A Thesis

entitled

Effects of Anticipated vs. Unanticipated Cutting Maneuvers

on Knee Biomechanics in High School Female Athletes

by

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Context: Adolescent female athletes are at a 4-6 times greater risk for an anterior cruciate ligament (ACL) injury than male adolescent athletes. Most ACL injuries occur during a non-contact mechanism while decelerating and/or changing direction. Previous research uses unanticipated cutting tasks to recreate realistic scenarios that show an increased load on the ACL when the task is unplanned. Biomechanical and neuromuscular factors can be modified for the athlete to be better prepared for the high demands placed on the knee. Identifying deficits in female athletes during unanticipated cutting maneuvers can contribute to improving mechanics at the knee and work to prevent ACL injuries. **Objective:** To determine differences in knee biomechanics during an anticipated and unanticipated sidestep cutting task through trunk, hip, knee, and ankle kinematics and kinetics. **Study Design:** Cross-over study. **Setting:** Laboratory. **Participants:** 10 healthy high school female athletes. Inclusion: Healthy with no lower extremity injury in the past six months or cleared by physician. Exclusion: History of ACL injury or repair, previous injury to ankle, hip, or knee in past 6 months, and any vestibular or balance disorders. **Intervention:** Participant will run 6 m at a speed of 3.5-5.0 m/s toward a force plate to perform either an anticipated or unanticipated sidestep cut or crossover cut. **Main Outcome Measures:** Kinematic data was assessed using a 12 camera 3D analysis. Kinetic data was assessed using an in-ground force plate. A time series analysis was conducted on the data. **Results:** No significant differences were found for the frontal plane, sagittal plane, or ground reaction forces for kinematics or kinetics. **Conclusion:** The data shows a trend that the female athletes were in a more at risk position of sustaining an ACL injury during the unanticipated task compared to the anticipated task.
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Chapter 1

Introduction

Since the inception of Title IX in 1972 there has been a significant increase in female athletes. As participation increases, there is also an increase in sports-related injuries (McLean SG, 1999). The ACL, globally, is one of the most injured ligaments in sports (DeHaven KE, 1986). Of note, adolescent female athletes are at a 4-6 times greater risk for an anterior cruciate ligament (ACL) injury than male adolescent athletes (Arendt E, 1995) (Arendt E, 1995; Ford KR, 2005; L. T. Hewett TE, Riccobene JV, Noyes FR, 1999; S. S. Pollard CD, Powers CM, 2007). The increase in participation has caused an increase in anterior cruciate ligament (ACL) injuries (Ford KR, 2005). Most ACL injuries occur during a non-contact mechanism while decelerating and/or changing direction (Boden BP, 2000). A sidestep cutting maneuver, an evasive technique commonly used in many sports, has been suggested to be a maneuver that increases the risk of non-contact ACL injuries (Andrews JR, 1977; McLean SG, 1999).

Neuromuscular factors are believed to contribute to the risk of ACL injuries in female athletes (P. C. Sigward SM, Powers CM, 2012). The control strategies females use during activity results in abnormal knee loading. Neuromuscular control refers to the unconscious activation of the dynamic restraints surrounding a joint in response to a
stimuli (Griffin LY, 2000). During the sidestep cutting maneuver, females have been shown to exhibit greater valgus and a decrease in knee flexion as compared to males during cutting and landing task (Malinzak RA, 2001). These biomechanics increase the risk of female athletes to sustain an ACL injury by putting them closer to the maneuver that causes excessive knee loading.

In an attempt to recreate a game-like scenario, unanticipated cutting maneuvers have been investigated and show there is an increased load on the ACL when the task is unplanned (Besier TF, 2001; K. M. O’Connor, Monteiro, Sarika K., Hoelker, 2009; D. I. Pollard CD, Hamill J, 2004). These studies used 3 dimensional motion analysis to determine the kinematics and kinetics of the lower extremity joints. However, the age group used in all three studies were collegiate aged. They also only used males or compared males and females to each other. It was found that females had increased risk of sustaining an ACL injury then males. A study by Weindhandl et al (Weinhandl JT, 2013) showed an increase load through angles and moments in the sagittal, frontal, and transverse planes on the knee during an unanticipated cutting maneuver.

The unplanned movements performed during an athletic event increases the risk of injury in female athletes. The highest injury rates have been found amongst the high school population. A longitudinal study by Myer et al (Myer GD, 2009) found that at puberty, mass and height increase but the females’ strength and neuromuscular adaptation did not keep up to the demands of the body causing an increased load on the ACL during activity. There have been many studies comparing males and females during an anticipated and unanticipated cutting maneuver. A study has not yet been completed
comparing only high school female athletes. Biomechanical and neuromuscular factors can be modified for the athlete to be better prepared for the high demands placed on the knee. Identifying deficits in female athletes during unanticipated cutting maneuvers can contribute to improving mechanics at the knee and work to prevent ACL injuries. The purpose of the study is to examine how anticipated and unanticipated cutting maneuvers will affect the biomechanics at the knee in high school female athletes.

1.1 Statement of the Purpose

There is considerable evidence regarding the effect of cutting motions and how deficiencies in this motion make an athlete more prone to anterior cruciate ligament injuries. High school female athletes have not yet been examined in anticipated and unanticipated cutting tasks. Differences have been seen in gender studies and collegiate athletes thus far. The purpose of the study is to examine how anticipated vs unanticipated cutting maneuvers will affect the knee in high school female athletes. By looking at the frontal and sagittal plane and ground reaction forces, potential difference between anticipated and unanticipated tasks will be examined.

1.1.1 Specific Aim #1

To examine the differences in kinematics of the lower extremity during an anticipated and unanticipated cutting task.
1.1.2. Hypothesis #1

It was hypothesized that there will be an increase in lateral trunk flexion, a decrease in hip flexion and abduction, a decrease in knee flexion angles, and an increase in knee valgus during the unanticipated cutting task.

1.1.3 Specific Aim #2

To examine the difference in kinetics of the lower extremity during an anticipated and unanticipated cutting task.

1.1.4 Hypothesis #2

It was hypothesized that there will be a decrease in hip flexion, an increase in hip adduction moments, and an increase in adduction and flexion moments at the knee.

1.1.5 Specific Aim #3

To examine the differences in ground reaction forces during an anticipated and unanticipated cutting task.

1.1.6 Hypothesis #3

It was hypothesized that there will be an increase in vertical and lateral ground reaction forces during the unanticipated sidestep cut compared to the anticipated cutting task.
1.2 Significance of the Study

ACL injuries occur between 80,000 to 250,000 times per year and approximately half occur in athletes 15-25 years old (Weinhandl JT, 2013). The cost of an ACL surgical repair for the 50,000 requiring a reconstruction is almost one billion dollars (H. X. Mclean SG, Su A, Van Den Bogert AJ, 2004). Not only is the cost high, but it has been found that within 10-20 years as many as 50% will present with osteoarthritis (Weinhandl JT, 2013). It has been found that females are 4-6 times more likely to tear their ACL compared to their male counterparts (Arendt E, 1995). Most ACL injuries in female athletes occur through a noncontact mechanism, deceleration and/or change in direction. The sidestep cutting task is a common mechanism of injury. To create realistic scenarios, unanticipated cutting maneuvers have been created. Cutting tasks without adequate planning can increase the risk of a noncontact knee injury. This study identifies deficits during an unanticipated cutting task that can contribute to improving knee mechanics to prevent ACL injury.

1.3 Operational Definition

Non-contact injury- No force is applied directly to the knee (no direct blow from an opponent or object, including the ground).

Cutting maneuver- The participant will run straight then sidestep or cross over at approximately a 45-degree angle.

Anticipated- Knowing the direction the participant will cut before the start of the task.

Unanticipated- The participant will not know the direction to cut prior to the start of the task. They will know the step before their foot contacts the force plate.
Kinematics- The branch of mechanics concerned with the motion of objects without reference to the forces that cause the motion.

Kinetics- The study of forces acting on the knee such as vertical and lateral ground reaction forces.

Athlete- Individual between the age of 14 and 18 who participate in sports at their high school.

Risk factor- A condition or behavior that increases risk of injury.

1.4 Assumptions
The following assumptions will apply to this study:

1. Subjects have a similar sports history/experience.
2. Subjects will give maximal effort for each maneuver.
3. Subjects performed the cutting maneuver correctly.
4. Hormone variance will not play a role.

1.5 Delimitations

1. The study is limited to females.
2. The study focuses on high school athletes age 14 to 18.
3. The athletes will have no previous injury to the lower extremity (knee and hip) in the past six weeks.
4. Each subject will complete the anticipated and unanticipated cutting task.
5. The markers will be placed by the same clinician.
1.6 Limitations

1. There will be a ±5° variance for the cutting task for each subject.

1.7 Dependent Variables

1. Kinematics
   a. trunk frontal plane
   b. trunk sagittal plane
   c. hip frontal plane
   d. hip sagittal plane
   e. knee frontal plane
   f. knee sagittal plane

2. Kinetics
   a. hip frontal plane moment
   b. hip sagittal plane moment
   c. knee frontal plane moment
   d. knee sagittal plane moment
   e. vertical ground reaction force
   f. lateral ground reaction force

1.8 Independent Variables

1. Anticipated cutting

2. Unanticipated cutting
Chapter 2

Literature Review

The purpose of the review is to review: 1.) anatomy, prevalence of injury, and etiology at the knee, 2.) biomechanics of the anticipated sidestep cut kinematics and kinetics at the trunk, hip, and knee, and ground reaction forces, 3.) biomechanics of the unanticipated sidestep cut kinematics and kinetics at the trunk, hip, knee, and ground reaction forces.

2.1 Anatomy

The tibiofemoral, tibiofibular, and patellofemoral joints form the knee complex. These joints have little bony support and must rely on soft tissue structures to control the forces transmitted through the joints (Starkey C, 2010). The femur and the tibia comprise the tibiofemoral joint of which are the two longest lever arms in the body. The patella is a sesamoid bone located in the patellar tendon and it functions to improve the mechanics of the quadriceps during knee extension. It dissipates the forces received from the extensor mechanism and protects the anterior portion of the knee (Starkey C, 2010).

