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The Effect of Maturation on Hip and Knee Kinetics and Kinematics During an Unanticipated Sidestep Cutting Task in Male Youth Lacrosse Players

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THE EFFECT OF MATURATION ON HIP AND KNEE KINETICS AND KINEMATICS DURING AN UNANTICIPATED SIDESTEP CUTTING TASK IN MALE YOUTH LACROSSE PLAYERS

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ABSTRACT

THE EFFECT OF MATURATION ON HIP AND KNEE KINETICS AND KINEMATICS DURING AN UNANTICIPATED SIDESTEP CUTTING TASK IN MALE YOUTH LACROSSE PLAYERS

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The incidence of noncontact anterior cruciate ligament (ACL) knee injuries has been studied extensively and has been reported as one of the highest injuries amongst high school and collegiate athletes. Little research has been focused on maturational changes in relation to the risk factors of such an injury. The purpose of this study is to determine if there is a difference between pre-pubescent (PRE), pubescent (MID) and post-pubescent (POST) male lacrosse athletes indicated by knee and hip kinetics and kinematics during an unanticipated sidestep cutting task (SS). Thirty-one male participants between the ages of nine and fourteen were recruited and categorized into three groups; PRE (n=8, 9.9±1.1years, 137.3±8.8cm, 32.7±7.1kg), MID (n=12, 11.4±0.9years, 153.6±10.7cm, 44.5±10.9kg) and POST (n=11, 12.9±0.7years, 165.6±5.9cm, 53.4±8.7kg) and were free of lower extremity injury. The Pubertal Maturation Observation Scale (PMOS) was used to allot the subjects into their corresponding maturation levels. Three-dimensional motion analysis, coupled with two force plates, was used to capture five successful SS trials. There was a significant difference found in the hip extension moment between maturation groups. Specifically, MID (-2.28±0.39Nm/kgm) subjects displayed a greater moment than both PRE (-1.85±0.28Nm/kgm) and POST (-1.84±0.34Nm/kgm) subjects (p=0.009). There were no other statistically significant differences between maturation levels at any time instance.

With this small difference between maturation levels, there is not evidence of a change in the biomechanics of the lower extremity during the maturation process of youth male lacrosse athletes.

I would first and foremost like to thank my family. They are who keep me sane and constantly show unconditional love, even when I'm 3,000 miles away.

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CHAPTER I

INTRODUCTION

The prevalence of anterior cruciate ligament (ACL) injuries within the current general population reported that there were approximately 95,000 new knee injuries per year in the United States (Miyasaka, Daniel, Stone, & Hirshman, 1991). According to studies conducted in other countries, the age range at which ACL tears are the highest was reported to be between the ages of 15-39 (Granan, Bahr, Steindal, Furnes, & Engebretsen, 2008; Granan, Forssblad, Lind, & Engebretsen, 2009). This age range includes the collegiate and adolescent athletes who have been reported to be at a higher risk for sustaining ACL injuries (Hinton, Lincoln, Almquist, Douoguih, & Sharma, 2005; Hootman, Dick, & Agel, 2007). Within the collegiate population, the National Collegiate Athletic Association (NCAA) reported that the number of ACL injuries across a 16 year period was 5,000 (Hootman et al., 2007). The cost of ACL injuries reflects the prevalence in that the reported total cost is $17,000 per patient (Cole et al., 2005; de Loes, Dahlstedt, & Thomee, 2000; Hewett, Lindenfeld, Riccobene, & Noyes, 1999; Nagda, Altobelli, Bowdry, Brewster, & Lombardo, 2010). In the younger population, it has been reported that there is an increase in ACL injuries throughout age and maturation; specifically, post-pubescent athletes are at the highest risk for sustaining an ACL injury (Garrett et al., 2006; Michaud, Renaud, & Narring, 2001). Injuries to the ACL have been shown to have negative long-term effects such as osteoarthritis, which can cause disability in the later stages of life (Lohmander, Ostenberg, Englund, & Roos, 2004).

There are two different mechanisms of injury; contact and non-contact mechanisms. Within the non-contact mechanisms, there have been proposed risk factors contributing to the incidence of ACL injuries. Several risk factors contribute to the increased incidence of non-contact ACL injuries, which include intrinsic and extrinsic factors. Intrinsic risk factors include anatomical, biomechanical, maturational and gender differences (Shultz, Schmitz, Nguyen, Chaudhari, et al., 2010) while extrinsic risk factors include environmental/external differences (Chaudhari, Hearn, & Andriacchi, 2005; Olsen, Myklebust, Engebretsen, & Bahr, 2004; Orchard & Powell, 2003; Scranton et al., 1997).

