5. Remain at the scene after emergency personnel have arrived to provide information.
6. Planning for such emergencies includes being trained in emergency first-aid procedures and CPR.

**If someone may have been poisoned:**

1. Dial 800-222-1222 to reach the Poison Control Center. The center can also answer questions about poisons and poison prevention.
2. If the person has collapsed, is not breathing, or is having a seizure, dial 911 or 765-285-1111.

**Information about Pandemic Influenza and Other Illness Outbreaks**

- Ball State University is aware of the impact a serious illness outbreak could have on our campus.
- To prepare, a committee of university leaders has worked with local and county officials to create a coordinated response plan.
- In the event of an outbreak, check the Ball State University home page for the latest news and important information about university events and activities.
- To learn more about pandemic influenza and some practical, common-sense measures you can take to reduce your risk of contracting the flu, visit www.bsu.edu/fluinfo.

# APPENDIX C

## CUTTING PROTOCOL

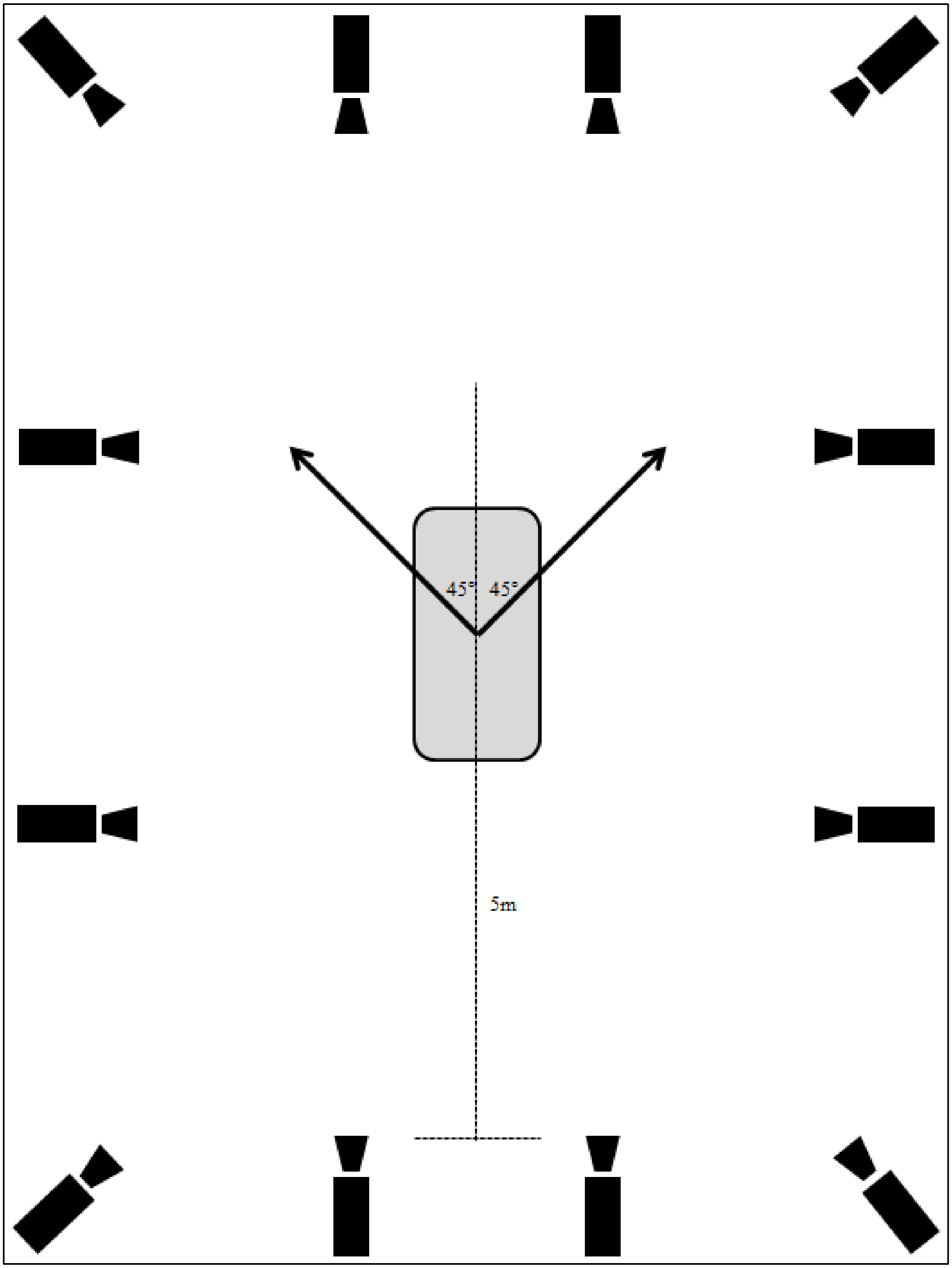

**Fig. 2** Cutting maneuver setup including 12 camera positioning, force platform locations, cutting angles and runway distance.