The medial and lateral articular condyles classifies the tibiofemoral joint as a double condyloid articulation, capable of the three degrees of freedom of which are flexion and extension, internal and external rotation, and abduction and adduction.
Anterior and posterior translation also occur between the tibia and femur (Starkey C, 2010). The cruciate ligaments are located outside of the synovial capsule. The anterior cruciate ligament (ACL) attaches from the anteromedial intercondylar eminence of the tibia traveling posteriorly and passes lateral to the posterior cruciate ligament (PCL) to insert on the medial wall of the lateral femoral condyle.

The anterior cruciate ligament serves as a static stabilizer against anterior translation of the tibia on the femur, internal rotation of the tibia on the femur, external rotation of the tibia on the femur, and hyperextension of the tibiofemoral joint (Starkey C, 2010). The ACL is comprised of two segments, the anteromedial and posterolateral bundles which are named for their attachment site on the tibia. When the knee is fully extended the posterolateral portion is taut and when the knee is flexed the anteromedial bundle is taut. The posterior cruciate ligament attaches from the posterior aspect of the tibia then moving superior and anterior to insert on the lateral portion of the femur’s medial condyle. The PCL is stronger and 120-150% wider than the ACL which makes it a primary stabilizer of the knee (Starkey C, 2010). The PCL is a primary restraint against posterior displacement of the tibia on the femur and a secondary restraint against external tibial rotation.

There are two collateral ligaments in the knee joint. The medial collateral ligament (MCL) is the primary medial stabilizer of the knee and consists of a deep and superficial layer. The deep layer is a thickening of the joint capsule and is attached to the medial meniscus (Starkey C, 2010). Separated from the deep layer by a bursa, the superficial layer attaches from a broad band just below the adductor tubercle and follows the inferoanterior path across the joint line deep to the pes anserine tendons (Starkey C,
The MCL acts to protect the knee against valgus forces while also providing a secondary restraint against external rotation of the tibia and anterior translation of the tibia on the femur. The lateral collateral ligament (LCL) does not attach to the joint capsule or meniscus. The cord-like structure attaches from the lateral femoral epicondyle and inserts on the proximal aspect of the fibular head. The LCL is the primary restraint against varus forces when the knee is the range between full extension to thirty degrees of knee flexion (Starkey C, 2010). It also provides a primary restraint against external tibial rotation and a secondary restraint against internal rotation of the tibia on the femur.

The musculature acting on the knee serves to allow motion in the three degrees of freedom. The anterior muscle group consists of the quadriceps femoris muscles. Each of the muscles has a common insertion on the tibial tuberosity via the patellar tendon. As a group, the quadriceps extend the knee (Starkey C, 2010). The posterior muscles are collectively known as the hamstring muscle group. They act to flex the knee and extend the hip (Starkey C, 2010). The pes anserine muscle group attach to the anterior medial tibia. This group not only assists in knee flexion but internally rotates the tibia when the foot is not planted on the ground. When the foot is planted, the pes anserine muscle group externally rotates the femur on the fixed tibia (Starkey C, 2010). The lateral muscle crossing the knee joint is the iliotibial band (IT band) which is an extension of the tensor fasciae latae muscle. It attaches at Gerdy’s tubercle on the anterolateral aspect of the femur. Although this muscle does not make a significant contribution to knee motion, the deep fibers of the IT band attach to the lateral joint capsule and function as an anterolateral knee ligament. This has a significant role in knee stability (Starkey C, 2010).
2.2 Prevalence of Injury

The occurrence of an ACL injury varies between genders, age, and sport. Although boys are found to have a higher overall rate of knee injuries, girls were found to be twice as likely to sustain a knee injury requiring major surgery (Ingram JG, 2008). The amount of athletic exposures for women are approaching those of men, reflecting increased participation of women’s sports. An increase in participation brings an increase in the amount of ACL injuries.

An athlete exposure is defined as 1 athlete’s participation in a practice or competition (Borowski LA, 2008; Ingram JG, 2008). The most commonly used method of ACL tear incidence measurement are tears per 1,000 exposures (Prodromos CC, 2007). An injury is defined as (1) having occurred as a result of participation in an organized high school practice or competition, (2) requiring medical attention by an ATC or physician, and (3) resulting in restriction of the athlete’s participation in either practice or competition for 1 or more days (Borowski LA, 2008; Ingram JG, 2008).

A difference in ACL tear incidence rates can be identified by comparing gender. The injury rates for women’s soccer and basketball are statistically significantly higher than men’s soccer and basketball (Agel J, 2005; DeHaven KE, 1986; Prodromos CC, 2007). The ACL injury rate in collegiate soccer for women over a 5 year period was more than double of the men’s game (Arendt E, 1995). ACL injury in women’s basketball were more than four times that of the men’s team (Arendt E, 1995). Per every 10,000 exposures, there was a rate of 3.89 knee injuries in soccer, basketball, and volleyball combined (Ingram JG, 2008). These sports have the highest injury rates which directly correlates to the amount of athlete exposures (Prodromos CC, 2007).
Certain sports have a higher rate of ACL injuries than others. Women’s soccer and basketball injury rates are greater compared to men’s and other female sports. However, women’s gymnastics and men’s spring football both had an injury rate of 0.33 per athlete exposures in which ranks closely to soccer and basketball (Hootman JM, 2007). Softball had an injury rate of only 0.08 (Hootman JM, 2007). These injury rates differ across many sports.

The age in which the most ACL injuries occur are the high school and collegiate level. These athletes are the most active and involved in activities that would put them at risk, therefore they have the highest incidence of injury. The average age of patients seen for an injury was 21.6 years (DeHaven KE, 1986). The peak age group was 16 to 19 years old which made up 45% of the cases (DeHaven KE, 1986).

Summary

Women’s basketball and soccer are shown to produce the highest incidence rate compared to males and female sports. High school age athletes are among the peak age group to experience a knee injury. Females are found to sustain a noncontact major knee injury more than males (Ingram 2008).

2.3 Etiology

To better understand why specific populations are at increased risk of injury, we must first understand the mechanism of injury. Boden et al interviewed 89 participants (100 knees) who tore their ACL (Boden BP, 2000). Sixty-five men (72 knees) and 25 women (28 knees) ranging from 14-48 years of age described their injury. A noncontact
mechanism was described in 72% of knees (Boden BP, 2000). The 28 contact injuries occurred from a lateral blow, medial blow, hyperextension, and backwards fall (Boden BP, 2000). Of the noncontact injuries, 38 of the patients injured their ACL while decelerating during or just before a change in direction. Landing after a jumping event caused 26 ACL injuries. Hyperextension and backward falling each contributed to an ACL rupture. These reports were based on memory recall which can result in skewed data; however, reports from a video analysis confirm the high rate of noncontact ACL injuries.

Video analysis has been conducted to decipher different mechanisms of ACL injuries. There are two noncontact mechanisms that have been found to occur most frequently. The first was a sharp deceleration associated with or without a change in direction and the second was landing on one or two legs (Boden BP, 2000; Olsen O, 2004). There was a forceful valgus with internal or external rotation with the knee close to full extension (Boden BP, 2000; Olsen O, 2004). The hip on the injured side was in a neutral position while the trunk was leaning backwards during the abrupt deceleration mechanism (Boden BP, 2000). Kobayashi et al (Kobayashi H, 2010) also found that most of the ACL injuries occurred through a noncontact mechanism. 305 of 551 had a “knee in and toe out” alignment, in which the athlete had gone into knee valgus and a foot abducted position (Kobayashi H, 2010). In a video analysis of basketball ACL injuries, 22 of 39 athletes experienced a noncontact mechanism, wherein all but one of these injuries occurred when another player was approximately 1 meter away (Krosshaug T, 2007).
Research has also investigated the stress on an ACL through in vivo and in vitro studies. Specifically, cadaver anterior cruciate ligaments have used to see how it reacts while undergoing compression and torsional forces. During compression, the femur displaces posterior relative to the tibia until the ACL fails and after failure (Meyer EG, 2008). The direction of the tibia changed from internal rotation in prefailure to external rotation after failure. During torsion, internal rotation of the tibia and valgus rotation of the femur occur during and after ACL injury (Meyer EG, 2008).

In soccer specifically, fifty three percent of 105 athletes had intended to change their direction towards the side of their injured knee, while only 10 intended to turn toward the uninjured limb (Fauno P, 2006). Twenty-six had sustained injury while landing. 95% of the injuries occurred during a noncontact change of direction or landing after a header (Fauno P, 2006).

**Summary**

Video analysis of ACL injuries conclude that plant-and-cut and landing are primary activities during injury (Krosshaug 2007). These injuries also occur during foot strike with minimal knee flexion and the trunk leaning backwards (Boden 2000). Valgus collapse and rotation of the knee was visible during a single leg landing mechanism or a sudden deceleration before a change in direction (Boden BP, 2000).
2.4 Biomechanics

2.4.1 Kinematics

Based on video and recall accounts of the timing of injury, body positioning is critical to risk of injury. Therefore, further investigation on kinematics of individuals during these at risk tasks are warranted.

2.4.1.1 Trunk

Trunk orientation and control play a key role in ACL injury as it is central to balance control. Stability is defined as the state of remaining unchanged, even in the presence of forces that would normally change the state or condition (Riemann BL, 2002). The base of support (BOS) is defined as the point bisecting the line of contact between the shoe and the floor at initial contact (Sheehan FT, 2012). To avoid a fall, the body’s posture must be altered so the COM falls with the BOS. However, the COM can fall outside the BOS, but if the distance is too great the recovery is not possible resulting in a fall (Sheehan FT, 2012).