In particular, there are many researchers that have examined biomechanical factors of the lower extremity to better recognize the lower extremity movements that may place athletes at increased risk for non-contact ACL injuries (Ford, Myer, Toms, & Hewett, 2005; Malinzak, Colby, Kirkendall, Yu, & Garrett, 2001; McLean, Huang, Su, & Van Den Bogert, 2004; McLean, Huang, & van den Bogert, 2005; McLean, Neal, Myers, & Walters, 1999; Pollard, Davis, & Hamill, 2004; Pollard, Sigward, & Powers, 2007; Sigward & Powers, 2006a, 2006b). In addition to the biomechanical analysis, various studies have looked at differences between pre-pubertal and post-pubertal subjects in attempts to understand what effect puberty has on biomechanical factors relating to ACL injuries (Ahmad et al., 2006; Davies & Rose, 2000; Hass et al., 2003; Hewett, Myer, & Ford, 2004; Quatman, Ford, Myer, & Hewett, 2006; Sigward, Pollard, Klenow, Montague, & Powers, 2007; Swartz, Decoster, Russell, & Croce, 2005).

In regards to gender differences, it has been extensively reported that females are at an increased risk for ACL injuries (Agel, Arendt, & Bershadsky, 2005; Arendt, Agel,

& Dick, 1999; Dick, Lincoln, et al., 2007), except in the sport of lacrosse, which has been shown to have different results (Hootman et al., 2007; Mihata, Beutler, & Boden, 2006). Recently, it was reported that there were no significant differences in the ACL injury rate between male and female lacrosse athletes, and the rate of ACL injury in men's lacrosse was twice as high as male soccer and basketball athletes (Mihata et al., 2006)

Although it has been shown that there is an increase in ACL injuries within youth athletes (Michaud et al., 2001) and that the injury rate between male and female lacrosse athletes is reported to be similar (Mihata et al., 2006), there has been little to no research in combining these two factors with a biomechanical analysis of a side step cutting task. Specifically, there has been only one other study (Sigward et al., 2007) to look at the differences between maturation levels during a side step cutting task.

Purpose Statement

The purpose of this study is to determine if there is a difference between pre-pubescent, pubescent and post-pubescent male lacrosse players as indicated by knee and hip kinetics and kinematics during an unanticipated side step cut.

Hypothesis

Null

There will be no statistically significant differences in lower extremity kinetics (knee abduction/adduction moment, knee flexion/extension moment, hip flexion/extension moment, hip adduction/abduction moment, vertical ground reaction force and posterior ground reaction force) and kinematics (knee abduction angle, knee flexion angle, hip flexion angle, and hip adduction angle) at certain time instances (initial contact, early deceleration, and peak stance) between maturation stages (pre-pubescent,

pubescent and post-pubescent) in males while performing an unanticipated sidestep cutting task.

Alternative

1. Post-pubescent males will demonstrate a decreased internal knee adduction moment when compared to pubescent and pre-pubescent males during the early deceleration phase (Sigward et al., 2007).
2. Post-pubescent subjects will display a increase in the internal knee extension moment when compared to pubescent and pre-pubescent during the early deceleration phase (Hass et al., 2003).
3. Post-pubescent males will show a decrease in the internal hip extension moment when compared to pre-pubescent males within the early deceleration phase (Pollard, Sigward, & Powers, 2007).
4. Pre-pubescent males will demonstrate a decreased internal hip adduction moment when compared to post-pubescent males within the early deceleration phase (Pollard et al., 2007)
5. There will be a decrease in the peak posterior ground reaction force in post-pubescent male subjects when compared to pre-pubescent subjects within peak stance (Hass et al., 2003)

Independent Variables

The independent variable of this study will be maturation stage within males with 3 levels; pre-pubescent, pubescent and post-pubescent.