The trunk relative to the leg may not be as important as the trunk relative to the foot, which is influenced not only by the trunk angle but the hip, knee, and ankle angles as well (Sheehan FT, 2012). Thus far, research suggests that, athletes who land with their COM more than two foot lengths posterior to the BOS with a dorsiflexed ankle are at increased risk of ACL injury (Sheehan FT, 2012). Healthy participants are thought to land with the ankle plantar flexed and the COM less than a single foot length posterior from the BOS.
Several noncontact ACL injuries in female athletes include a high knee abduction angle and lateral trunk motion with the body shifted over the injured leg and the plantar surface of the foot fixed flat on the playing surface, displaced away from the center of mass of the body and low knee flexion (T. J. Hewett TE, Boden BP, 2009). A regression model that included lateral trunk motion predicted ACL injury in females with 83% sensitivity and 73% specificity. In ACL injured athletes, the mean lateral trunk angle relative to the vertical was higher in female athletes then in males and trended toward being greater than female controls (T. J. Hewett TE, Boden BP, 2009). Impaired control of the trunk and hip can increase lower extremity injury (T. J. Hewett TE, Boden BP, 2009).

2.4.1.2 Hip

Lower extremity biomechanics during cutting tasks have shown gender differences in kinematics. Compared to males, females have demonstrated increased hip abduction, rotation, and less hip flexion (Malinzak RA, 2001; L. S. McLean SG, Van Den Bogert AJ, 2004; S. S. Pollard CD, Powers CM, 2007). Hip flexion occurs due to the forward and downward momentum of the trunk (L. S. McLean SG, Van Den Bogert AJ, 2004). The hip then extends through to toe off phase of cutting (L. S. McLean SG, Van Den Bogert AJ, 2004). Maximum hip flexion was found to occur significantly later in men compared to women (McLean SG, 1999). This delay most likely corresponds to a greater percentage of stance phase time during which the quadriceps are eccentrically loaded (McLean SG, 1999). However, it has been found that sagittal plane loading alone cannot injury the ACL (H. X. Mclean SG, Su A, Van Den Bogert AJ, 2004; Withrow TJ,
These results demonstrate that females use less sagittal plane hip motion during the stance phase of the cutting maneuver (S. S. Pollard CD, Powers CM, 2007).

During the stance phase of cutting there is a variation in hip rotation results. When females exhibit greater valgus angles, an increase in hip internal rotation was found (S. S. Pollard CD, Powers CM, 2007). This increased internal rotation during functional activities may result in altered alignment leading to a predisposition to ACL injury (S. S. Pollard CD, Powers CM, 2007). However, when a cutting maneuver was performed with and without defense and no predetermined increased valgus, a decrease in internal rotation was found compared to males (L. S. McLean SG, Van Den Bogert AJ, 2004). Increased hip external rotation will cause increased valgus and pronation. With this valgus load, the limb becomes more sensitive to the amount of hip rotation and females compensate by controlling their hip rotation more tightly (L. S. McLean SG, Van Den Bogert AJ, 2004). Fatigue or an unexpected perturbation may cause an increase in valgus where an injury can occur (L. S. McLean SG, Van Den Bogert AJ, 2004).

In the frontal plane at the hip, an increase in abduction has been shown to increase strain on the ACL. Maximum knee abduction during the stance phase of sidestep cutting was statistically significantly larger for women compared with men (Krosshaug T, 2007; McLean SG, 1999). Women tend to land and remain in a more abducted position during the stance phase (McLean SG, 1999). The increased angles suggest that the subjects were reaching out farther laterally with their foot in an attempt to facilitate the change in direction required of the cutting task (P. C. Sigward SM, 2007).
2.4.1.3 Knee

The ACL prevents forward translation of the tibia relative to the femur. Cadaver studies have shown that at 30° of knee flexion the ACL represents 85% of the total capsular and ligamentous resistance (Butler DL, 1980; Olsen O, 2004). Contraction of the quadriceps increases ACL strain between 15° and 30° of knee flexion (Beynnon B, 1995; Olsen O, 2004). Decreased peak knee flexion has been reported in females for sidestep cutting (Malinzak RA, 2001; L. S. McLean SG, Van Den Bogert AJ, 2004). Contraction of the quadriceps may result in significant anterior shear forces on the proximal tibia (Olsen O, 2004). It has been interpreted as a risk factor for ACL injury due to the increased knee anterior drawer action of the quadriceps (Malinzak RA, 2001; L. S. McLean SG, Van Den Bogert AJ, 2004).

In the transverse plane of the knee during a cutting maneuver, results have shown an increase in internal rotation. Excessive internal rotation of the tibia with respect to the femur can jeopardize the integrity of the ACL (McLean SG, 1999). The addition of tibia rotation to forceful quadriceps contraction in a valgus position may cause impingement of the ACL on the femoral condyle (Ebstrub JF, 2000; Olsen O, 2004). Increased variability in rotation has been displayed by women during sidestep cutting compared with men (McLean SG, 1999). It has also been found that females exhibit less internal tibia rotation during sidestep cutting than males (L. S. McLean SG, Van Den Bogert AJ, 2004). This suggests that increased valgus found in females is the dominant risk factor for ACL injury (L. S. McLean SG, Van Den Bogert AJ, 2004).

Knee valgus is a key mechanism to noncontact ACL injury (Besier TF, 2001; L. S. McLean SG, Van Den Bogert AJ, 2004). The relative risk for sustaining a valgus
collapse has been shown to be 5.3 times greater in females than males (Krosshaug T, 2007). Women possess a larger Q angle than males in which accompanied by an increase in genu valgum, a larger moment arm would increase the valgus angle during the stance phase (McLean SG, 1999). Hewett et al (M. G. Hewett TE, Ford KR, Heidt RS, Colosimo AJ, McLean SG, van den Bogert AJ, Paterno MV, Succop P, 2005) found that landing with a valgus loading pattern predicted ACL injury (Krosshaug T, 2007). Females demonstrate ligament dominance implying that their ligaments rather than muscle absorb more of the impact forces (S. A. Hewett TE, Nance TA, Noyes FR, 1996; Krosshaug T, 2007). Insufficient neuromuscular control may be the reason for valgus collapse (S. A. Hewett TE, Nance TA, Noyes FR, 1996). It has been found that neuromuscular training can drastically reduce this joint-loading pattern (S. A. Hewett TE, Nance TA, Noyes FR, 1996).

**Summary**

Demonstrating trunk flexion during landing compared with a more erect or trunk-extending landing posture places the lower extremity in a position associated with decreased risk of ACL injury (Blackburn 2009). Gender differences in hip and ankle rotation during the stance phase contribute to increases in knee valgus. Increases in stance-phase valgus angles observed in females compared with males adds to the risk of ACL injury (L. S. McLean SG, Van Den Bogert AJ, 2004). The loading pattern during the stance phase of the cutting task can cause injury to the ACL.
2.4.2 Kinetics

The internal forces generated during cutting can cause additional strain to the ACL. The kinetic chain is influenced from the trunk to the ground reaction forces. Using altered neuromuscular strategies during the cutting mechanism increases moments at the trunk, hip, and knee.

2.4.2.1 Trunk

There is a consensus forming around the concept that an ACL injury is likely caused by a combination of forces. Altering the sagittal plane body position during landing influences trunk and lower extremity biomechanics that may potentially alter ACL injury risk (Shimokochi Y, 2013). Landing upright increases the vertical ground reaction forces and peak knee extensor moments while decreasing the knee flexion angle and producing less or no hip extensor moment (Shimokochi Y, 2013). A forward leaning landing decreases the vertical ground reaction forces and peak knee extensor moments while increasing the knee flexion angle and hip extensor moments at the time of the peak knee extensor moment (Shimokochi Y, 2013). This flexed landing achieves an enhanced ability of the lower extremity musculature to absorb landing forces, reducing stress to the capsuloligamentous and skeletal structures (Blackburn J, 2009). This indicates that landing with a forward lean protects the ACL more than landing upright (Shimokochi Y, 2013).

Trunk stability is related to the ability of the hip to control the trunk in response to forces generated from distal body segments as well as from unexpected perturbations (T.
J. Hewett TE, Boden BP, 2009). Ipsilateral trunk lean may be a sign of weak hip abductors as it moves the center of mass closer to the stance limb to reduce demand on the weak abductors (T. J. Hewett TE, Boden BP, 2009). If the trunk moves laterally, the ground reaction force vector may move laterally and have a greater lever arm relative to the knee joint center (T. J. Hewett TE, Boden BP, 2009). Because the trunk comprises greater than half of the body’s mass, lateral trunk motion increases ground reaction forces and knee abduction loads (T. J. Hewett TE, Boden BP, 2009).

2.4.2.2 Hip

When females demonstrate increased knee valgus moments, they have been found to have greater hip adductor moments compared to male athletes during a cutting maneuver (S. S. Pollard CD, Powers CM, 2007). All subjects were in an abducted position during the stance phase. However, gender differences aside it is suspected that the increased adductor moment may be the result of a trunk lean over the stance limb (S. S. Pollard CD, Powers CM, 2007). This would shift the center of mass laterally to increase the adductor moment (S. S. Pollard CD, Powers CM, 2007). During an anticipated jump landing, a significantly smaller hip abduction moment was found during peak stance compared to men as well (Brown TN, 2009).

Females also exhibited decreased hip extensor moments compared to males (S. S. Pollard CD, Powers CM, 2007). This suggests the male athletes were better able to activate their hip extensors during the stance phase. It is possible that the female athletes lack the strength needed to decelerate in the sagittal plane (S. S. Pollard CD, Powers CM, 2007). This results in alternate proximal control strategies (S. S. Pollard CD, Powers CM,
2007). Leetun et al (Leetun DT, 2004) also found decreased hip strength in female collegiate athletes suggesting that the weakness may permit lower extremity positioning associated with noncontact ACL injuries (Leetun DT, 2004).

2.4.2.3 Knee

Poor or abnormal neuromuscular control during sidestep cutting execution as become increasingly viewed as a major contributor to ACL injury risk (Boden BP, 2000). Females demonstrating increased valgus exhibited six times greater valgus moment compared to a normal frontal plane moment group (P. C. Sigward SM, 2007). The excessive valgus group utilized a different lower extremity loading strategy than those who exhibited normal frontal plane moments. Sigward et al (P. C. Sigward SM, 2007) found that a greater lateral ground reaction force, increased hip abduction and hip internal rotation, and a more internally rotated foot progression explained 49% of the variance in peak knee valgus moment (P. C. Sigward SM, 2007).

In cadaveric knees, when the impact loading included the knee valgus moment in addition to the flexion moment, the anteromedial ACL strain increased significantly more than when it did without the valgus moment (Withrow TJ, 2006). The peak normalized ACL was 30% larger for the impulsive compression loading in valgus and flexion compared with loading in flexion alone (Withrow TJ, 2006). Realistic neuromuscular perturbations were performed on athletes to produce significant increases in knee anterior force, valgus, and internal rotation moments (H. X. Mclean SG, Su A, Van Den Bogert AJ, 2004). McLean et al (H. X. Mclean SG, Su A, Van Den Bogert AJ, 2004) found that peak anterior drawer forces never exceeded 2000 N in any model, failing to cause ACL

**2.4.2.4 Ground Reaction Forces**

A reduction in peak ground reaction forces (GRF) during a cutting task appears to be an important factor in preventing injuries (Cowley, 2006). Increased lateral ground reaction forces have been demonstrated by an excessive valgus moment group during a sidestep cut (P. C. Sigward SM, 2007). This group had three times greater forces than those with exhibited normal frontal knee plane moments (P. C. Sigward SM, 2007). The results suggest the subjects contacted the ground differently by pulling their foot in medially during loading. After accounting for the forces and moments acting on the foot segment, a laterally directed GRF would impose a lateral force at the distal tibia (P. C. Sigward SM, 2007). A larger level arm would result in a larger laterally directed force to create a greater valgus moment at the knee (P. C. Sigward SM, 2007). McLean et al (L. S. McLean SG, Van Den Bogert AJ, 2004) found only a two degree difference between genders in peak valgus. It may appear small however, it can lead to a 40 Nm change in valgus moment, assuming a GRF of 2500 N making the limb more sensitive to valgus buckling (L. S. McLean SG, Van Den Bogert AJ, 2004).

A slight increase in hip abduction as an addition to excessive valgus may contribute to an increase in vertical ground reaction forces (P. C. Sigward SM, 2007). Increased hip abduction moves the center of pressure laterally with respect to the center
of the tibia thereby creating a larger moment arm for the vertical GRF (P. C. Sigward SM, 2007).

**Summary**

Lower extremity neuromuscular control is crucial during an athletic task. Small changes in kinematics can significantly affect moments at the knee. Decreased ground reaction forces have been shown to be an important factor in preventing injuries.

**Unanticipated**

Unanticipated cutting maneuvers have been used in studies to recreate realistic scenarios (Besier TF, 2001; K. M. O’Connor, Monteiro SK, Hoelker IA, 2009; D. I. Pollard CD, Hamill J, 2004). During unanticipated cutting, many differences exist when compared to anticipated tasks. To assess ACL injury risk, researchers have quantified neuromuscular control during athletic tasks using kinematic, kinetic, and ground reaction force data.

2.5.1 **Kinematics**

2.5.1.1 **Trunk**

A lateral trunk orientation and decreased stride width are associated with unanticipated cutting tasks. Changes in step width if not compensated for by trunk position may alter knee moments increasing the risk for ACL injury (Houck JR, 2005). An increase in lateral trunk orientation was found during an unanticipated task compared to an anticipated task (Houck JR, 2005). The alterations in in trunk kinematics suggest
the mechanical demands of the task constrained the subject’s ability to implement a new motor plan (Houck JR, 2005).

2.5.1.2 Hip

During the stance phase of cutting, variation exists at the hip during unanticipated tasks. When compared to males during unanticipated side step cut, females exhibit less hip flexion and more hip external rotation with smaller hip flexion moments (Landry SC, 2007). Females tended to go from internal to external rotation as the stance phase progressed compared to males who remained in an internally rotated position throughout the cutting task (Landry SC, 2007). Lower hip flexion angles have been shown to generate higher impact forces. Reducing hip flexion angles in female athletes may increase knee joint loading thereby increasing the ACL injury risk (Landry SC, 2007; H. X. Mclean SG, Su A, Van Den Bogert AJ, 2004). A decrease in hip abduction angles were also found suggesting a failure of the lower extremity to medially rotate around the subtalar joint during an unanticipated task (Houck JR, 2005).

2.5.1.3 Knee

Knee angles have been shown to significantly change during an unanticipated cutting task. In the frontal plane, females demonstrated greater knee valgus angles compared to males (Ford KR, 2005). The frontal plane loading of the ACL was 26% of total knee loading (Weinhandl JT, 2013). Compared to preplanned tasks, there was an increase in internal rotation and knee valgus (Besier TF, 2001). Females had greater knee abduction angles at initial contact (Besier TF, 2001). Sagittal plane loading contributed to
62% of total ACL loading during an unanticipated task and the transverse plane contributed 12% (Weinhandl JT, 2013). These findings suggest that cutting maneuvers performed without adequate planning may increase the risk of non-contact knee ligament injury (Besier TF, 2001).

**Summary**

Unanticipated cutting tasks have been shown to change lower extremity kinematics. Increased loading at the trunk, hip, and knee can cause additional strain on the ACL. A lack of neuromuscular and motor control may contribute to the injury mechanism.

**2.6.1 Kinetics**

Unanticipated kinematic data has shown increased strain on the ACL. A change in these angles during an unanticipated cutting task has also shown a change in the kinetic chain. An increase in the moments and ground reaction forces in female athletes explain why they are more prone to injury during this task.

**2.6.1.1 Hip**

Unanticipated cutting task effects the moments at the hip. Decreased hip flexion moments were observed in females when compared to male subjects (Landry SC, 2007). Greater hip flexion moments in males combined with a greater hip flexion angle could help to increase hip joint stability to make the ACL less vulnerable to injury compared with their female counterparts (Landry SC, 2007). Female subjects exhibited a larger hip
external rotation and a hip adduction moment as male subjects demonstrated a hip abduction moment. (Landry SC, 2007). Houck et al (Houck JR, 2005) also observed a decrease in hip abduction in females during the stance phase of unanticipated cutting.

2.6.1.2 Knee

Anticipation effects the knee joint loading moments during a cutting mechanism. An increase in the sagittal plane moment was observed due to an increased shear tibiofemoral contact force and a relatively large anterior shear force supplied by the patellar tendon (Weinhandl JT, 2013). However, Landry et al (Landry SC, 2007) observed no difference in knee flexion moments. In the frontal plane, the knee moment started as abduction in the beginning of the stance phase but then a significant increase in adduction suggesting an immediate response to redirect the center of mass away from the stance foot, toward the new direction of travel (Houck JR, 2005). The transverse plane revealed minimal differences between anticipated and unanticipated cutting (Weinhandl JT, 2013). The loading pattern of the ACL during side step cutting cannot be explained by the quadriceps mechanism or frontal plane loading alone. It results from a multifaceted interaction of sagittal plane shear forces, as well as frontal and transverse plane knee moments.

2.5.1.3 Ground Reaction Forces

Both basketball and soccer require athletes to perform high risk maneuvers. During an unanticipated cut female soccer players demonstrated increased vertical ground reaction forces (GRF) and decreased stance time over female basketball players
(Cowley, 2006). An increase in force may cause the ligaments to absorb it resulting in ACL injury risk. A reduction in peak GRF appears to be an important factor in preventing injuries (Cowley, 2006). Females demonstrate increased vertical ground reaction forces during an unanticipated sidestep cut rather than a pivot or drop-jump (Cortes N, 2011).

**Summary**

Moments in all planes contribute to the increases in force production. During unanticipated cutting maneuvers, differences in kinematics, kinetics, and ground reaction forces have been revealed in female athletes compared to an anticipated cut.
Chapter 3

Methodology

3.1 Study Design

This was a descriptive laboratory study with a cross over design comparing an anticipated and unanticipated sidestep cut on frontal and sagittal plane knee, hip and trunk kinematics and kinetics in high school female athletes was completed. This study was approved by the University of Toledo’s Institutional Review Board #201019 prior to the enrollment of participants.

3.2 Participants

There were 10 female subjects included in the study. Subjects were recruited from a local high school in Toledo, Ohio. All Volunteers were female athletes participating in soccer, basketball, or volleyball between the ages of 14-18 years old. Subjects were healthy with no lower extremity injury in the last six weeks and no lower extremity surgery in the past year. Subjects were excluded if they reported any of the following: (1) history of ACL injury or repair; (2) any vestibular or balance disorder.
Figure 3.1 Demographics

<table>
<thead>
<tr>
<th>Participants (n=10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
</tr>
<tr>
<td>-----------</td>
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<tr>
<td>16.2</td>
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</tbody>
</table>

3.3 Instruments

3.3.1 Kinematics

This study utilized the 12 camera, digital Eagle motion analysis 3-D system (Motion Analysis Corporation, Santa Rosa, CA) sampled at 200Hz. During processing, the kinematic data was filtered with a low-pass Butterworth filter at a cutoff frequency of 12Hz (Erickson, Thomas et al. 2015).

3.3.2 Kinetics

All GRF data was measured using force plate 1 (OR5-6, Advance Mechanical Technologies Inc.) sampled at 2000Hz. The force plate information was also used to determine heel strike and toe off during each of the cutting trials.

3.3.3 Timing Gates/ Laptop

The gates were used to assess speed and inform the subject which direction to cut during the anticipated and unanticipated cutting tasks. The gates were custom made at the University of Toledo with a small piece of wood cut into a square that was attached to the
top of a tripod. A battery pack, boat light, and garage door sensor are attached to the top of the wood. The opposing gate has a reflector attached to it allowing the sensor to detect when the participant passed through it. A laptop was used to run the timing gates and randomize the direction of the cut. It also gave us the speed that the participant ran. All subjects wore a standard Asics shoes throughout the collection process.