Dependent Variables

Kinetics:

1. Internal knee extension-flexion moment (Nm/Kgm)
2. Internal knee abduction-abduction moment (Nm/Kgm)
3. Internal hip extension-flexion moment (Nm/Kgm)
4. Internal hip abduction-abduction moment (Nm/Kgm)

Kinematics:

1. Knee flexion/extension angle (degrees)
2. Knee abduction/adduction angle (degrees)
3. Hip flexion/extension angle (degrees)
4. Hip abduction/adduction angle (degrees)

Ground Reaction Forces:

1. Peak vertical ground reaction force (N/BW)
2. Peak posterior ground reaction force (N/BW)

Kinetic variables were measured at initial contact and the peak within the first twenty percent of the stance phase. Ground reaction force variables were measured within the first twenty percent of the stance phase and peak stance.

Operational Definitions

1. Internal moment- the internal moments are defined as the torque acting on the joint during the time instance or phase defined. The internal moments are measured in Newton meters and normalized to height and mass
2. Ground Reaction Force- the ground reaction forces are the forces recorded by the force plates during the side step cutting task. The ground reaction forces are measured in Newtons and normalized to body weight.

3. Joint angles - the angles are the measures of distal segments moving about the proximal segments recorded by the reflective markers placed on the subjects and are measured in degrees (Wu et al., 2002).
4. Stages of puberty- the stages of puberty were determined with a previously validated questionnaire (Davies, 1995). The questionnaire differentiates which stage of puberty an individual is currently in and corresponds with the appropriate Tanner Staging scale which is a scale based on secondary sexual characteristics that show the degree to which pubertal maturation has occurred among young adults. Tanner Stage 1 corresponds with pre-pubescent males, stages 2 through 4 correspond with pubescent males and stage 5 corresponds with post-pubescent males.
5. Initial contact- defined as the moment that the vertical ground reaction force is greater than 10 Newton's (Bennett et al., 2008; Blackburn & Padua, 2008; Cowley, Ford, Myer, Kernozek, & Hewett, 2006; Houck, 2003; Houck, Duncan, & De Haven, 2006; McLean, Huang, & van den Bogert, 2005).
6. Peak value within the first twenty percent of the stance phase (early deceleration) - defined as the time instant that each variable reached its peak within the first twenty percent of the phase between initial contact and final toe off during the side step cut.(Boden, Dean, Feagin, & Garrett, 2000; McLean et al., 2007; McLean, Huang, et al., 2005).
7. Peak stance phase- defined as the time instant that each variable is at its peak from initial contact until the point the individual is half way through the full

stance phase (McLean, Walker, & van den Bogert, 2005; Pflum, Shelburne, Torry, Decker, & Pandy, 2004).

8. Knee abduction/adduction- knee abduction/adduction is the motion of and forces acting on the knee in the frontal plane.
9. Hip abduction/adduction- hip abduction/adduction is motion of and forces acting on the hip in the frontal plane
10. Knee flexion/extension- knee flexion/extension is the motion of and the forces acting on the knee in the sagittal plane
11. Hipflexion/extension- hip flexion/extension is the motion of and the forces acting on the hip in the sagittal plane
12. Unanticipated side step cut- consisted of having the individual approach the force plates at a minimum speed of 2.5 m/s. A projector displayed one of two signifiers to indicate either a side step cutting task or a stop jump task. The side step cutting task required the individual to place the dominant foot on one force plate and cut at an angle between 35 and 55 degrees while maintaining the indicated speed (Pollard et al., 2007).

Assumptions

1. The equipment used for motion analysis is both valid and reliable
2. The maturation questionnaire will accurately place the subjects into pubertal groups.
3. There will be a minimal learning curve for the tasks being administered and the subjects will not be trying to anticipate the movement task

4. The subjects will interpret the instruction regarding the side step cutting task the same regardless of which investigators provided the instruction
5. All subjects will put forth maximal effort into each of the unanticipated side step cutting tasks.

Limitations

1. The researchers will require all participants to wear athletic shoes, but the subjects will not all have the same shoes.
2. There is no way to control for the parents guessing answers regarding their children during the completion of the pubertal maturational observational scale.
3. Our subjects, when in competition, have a lacrosse stick in their hands. This study did not account for that variable and the subjects were not holding any type of lacrosse stick
4. The recommended sample size determined by the power analysis was not met.
5. The subjects are a sample of convenience.

Delimitations

All subjects were male youth lacrosse players between the ages of 9 and 14. The subjects were grouped according to their maturation stage, as determined by the Pubertal Maturational Observation Scale (PMOS) questionnaire. If the subject previously sustained any major lower extremity injury that required surgery, or if they sustained an injury not requiring surgery within the last six months, they were excluded from the study.