3.4 Procedure

Figure 3.2

All participants attended one testing session where they completed an unanticipated and anticipated cutting task. Upon arrival to the University of Toledo’s Musculoskeletal Health & Movement Science Laboratory, all subjects and parents/guardians read and signed a consent form approved by the Universities Institutional Review Board. They were also assessed to ensure they met all inclusion and exclusion criteria.

Prior to marker placement, all participants were familiarized to the cutting task providing a minimum of 3 trials in each direction (cross over cut, side-step cut), but more could be provided until the participant felt comfortable. We included both the crossover
cut and sidestep cut to ensure we could create an unanticipated condition. Once participants were familiarized, we placed 42 reflective markers on the subjects, including the right inferior angle of the scapula (1), sternal notch (1), C7 (1), Acromioclavicular joints (2), anterior superior iliac spine (2), posterior superior iliac spine (2), greater trochanter (2), Thigh cluster (4 for each leg), lateral femoral condyles (2), medial femoral condyles (2, only on static trials), shank cluster (4 for each leg), medial malleoli (2, only on static trial), lateral malleoli (2), 2nd metatarsal head (2), base of the 5th metatarsal (2), calcaneus (2), and base of the fifth metatarsal (2) for the 3D motion capture. The same individual placed the markers for all participants.

The force plate was set up 6 m from the starting position and the subjects ran through the gates to the left or right after contact. The lights on the gates were used to tell the subject which way to cut and all them to see the light easily. They were placed on the gates in from of the plate to give a direct line of vision to the subject. (Landry 07, Weinhandl 13, Beiser 01) Through pilot testing the approach speed was found to work best at 3.5-5.0 m/s with the available space. The subjects had 3.5 m, approximately 2 steps, from the first gate to the force plate, to process which direction to cut.

For the anticipated maneuver, before the participant begins the trial, the light indicated the direction which they would cut. For the unanticipated maneuver, the participant was instructed to run toward the force plate and there would be a light to indicate which direction they would cut the step before the plate. Each successful test session consisted of three criteria that must be met which consists of 1.) the participant’s foot must come into contact with the force plate, 2.) the participant must remain within the designated pathway, 3.) the required approach speed was maintained. The participants
completed a total of 20 trials including: 5 unanticipated sidestep cuts, 5 unanticipated crossover cuts, 5 anticipated sidestep cuts, 5 anticipated crossover cuts. The right foot was used for each trial and only the sidestep cuts were processed for this study.

3.5 Participation
The parent/guardians signed the consent form and the participants completes the Tegner activity scale and the KOOS upon arrival to the Musculoskeletal Health & Movement Science laboratory. Participants were healthy with no lower extremity injury in the last six months and no lower extremity surgery in the past year. Participants were excluded if they reported any of the following: (1) history of ACL injury or repair; (2) any vestibular or balance disorder. Immediately following, participant’s demographic (age, height, weight, years of experience, dominant limb, physical activity/week) information was collected.

3.6 Data Reduction
The data collection and processing was done through the Cortex 5.5.0 software. Visual 3D was used to build the biomechanical model and for the kinematic and kinetic data analysis. The period of initial contact heel strike to toe off was normalized to 100 points and each data point was made to represent 1% of the cut cycle.

3.7 Statistical Analysis
A time series analysis was conducted on the data. A sequence of times series confidence interval analyses were performed across the entire cut cycle to determine any
increments where the confidence intervals did not overlap. This was completed comparing anticipated and unanticipated cutting tasks of each subject. There were no differences comparing the anticipated kinematic and kinetic data to the unanticipated cuts. An priori alpha level was set at p< 0.1 for all analyses.
Chapter 4

Results

After completing the time series analysis across the cut cycle, all kinematic and kinetic data for the trunk, hip, and knee and ground reaction forces in the sagittal plane can be found in Figure 4.1. There were no significant difference found in the anticipated versus the unanticipated group. The data for the kinematics and kinetics in the trunk, hip, knee, and ground reaction forces in the frontal plane can be found in Figure 4.2. The individual graphs for each variable can be found in Figures 4.3-4.14. The average speed for the anticipated sidestep cut was 4.12 m/s and 4.31 for the unanticipated sidestep cut. There were no significant differences between the speeds. There were no significant difference in the frontal, sagittal, or ground reaction forces between the anticipated and unanticipated cutting task.
Figure 4.1

Knee, Hip, and Trunk Sagittal Plane Kinematics and Kinetics with 90% Confidence Intervals
Figure 4.2

Knee, Hip, Trunk Frontal Plane Kinematics and Kinetics with 90% Confidence Interval

Knee Joint

Hip Joint

Trunk

Unanticipated
Anticipated
Figure 4.3

Knee Sagittal Plane Kinematics with 90% Confidence Interval

Figure 4.4

Knee Frontal Plane Kinematics with 90% Confidence Interval
Figure 4.5

Hip Sagittal Plane Kinematics with 90% Confidence Interval

Figure 4.6

Hip Frontal Plane Kinematics with 90% Confidence Intervals
Figure 4.7

Trunk Sagittal Plane with 90% Confidence Interval

Figure 4.8

Trunk Frontal Plane with 90% Confidence Interval
Figure 4.9

Knee Sagittal Plane Moment with 90% Confidence Interval

Figure 4.10

Knee Frontal Plane Moment with 90% Confidence Interval
Figure 4.11

Hip Sagittal Plane Moment with 90% Confidence Interval

Figure 4.12

Hip Frontal Plane Moment with 90% Confidence Interval
Figure 4.13
Vertical Ground Reaction Force with 90% Confidence Interval

Figure 4.14
Lateral Ground Reaction Force with 90% Confidence Interval
Chapter 5

Discussion

The purpose of this study was to compare an anticipated cutting task to an unanticipated task through observing selected kinematic and kinetic variables. The two tasks were compared to determine if the unanticipated task put female athletes in an anatomical position that would be associated with a greater risk of injury. We found no significant differences between the two tasks, for any of the variable that were measured, when examining the time period from right heel strike to right toe off.

Kinematics

Trunk positioning during landing and cutting tasks has often been considered as a potential variable influencing lower body kinematics in ways that influence injury risk. Trunk kinematics in the frontal plane appeared to show a greater variance than in the sagittal plane. This degree of variability was expected that lateral trunk flexion would be more variable. A study by Hewett (T. J. Hewett TE, Boden BP, 2009) found, in jump landings, increased lateral trunk motion was greater, at least in females. He proposed that landing in a more trunk flexed position with diminished lateral trunk flexion, puts the center of mass over the base of support allowing for improved stability. If the center of mass falls outside the base of support such as during increased lateral trunk lean, the distance from the base of support may be too great to recover, thus causing injury. Thus,
from our results, our subjects appeared to be using a strategy that may have increased the risk of an ACL injury based on the frontal plane kinematics.

A second variable of particular interest is hip flexion. In previous research, hip flexion in female athletes has been found to be significantly less during the cut cycle as compared to males (Landry SC, 2007; L. S. McLean SG, Van Den Bogert AJ, 2004). A study by Landry et al (Landry SC, 2007) found that lower hip flexion angles have been shown to be associated with higher impact forces. Thus, it was thought that, in our study, when subjects anticipated that a cut was to be made they would have intentionally decreased hip flexion. However, in our study, when comparing the anticipated and unanticipated conditions, hip flexion angles were quite similar. While this finding is of interest, independently, it does not necessarily reflect on risk of injury. A study by McLean (H. X. Mclean SG, Su A, Van Den Bogert AJ, 2004) et al found that sagittal plane biomechanics alone cannot predict injury in the ACL. Therefore, our results do not necessarily reflect additional risk. However, as with all of the variables studied in this research, these results may have been influenced by the speed at which the athletes performed the cutting task.

Another variable of interest was hip abduction/adduction. For both the anticipated and unanticipated tasks, all subjects remained in hip abduction from heel strike to toe off. In comparison to previous studies that have used male subjects, the females in our study were found to have an increased abduction angle. This may be due to the fact that females have larger Q angles (McLean SG, 1999). The data found in this study appears to show an increase in hip abduction angles during the unanticipated task. When considering the potential influence that hip abduction may have on structures lower in the
kinetic chain, the increased hip abstraction that our subjects demonstrated may reflect a factor that is putting them more at risk of injury.

Knee flexion during cutting is a variable that has been studied extensively, as it is involved both in dissipating the ground reaction force of the cutting step and changing the direction of the athlete making the cut. In previous research it has been found to be decreased in females during the sidestep cut when compared to males (Malinzak RA, 2001; H. X. Mclean SG, Su A, Van Den Bogert AJ, 2004). This decrease in flexion can be problematic due to the eccentric contraction of the quadriceps that must occur as the knee flexes under load, and its role in causing an anterior shear force on the tibia (Olsen O, 2004). A study by Olsen et al (Olsen O, 2004) has reported that between 15 and 30 degrees of flexion is where the ACL strain is at its highest. In spite of the potential importance of knee flexion, and what has been seen when comparing males and females, there were no significant differences in the sagittal plane knee motion in this study. Only during the last 10%, right before toe off, of the cutting cycle did the subjects reveal decreased flexion below 30 degrees. This may suggest that flexion during the anticipated and unanticipated tasks would not add to the risk of injury at these speeds.

Although our results showed no significant differences in the frontal plane angles at the knee, there were some interesting trends concerning the biomechanics of the unanticipated task. The subjects appeared to have increased valgus throughout the duration of the unanticipated cutting tasks. A study by Krosshaug et al (Krosshaug T, 2007) found that the relative risk associated with valgus collapse has been shown to be 5.3 times greater in females. Insufficient neuromuscular control can cause this deficit in
cutting mechanics that has been linked to an ACL injury (S. A. Hewett TE, Nance TA, Noyes FR, 1996). It may be the additional central processing demands associated with the unanticipated cut contributed to the diminished control of valgus, thus potentially increasing risk of injury during this condition. Thus, in our study, at the current speed, and even in a controlled environment, the risk of valgus collapse was still evident.

Kinetics

Throughout the duration of the cut cycle the unanticipated hip extensor moments appeared to be less than the anticipated hip extensor moments. A study by Pollard et al (S. S. Pollard CD, Powers CM, 2007) has found that, compared to males the hip extensor moment in females was also decreased. If it is assumed that the greater hip extensor moment patterns of males reflect some margins of safety, the fact that our female subjects evidenced lower hip extensor patterns in the unanticipated condition suggests that this condition increased vulnerability to injury. Why this occurred is not known. However, it is possible that the subjects lacked the strength in their extensor muscles to decelerate and make the cut, with the increased decision-making and complexity of timing that occurred with the unanticipated condition.

The results of the hip frontal plane moment showed no significant differences. Both tasks caused an increased adductor moment that may suggest an overcompensation of the hip abductor muscles. The alterations at the hip show why neuromuscular control should be emphasized (Houck JR, 2005).

The knee sagittal plane moment showed no significant differences across the two conditions. A study by Landry et al (Landry SC, 2007) also observed no significant
differences in knee flexion moments. The anterior force during the cutting task is not enough to injury the ACL. However, combined with valgus and rotation, the risk significantly increases.

Valgus loads have been found to reach high enough forces to cause injury (H. X. Mclean SG, Su A, Van Den Bogert AJ, 2004). There were no significant differences in this study across the two tasks. The angles for valgus were not significant as previously stated but the means appeared to be somewhat different throughout the cut cycle. However, the moment in the frontal plane did not reveal a similar finding. The forces were not high which may suggest that the speed at which the subjects were asked to perform was not high enough to generate the increased loads at the knee. The amount of force generated was enough to facilitate the change in direction but not cause addition risk during the unanticipated task.

**Ground Reaction Forces**

The ground reaction forces revealed no significant difference. However, there is a spike earlier in the cut cycle for both vertical and lateral forces. This could suggest, combined with the increase in hip abduction and trunk lateral flexion angle, that the subjects were reaching out further laterally and hitting the ground at higher forces to facilitate the change in direction (P. C. Sigward SM, 2007). This may cause an increase in the valgus angle at the knee putting it in a more vulnerable position for injury.

The vertical ground reaction force presented no significant findings. After the initial spike in the cut cycle the mean unanticipated vertical forces decreased as compared to the anticipated mean. This slight decrease combined with the main increase in trunk
flexion may reveal that the position potentially could have taken force away from the quadriceps and strain on the ACL (Blackburn J, 2009). A flexed trunk position may decrease vertical reaction forces up the kinetic chain.

Although there were no differences found overall, the kinematics revealed more of a trend than the kinetic data. The subjects increased angles but the forces were quite similar for both tasks. In an attempt to control the internal forces the body creates, larger angles may have been generated at the trunk, hip, and knee. This may have been an uncounscious way to protect the body from creating forces that could cause failure. As neuromuscular control is the uncounscious activation of the dynamic stabilizers around a joint, (Griffin LY, 2000) this could have been lacking causing the increase in the angles as a way of compensation. Had the forces been higher the body may not have acted as such and there could have been differences in the joint moments.

**Limitations**

Although the cutting task revealed no significant differences, we did not include the transverse plane kinematics or kinetics. These analyses may suggest the unanticipated cutting task put the subjects more at risk than the anticipated task. Differences may not have been seen due to the speed. The speed was chosen to provide a more gamelike scenario. However, it may not have been fast enough to show significant differences. Theoretically, faster speeds would result in higher forces during the stance phase to facilitate the change in direction. We were limited by the number of subjects involved in the study. A larger sample size may have provided more power for the study and produced significant differences even at these speeds.
Conclusion

In summary, although no significant differences were found deductions may be made based off the results. Increased kinematics in the frontal plane may increase risk of injury on the knee joint. Identifying the lower extremity mechanisms that can lead to potential injury is the first step to preventing ACL injury. Further research is needed to examine dual tasking within the external environment to simulate a more gamelike scenario.
References


Appendix A

Additional Methods

Demographics
- Age
- Height
- Weight
- Physical Activity
- Dominant limb
- Years of experience

Tegner Activity Scale

Knee Injury and Osteoarthritis Outcome Score Survey (KOOS)

Cortex Hardware and Software Set-up
1. Turn on cameras (located to the right of the computer)

2. Open Cortex 3.6.1
   a. Open File “Jon and Chelsey Thesis” and “set as working folder”

3. All lights on force plate should be off (use calibration square for calibration)
   a. To change collection sample rate- Change Multiple of Frame Rate
      - Cameras collect 200 Frames/sec
   b. Save calibration
c. Click “all on” and “connect to cameras”

4. Calibration of the cameras
   a. Do “update calibration”
      - Every once in a while do “floor calibration”
      - At the beginning of every day of data collection click calibrate for cameras
      - Click “ok to overwrite” and collect for 2 minutes with calibration wand
      - Check volume
      - When calibrating go through all cameras and mask any reflections

   b. Click center wheel and drag. Then right click to delete.
      - 3D Residual: Average approximately 0.5 and deviation approximately one half of average

5. Calibration of force plate
   a. Calibration square goes around force plate 1 (back corner – closet to door and computer

**Floor Set-up**
1. Measure 6 m from the center of force plate 1 to where you first walk into Biomechanics lab
2. Mark the 6 m point with tape so the subjects know where to start
3. Mark two 45 degree angles from the corners of force plate 2 with tape so the subjects know the angle to cut during the trials
4. The first gate will be placed 2.5 m from the force plate to trigger light for unanticipated task  
   a. For anticipated task light will be on before the start of the trial  
5. The 2 tripods with the indicator light will be placed 1.473 m from the top corners in front of the force plate, the additional 2 tripods will be placed 2.25 m from the top corners of the force plate, and the subjects will be able to run through the gate in the given direction  
   a. Tape will be used to mark the legs of the tripod as to repeat the exact position for the next data collection day  
6. Tilt the television on the wall to the direction the subjects will start, a countdown clock will be visible so the subject knows when to begin each trial  
7. The trials will be randomized with a total of 20  
8. The speed to be maintained is 3.5-5.0 m/s  

Cortex Data Collection Procedures (General Set-up)  
1. Marker Placement  
   a. Double sided tape was pre-applied to the markers prior to the subject arrival at the Exercise and Sport Injury Laboratory  
   b. All areas were shaved as needed  
2. To bring up saved markers click on Marker Sets “add/remove”  
   a. Check the box next to “J & C MS”  
   b. Markers will then be on the right of the screen
3. Marker Placement
   a. 42 Reflective markers
      i. Right inferior angle of the scapula (1)
      ii. Sternal notch (1)
      iii. C7 (1)
      iv. Sacrum (1)
      v. Acromioclavicular joints (2)
      vi. Anterior superior iliac spine (2)
      vii. Posterior superior iliac spine (2)
      viii. Greater trochanter (2)
      ix. Thigh Cluster (4, one on each thigh)
      x. Lateral femoral condyle (2)
      xi. Medial femoral condyle (2) (Static Trial Only)
      xii. Shank Cluster (4, one on each thigh)
      xiii. Medial malleoli (2) (Static Trial Only)
      xiv. Lateral malleoli (2)
      xv. 2nd metatarsal head (2)
      xvi. Base of 5th metatarsal (2)
      xvii. Calcaneus (2)
4. Each subject collection
   b. Get rid of ghost markers and reflectors in 2D by clicking the center button on the mouse and covering it with a small box to block area
   c. Name static trial- subject will do 2 of these
      - Make sure marker set is on the static set
   d. Go to recording settings and change time to 5 seconds
      - Subject will stand still for 5 seconds with arms crossed over chest
   e. For the dynamic trial take of medial markers, malleoli and femoral condyle
      - Switch marker set to dynamic
      - Do 2 trials of the dynamic pose
      - Subject will stand still for 2 seconds and when cued will begin marching in place for the next 3 seconds with arms crossed over chest
   f. Load last capture
   g. Quick ID
   h. Rectify- have all markers clicked on
   i. Cubic join
   j. Smooth
   k. Delete Unnamed- look at timeline
   l. Create template
      - This template will allow the marker set to be recognized for the future trends with this subject. It will also recognize marker set up with other subjects.
   m. File- Save Capture and name dynamic
   n. File- Save Setup
5. Go back to Live Mode- check for correct marker set and name trials
6. Save each subject on an external hard drive- click Quick Files on top right of screen

Laptop Set-up
1. Turn on computer and log in with username and password written on computer
2. Connect to “Linksys 2504” internet
3. Click on “new folder” file
4. Go to “windows application 12”
5. This system is where the countdown will be initiated to begin each trial
   a. The researcher can input the randomized order of the trials before each subject begins
   b. The participant will complete a total of 20 trials
      - 5 unanticipated sidestep cuts
      - 5 anticipated sidestep cuts
      - 5 unanticipated crossover cuts
      - 5 anticipated crossover cuts

Anticipated Cutting Procedure
1. The participants will have 3-5 practice trials
2. The participants will begin at the marked 6 m distance
   a. The light on either gate will indicate which direction to cut before the start of the trial
   b. The participants will cut with their right foot on the force plate and run past the second gate
   c. The clock counts down on the television to indicate when to begin
   d. After completion of the trial the clock will count down 30 seconds before the start of the next trial

Unanticipated Cutting Procedure
1. The participants will begin at the marked 6 m distance
   a. The clock will count down on the television to indicate when to begin
   b. When the participants cross the first gate (approximately the step before they touch the force plate) they will see a light on either the right or left gate and will cut in that direction
   c. The participant will cut contacting their right foot on the force plate and run past the second gate
   d. They will have 30 seconds of rest and begin at the 6 m point to complete the next trial
Cortex Processing

1. After the trials have been completed, they are must be reviewed to ensure all 38 markers stayed on and the template was recognized.
   a. If they were not, they need to be identified again as well as cubic joined, smoothed, and the unnamed markers deleted
   b. Check the timeline for gaps in the markers
2. While the data is in post process, the time right before heel strike and immediately after toe off can be cut
   a. Type in the frame numbers which appear at the bottom center of the screen into the space that reads “0” for heel strike and “1000” for toe off
   b. Then click “Cut Outside”
   c. Check the timeline- you should only see the small area that was not cut
   d. Save Capture
   e. Export into the C3D file