CHAPTER II

REVIEW OF LITERATURE

Introduction

This review of literature includes information related to the anatomy of the ACL, epidemiology of ACL injuries, mechanisms of ACL injuries and risk factors associated with injuries to the ACL. Additionally discussed are the components of kinetic and kinematic variables associated with lower extremity injuries.

Anatomy of the Anterior Cruciate Ligament

The ACL has two main functions within the tibiofemoral joint. The ACL resists anterior translation and increases rotary stability of the tibiofemoral joint (Matsumoto et al., 2001). The ACL works in conjunction with the musculature around the tibiofemoral joint to provide stability about the joint (Ireland, 1999). The functions of the ACL have a direct correlation with the attachment sites on the tibia and femur.

It is widely accepted that the ACL is made up of 2 bundles, the anteromedial and posterolateral bundles (Duthon et al., 2006; Papachristou, Sourlas, Magnissalis, Plessas, & Papachristou, 2007). When the tibiofemoral joint is flexed, the two bundles rotate around each other and the femoral attachment of the posterolateral attachment is anterior to the attachment of the anteromedial attachment. When the tibiofemoral joint is extended, the bundles are no longer rotated around each other and the femoral attachments switch anatomical locations therefore changing the length of the bundles in different ranges of motion at the tibiofemoral joint (Amis & Dawkins, 1991). Although the two-bundle theory is the most accepted anatomy, it has also been shown that there are actually three bundles of the ACL (Amis & Dawkins, 1991; Hollis, Takai, Adams, Horibe, & Woo, 1991). Along with this theory, Amis and Dawkins (1991) showed that the ACL of younger patients are covered in a synovium, making it difficult to distinguish between bundles. As the human body ages, the bundles of the ACL become more prominent, the synovium surrounding them becomes thinner, and the bundles become easier to distinguish from each other within the joint space.

The ACL runs posteriorly from the anteromedial intercondylar eminence of the tibia to the medial portion of the lateral femoral condyle (Norwood & Cross, 1979). The anteromedial bundle runs on the anterior portion of the ACL while the posterolateral bundle runs on the posterior portion of the ACL. In looking at the connection of the tibia to the femur through the ACL, the anterior part of the femoral attachment is connected to the tibia on the anterior portion of the attachment and the posterior part of the femoral attachment is connected to the tibia on the posterior portion of the attachment. This is also true in the proximal and distal portions of the ACL within the joint space, the proximal portion is attached to the medial portion of the tibia and femur, and the distal portion is attached to the lateral potion of the tibia and femur (Mommersteeg et al., 1995).

The most prominent nerve that innervates the ACL are branches coming from the posterior tibial nerve called the posterior articular branches. These branches wrap around the popliteal artery and vein and enter the capsule through the popliteal plexus (Kennedy, Alexander, & Hayes, 1982). Most of the nerve supply found in the ACL is found in the tibial end of the ligaments and within the synovium that surrounds it (Kennedy et al., 1982). The blood supply that nourishes the ACL is provided by the middle genicular artery, which is a branch of the popliteal artery (Duthon et al., 2006; Scapinelli, 1997). This artery enters the joint capsule through the posterior capsule of the knee. There is an area that is avascular within the ACL which is the tissue between the attachments of the ACL to its bony landmarks (Scapinelli, 1997).

Epidemiology

The prevalence of ACL injuries within the general population in United States has not received the appropriate attention. The most accurate account is an incidence of one injury per 3000 people (Miyasaka et al., 1991). Other countries have studied the number of ACL surgeries and reported them as the incidence of ACL injuries (Gianotti, Marshall, Hume, & Bunt, 2009; Granan et al., 2008). A study gathered in Norway looked at the prevalence of ACL injuries in their country and found that thirty-four people per 100,000 underwent ACL reconstruction surgery and a study in New Zealand found a similar incidence at 36.9 surgeries per 100,000 people (Gianotti et al., 2009; Granan et al., 2008). They also found that in the "at risk" age group, which was identified as age 15-39, the incidence increased to eighty-five people per 100,000 that under went a reconstruction to their ACL and more than doubled in other Scandinavian countries (Granan et al., 2008; Granan et al., 2009).