**Visual 3D**
1. Open Visual 3D
2. Go to Model- Create (Add Static Calibration)
3. Open the Static file for the subject
4. Go to Model- Apply Model Template that is under Cutting Study
5. Enter the subject mass and height under Subject Data/Metrics
6. Inspect Skeleton for errors
7. Go to File- open C3D file for that subject and highlight all 20 trials and open
8. Model- Assign Model to Motion File
9. Check box for all trials for that subject and apply
10. Click on the second E at the top of the page to mark one frame before heel strike and one frame after toe off
    a. Click RHS- Create event at current animation frame
    b. Click RTO- Create event at current animation frame
11. If the wrong phase is clicked on go to the first E and click on error then Remove
12. Every 3-4 trials go to File- Save Workspace
13. To make graphs go to Reports
    a. Insert Page
    b. Modify ADD for graph set up
    c. Line Style- Null
    d. Data Type- x axis- Frame Number
    e. Range RHS to RTO
    f. Check box- Graph with range of event
    g. Data Type- Link_Model_Based
    h. Data Name- Processed
    i. Click Done
    j. Complete for each variable- anticipated and unanticipated go onto the same graph to be compared
    k. Click Export

**Excel**
1. Make Confidence Interval
2. Create Upper and Lower Limits
3. Highlight the mean of anticipated and unanticipated, and upper and lower limits for both
4. Go to Insert- create graph on top left of drop down box
5. Label Graph with Chart Title and Axis Title
Appendix B

RESEARCH SUBJECT INFORMATION AND CONSENT FORM

LOWER EXTREMITY BIOMECHANICS IN HIGH SCHOOL FEMALE ATHLETES

Principal Investigator: Luke Donovan, PhD, ATC
Other Staff (identified by role): Chelsey Roe, ATC (student-investigator)
Jonathan Niesz, ATC (student-investigator)
Contact Phone number(s): (419)-530-5305

What you should know about this research study:

- We give you this consent/authorization form so that you may read about the purpose, risks, and benefits of this research study. All information in this form will be communicated to you verbally by the research staff as well.
- Routine clinical care is based upon the best-known treatment and is provided with the main goal of helping the individual patient. The main goal of research studies is to gain knowledge that may help future patients.
- We cannot promise that this research will benefit you. Just like routine care, this research can have side effects that can be serious or minor.
- You have the right to refuse to take part in this research, or agree to take part now and change your mind later.
- If you decide to take part in this research or not, or if you decide to take part now but change your mind later, your decision will not affect your routine care.
- Please review this form carefully. Ask any questions before you make a decision about whether or not you want to take part in this research. If you decide to take part in this research, you may ask any additional questions at any time.
- Your participation in this research is voluntary.

PURPOSE (WHY THIS RESEARCH IS BEING DONE)

You are being asked to take part in a research study examining how your legs move during the common athletic task of running forward and then changing directions to either your right or left, this is known as cutting. The purpose of the study is to examine the difference in how your legs move during a cut in which you know which way you are going to cut before you start running known as an anticipated cut or a cut in which you do not know which way you will cut until after you start running known as an unanticipated cut.

You were selected as someone who may want to take part in this study because you are a high school female athlete participating in soccer, basketball, volleyball, tennis, lacrosse, or field hockey. This research study will be conducted in the Musculoskeletal Health and Movement Science Laboratory in the Health Science and Human Service Building at the University of Toledo Main Campus. We will be enrolling 40 subjects between the age of 14-18 years.
DESCRIPTION OF THE RESEARCH PROCEDURES AND DURATION OF YOUR INVOLVEMENT

If you decide to take part in this study, you will be asked to report to the Musculoskeletal Health and Movement Sciences Laboratory at the University of Toledo on a single occasion. You will perform a side-step cutting task, similar to what you would do if you were playing basketball. We will record your leg movement while you perform these tasks both in an anticipated and unanticipated manner. This entire testing session will take approximately 2.5 hours.

Eligibility Screening
Before you can officially enroll in this study, you will be asked a series of questions to determine your eligibility. These questions are similar to ones you would be asked in a health history screening at your doctor’s office. You will also have your height and weight measured as you would at your doctor’s office. Finally, all female participants will be asked to disclose if they may be pregnant. There are no known risks to unborn children at this point.

Warm-Up
You will be allowed up to 10 minutes to warm up your muscles by walking on a treadmill.

Cutting Task
For the side-step cutting task, you will take approximately a four-step approach, strike a target on the floor with the appropriate limb, and cut at a 45° angle. You will be asked to perform up to 5 trials of this task for each limb and in two conditions, anticipated and unanticipated. For unanticipated, the direction of your cut will be presented to you one step prior to your foot striking the target on the floor. For the anticipated task, the direction of your cut will be presented before your four-step approach. You will be offered as much rest as you need between trials. This task will take approximately 40 minutes to perform.

Surveys
You will be asked to complete two brief surveys to provide the researchers with information regarding how well your knee is functioning and in what types of activities you are currently able to participate. Those will take approximately 10 minutes to complete.

RISKS AND DISCOMFORTS YOU MAY EXPERIENCE IF YOU TAKE PART IN THIS RESEARCH

Likely Risks
- Muscle soreness or knee discomfort. You will be given adequate warm-up and offered ice bags after participation to reduce the risk of soreness and discomfort.

Unlikely Risks
- Injury to your knee. This risk is unlikely if you have been cleared for full activity.

There are no known risks to unborn children at this point. There may be risks that the researchers are unaware of at this time.

POSSIBLE BENEFIT TO YOU IF YOU DECIDE TO TAKE PART IN THIS RESEARCH

There are no direct benefits to you for participating in this research study. This study is designed for the investigators to learn more about biomechanics in an adolescent population during anticipated and unanticipated sport specific tasks.

COST TO YOU FOR TAKING PART IN THIS STUDY

You will be asked to pay for all costs associated with travel to and from the University of Toledo’s main campus as a result of participating in this study.
PAYMENT OR OTHER COMPENSATION TO YOU FOR TAKING PART IN THIS RESEARCH
If you decide to take part in this research you will not receive any financial compensation for participating.

ALTERNATIVE(S) TO TAKING PART IN THIS RESEARCH
The only alternative to taking part in this research is not to participate. Your care through the University of Toledo Medical Center will not be affected should you decline participation.

CONFIDENTIALITY - (USE AND DISCLOSURE OF YOUR PROTECTED HEALTH INFORMATION)
By agreeing to take part in this research study, you give to The University of Toledo (UT), the Principal Investigator and all personnel associated with this research study your permission to use or disclose health information that can be identified with you that we obtain in connection with this study. We will use this information for the purpose of conducting the research study as described in the research consent/authorization form.

Under some circumstances, the Institutional Review Board, or the Research and Sponsored Programs of the University of Toledo may review your information for compliance audits. If you receive any payments for taking part in this study, your personal information and limited information about this study will be given to The University of Toledo’s accounts payable department as necessary to process payments to you. We may also disclose your protected health information when required by law, such as in response to judicial orders.

The University of Toledo is required by law to protect the privacy of your health information, and to use or disclose the information we obtain about you in connection with this research study only as authorized by you in this form. There is a possibility that the information we disclose may be re-disclosed by the persons we give it to, and no longer protected. However, we will encourage any person who receives your information from us to continue to protect and not re-disclose the information.

Your permission for us to use or disclose your protected health information as described in this section is voluntary. However, you will not be allowed to participate in the research study unless you give us your permission to use or disclose your protected health information by signing this document.

You have the right to revoke (cancel) the permission you have given to us to use or disclose your protected health information at any time by giving written notice to:

Luke Donovan, PhD, ATC at 419-530-5305

However, a cancellation will not apply if we have acted with your permission, for example, information that already has been used or disclosed prior to the cancellation. Also, a cancellation will not prevent us from continuing to use and disclose information that was obtained prior to the cancellation as necessary to maintain the integrity of the research study.

Except as noted in the above paragraph, your permission for us to use and disclose your protected health information will stop at the end of the research study.

A more complete statement of University of Toledo’s Privacy Practices is set forth in its Joint Notice of Privacy Practices. If you have not already received this Notice, a member of the research team will provide this to you. If you have any further questions concerning privacy, you may contact the University of Toledo’s Privacy Officer at 419-383-8933.
IN THE EVENT OF A RESEARCH RELATED INJURY
In the event of injury resulting from your taking part in this study, treatment can be obtained at a health care facility of your choice. You should understand that the costs of such treatment will be your responsibility. Financial compensation is not available through The University of Toledo or The University of Toledo Medical Center.

By signing this form you are not giving up any of your legal rights as a research subject. In the event of an injury, contact:

Luke Donovan, PhD, ATC at 419-530-5305.

VOLUNTARY PARTICIPATION
Taking part in this study is voluntary. You may refuse to participate or discontinue participation at any time without penalty or a loss of benefits to which you are otherwise entitled. If you decide not to participate or to discontinue participation, your decision will not affect your future relations with the University of Toledo or The University of Toledo Medical Center.

NEW FINDINGS
You will be notified of new information that might change your decision to be in this study if any becomes available.

OFFER TO ANSWER QUESTIONS
Before you sign this form, please ask any questions on any aspect of this study that is unclear to you. You may take as much time as necessary to think it over. If you have questions regarding the research at any time before, during or after the study, you may contact:

Luke Donovan, PhD, ATC at 419-530-5305

If you have questions beyond those answered by the research team or your rights as a research subject or research-related injuries, please feel free to contact the Chairperson of the University of Toledo Biomedical Institutional Review Board at 419-333-6796.

Minor Participation
In the event of a minor participating in the study, parents or legal guardians will not be required to stay at the UT facility throughout the entire duration of the participation; however, may stay if they choose. An Employee of Toledo will be present for the entire duration of the study to supervise the minor. This employee will be Dr. Luke Donovan, Ms. Chelsey Roe, or Mr. Jonathan Niece.

SIGNATURE SECTION (Please read carefully)
YOU ARE MAKING A DECISION WHETHER OR NOT TO PARTICIPATE IN THIS RESEARCH STUDY. YOUR SIGNATURE INDICATES THAT YOU HAVE READ THE INFORMATION PROVIDED ABOVE, YOU HAVE HAD ALL YOUR QUESTIONS ANSWERED, AND YOU HAVE DECIDED TO TAKE PART IN THIS RESEARCH.

BY SIGNING THIS DOCUMENT YOU AUTHORIZE US TO USE OR DISCLOSE YOUR PROTECTED HEALTH INFORMATION AS DESCRIBED IN THIS FORM.
IRB # ____________________________

The date you sign this document to enroll in this study, that is, today’s date, MUST fall between the dates indicated on the approval stamp affixed to the bottom of each page. These dates indicate that the form is valid when you enroll in the study but do not reflect how long you may participate in the study. Each page of this Consent/Authorization Form is stamped to indicate the form’s validity as approved by the UT Biomedical Institutional Review Board (IRB).

Name of Subject (please print) ________________________________ Signature of Subject or Person Authorized to Consent ______________ Date __________

Relationship to the Subject (Healthcare Power of Attorney, authority or Legal Guardian) ________________________________ Time ______________

Name of Person Obtaining Consent (please print) ______________ Signature of Person Obtaining Consent ______________ Date __________

Name of Witness to Consent Process (when required by ICH Guidelines) (please print) ________________________________ Signature of Witness to Consent Process (when required by ICH Guidelines) ______________ Date __________

YOU WILL BE GIVEN A SIGNED COPY OF THIS FORM TO KEEP.

□
The University of Toledo Kinesiology Department

Study: The effect of anticipated and unanticipated cutting maneuvers on knee biomechanics in high school female athletes

Subject General History Form

Subject ID Number: ____

Date of Birth: ____

Gender: (Male/Female) ____

Height: ____________ (inches)

Weight: ____________ (lbs)

Dominant Leg (limb you kick a ball): (Right/Left) ____

Previous Injuries/Illnesses and description:

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

Inclusion criteria for this study (Answer must by yes):
1. High School female athlete who participates in soccer, basketball, volleyball, tennis, lacrosse, or field hockey

Exclusion criteria for this study (Answer must be no):
1. Previous history of ACL injury or repair
2. Previous injury that resulted in ligamentous laxity at the hip or knee
3. Lower extremity injury in the past 6 weeks
4. Any vestibular or balance disorder
### Tegner Activity Level Scale

Please indicate in the spaces below the HIGHEST level of activity that you participated in **BEFORE YOUR INJURY** and the highest level you are able to participate in **CURRENTLY**.

**CURRENT:** Level ______

<table>
<thead>
<tr>
<th>Level 10</th>
<th>Competitive sports- soccer, football, rugby (national elite)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 9</td>
<td>Competitive sports- soccer, football, rugby (lower divisions), ice hockey, wrestling, gymnastics, basketball</td>
</tr>
<tr>
<td>Level 8</td>
<td>Competitive sports- racquetball or handy, squash or badminton, track and field athletics (jumping, etc.), down-hill skiing</td>
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<tr>
<td>Level 7</td>
<td>Competitive sports- tennis, running, motorcyle speedway, handball</td>
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<tr>
<td></td>
<td>Recreational sports- soccer, football, rugby, handy, ice hockey, basketball, squash, racquetball, running</td>
</tr>
<tr>
<td>Level 6</td>
<td>Recreational sports- tennis and badminton, handball, racquetball, down-hill skiing, jogging at least 5 times per week</td>
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<tr>
<td>Level 5</td>
<td>Work- heavy labor (construction, etc.)</td>
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<tr>
<td></td>
<td>Competitive sports- cycling, cross-country skiing</td>
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<tr>
<td></td>
<td>Recreational sports- jogging on uneven ground at least twice weekly</td>
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<tr>
<td>Level 4</td>
<td>Work- moderately heavy labor (e.g. truck driving, etc.)</td>
</tr>
<tr>
<td>Level 3</td>
<td>Work- light labor (nursing, etc.)</td>
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<tr>
<td>Level 2</td>
<td>Work- light labor</td>
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<tr>
<td></td>
<td>Walking on uneven ground possible, but impossible to back pack or hike</td>
</tr>
<tr>
<td>Level 1</td>
<td>Work- sedentary (secretarial, etc.)</td>
</tr>
<tr>
<td>Level 0</td>
<td>Sick leave or disability pension because of knee problems</td>
</tr>
</tbody>
</table>

KOOS KNEE SURVEY

Subject ID:

INSTRUCTIONS: This survey asks for your view about your knee. This information will help us keep track of how you feel about your knee and how well you are able to perform your usual activities. Answer every question by ticking the appropriate box, only one box for each question. If you are unsure about how to answer a question, please give the best answer you can.

Symptoms
These questions should be answered thinking of your knee symptoms during the last week.

51. Do you have swelling in your knee?
   Never  Rarely  Sometimes  Often  Always
   □     □     □     □     □

52. Do you feel grinding, hear clicking or any other type of noise when your knee moves?
   Never  Rarely  Sometimes  Often  Always
   □     □     □     □     □

53. Does your knee catch or hang up when moving?
   Never  Rarely  Sometimes  Often  Always
   □     □     □     □     □

54. Can you straighten your knee fully?
   Always  Often  Sometimes  Rarely  Never
   □     □     □     □     □

55. Can you bend your knee fully?
   Always  Often  Sometimes  Rarely  Never
   □     □     □     □     □

Stiffness
The following questions concern the amount of joint stiffness you have experienced during the last week in your knee. Stiffness is a sensation of restriction or slowness in the ease with which you move your knee joint.

56. How severe is your knee joint stiffness after first waking in the morning?
   None  Mild  Moderate  Severe  Extreme
   □     □     □     □     □

57. How severe is your knee stiffness after sitting, lying or resting later in the day?
   None  Mild  Moderate  Severe  Extreme
   □     □     □     □     □

Assigned Version Date: 01/12/2016
Pain
P1. How often do you experience knee pain?

- Never
- Monthly
- Weekly
- Daily
- Always

What amount of knee pain have you experienced the last week during the following activities?

P2. Twisting/pivoting on your knee

- None
- Mild
- Moderate
- Severe
- Extreme

P3. Straightening knee fully

- None
- Mild
- Moderate
- Severe
- Extreme

P4. Bending knee fully

- None
- Mild
- Moderate
- Severe
- Extreme

P5. Walking on flat surface

- None
- Mild
- Moderate
- Severe
- Extreme

P6. Going up or down stairs

- None
- Mild
- Moderate
- Severe
- Extreme

P7. At night while in bed

- None
- Mild
- Moderate
- Severe
- Extreme

P8. Sitting or lying

- None
- Mild
- Moderate
- Severe
- Extreme

P9. Standing upright

- None
- Mild
- Moderate
- Severe
- Extreme

Function, daily living
The following questions concern your physical function. By this we mean your ability to move around and to look after yourself. For each of the following activities please indicate the degree of difficulty you have experienced in the last week due to your knee.

A1. Descending stairs

- None
- Mild
- Moderate
- Severe
- Extreme

A2. Ascending stairs

- None
- Mild
- Moderate
- Severe
- Extreme

Assigned Version Date: 01/12/2016

APPROVED BY
UNIVERSITY OF TOLEDO IRB
For each of the following activities please indicate the degree of difficulty you have experienced in the **last week** due to your knee.

<table>
<thead>
<tr>
<th>Activity</th>
<th>None</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
<th>Extreme</th>
</tr>
</thead>
<tbody>
<tr>
<td>A3. Rising from sitting</td>
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<tr>
<td>A4. Standing</td>
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<td>A5. Bending to (or) pick up an object</td>
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<td>A6. Walking on flat surface</td>
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<td>A7. Getting in/out of car</td>
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<td>A8. Going shopping</td>
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<tr>
<td>A9. Putting on socks/stockings</td>
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<td>A10. Rising from bed</td>
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<td>A11. Taking off socks/stockings</td>
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<td>A12. Lying in bed (turning over, maintaining knee position)</td>
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<tr>
<td>A13. Getting in/out of bath</td>
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<tr>
<td>A14. Sitting</td>
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<tr>
<td>A15. Getting on/off toilet</td>
<td></td>
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</tr>
</tbody>
</table>
For each of the following activities please indicate the degree of difficulty you have experienced in the last week due to your knee.

A16. Heavy domestic duties (moving heavy boxes, scrubbing floors, etc)
- None
- Mild
- Moderate
- Severe
- Extreme

A17. Light domestic duties (cooking, dusting, etc)
- None
- Mild
- Moderate
- Severe
- Extreme

Function, sports and recreational activities
The following questions concern your physical function when being active on a higher level. The questions should be answered thinking of what degree of difficulty you have experienced during the last week due to your knee.

SP1. Squatting
- None
- Mild
- Moderate
- Severe
- Extreme

SP2. Running
- None
- Mild
- Moderate
- Severe
- Extreme

SP3. Jumping
- None
- Mild
- Moderate
- Severe
- Extreme

SP4. Twisting/pivoting on your injured knee
- None
- Mild
- Moderate
- Severe
- Extreme

SP5. Kneeling
- None
- Mild
- Moderate
- Severe
- Extreme

Quality of Life

Q1. How often are you aware of your knee problem?
- Never
- Monthly
- Weekly
- Daily
- Constantly

Q2. Have you modified your lifestyle to avoid potentially damaging activities to your knee?
- Not at all
- Mildly
- Moderately
- Severely
- Totally

Q3. How much are you troubled with lack of confidence in your knee?
- Not at all
- Mildly
- Moderately
- Severely
- Extremely

Q4. In general, how much difficulty do you have with your knee?
- None
- Mild
- Moderate
- Severe
- Extreme

Thank you very much for completing all the questions in this questionnaire.