The cost of treating an ACL injury has been recorded to cost about $17,000 total per patient, $1,131 for just the initial diagnosis and approximately $5,100 for the cost of the surgery (Cole et al., 2005; de Loes et al., 2000; Hewett et al., 1999; Nagda et al., 2010). Gianotti and colleagues reported the cost of ACL surgeries to be $11,157 for operations performed in New Zealand. The reported costs are indicative of acute treatment of ACL injuries and do not account for the long-term effects of sustaining and ACL injury.

Many researchers have focused more on the collegiate population in regards to ACL injury. The National Collegiate Athletic Association (NCAA) implemented an Injury Surveillance System (ISS) in which injuries are tracked throughout college level athletics (Arendt & Dick, 1995). In a 16-year period from 1988-89 to 2003-04, 4800 ACL injuries were reported in a total of 15 sports within males and females. Within this number, 1520 of the injuries were reported for basketball, soccer and lacrosse athletes with466 being male participants and 1054 being female participants (Hootman et al., 2007). In the 2005-2006 high school year, the Centers for Disease Control and Prevention (CDC) performed a study to analyze injuries among high school athletes, due to the large increase in athletic injuries at the high school level and found an injury rate of 2.44 injuries per 1000 athletes (Comstock, Knox, & Gilchrist, 2006). In the skeletally immature population, defined as under the age of sixteen years old, sports participation will continue to increase, therefore increasing the incidence of ACL injuries in this population (Fuchs et al., 2002)

A survey was given to members of The Herodicus Society of The ACL Study Group whose members were either international experts in sports medicine or international experts in ACL injuries. The survey found that 88% of the respondents had treated a skeletally immature patient with an ACL injury during the past year and 78% did an ACL reconstruction on a skeletally immature patient (Kocher, Saxon, Hovis, & Hawkins, 2002). Another research study found that the incidence of ACL ruptures was recorded as 60 over a 10-year span in the immature population and therefore a different treatment plan should be considered because of the adverse effects of long-term outcomes. In the past, the injuries went untreated and caused future disability within the patients, therefore the reconstruction of the ACL in the immature population started and revealed good results compared to no treatment (Aichroth, Patel, & Zorrilla, 2002). This information regarding prevalence and cost shows the need to further examine injuries to the ACL in order to determine prevention strategies.

The incidence of ACL injuries has been shown above to be a problem within the young athletic population. Within this population, it has been reported that the incidence of ACL injuries is higher in females (Agel et al., 2005; Arendt et al., 1999; Dick, Putukian, Agel, Evans, & Marshall, 2007), but the sport of lacrosse has been shown to have different results. In 2006, it was reported that there was no statistically significant difference in the ACL injury rate between male and female lacrosse athletes regardless of mechanism of injury (Mihata et al., 2006). The authors also reported that the rate of ACL injury in men's lacrosse was twice as high as male soccer and basketball athletes, and the ACL injury rate in female lacrosse players was significantly lower than in female soccer or basketball athletes (Hootman et al., 2007; Mihata et al., 2006). The researchers concluded that the "allowable contact" in men's lacrosse could be the attributing factor for the differences found, yet the research is limited in this area and this study did not examine the mechanism of injury (Mihata et al., 2006). Another study found that in high school lacrosse athletes, knee injuries in males is one the most prevalent injury in lacrosse, next to ankle and head injuries (Hinton et al., 2005)

Mechanism of ACL Injuries

There are two main mechanisms of injury that occur to the ACL, contact and non-contact. Contact refers to a direct blow to the knee that results in a rupture of the ligament (Olsen, Myklebust, Engebretsen, & Bahr, 2004). One definitions of a non-contact mechanism is when the participants does not sustain player-to-player or body-to-body contact during a cutting, deceleration, or landing event. This can injure the ACL in by not having control of the musculature about the tibiofemoral joint (Ireland, 1999; Myklebust et al., 2003). Other researchers have other theories surrounding the true reason the ACL is injured without contact. One theory explains that the injury occurs when four events take place concurrently. The events include a ground reaction forces rather than increased muscle forces, inefficient kinematics at the knee and hip, delayed activation of the quadriceps and hamstrings, and anatomical difference in the tibial plateau and tibial slope (Hashemi et al., 2010) Another theory explains a multiplanar biomechanical factors and multiplanar sports movements, rather than single plane factors, contribute to non-contact ACL injuries (Quatman & Hewett, 2009). Non-contact ACL injuries occur more frequently in athletes than contact injuries with a range of 64%-83% being non-contact injuries (Agel et al., 2005; Hewett et al., 1999; Hewett, Myer, & Ford, 2006; Ireland, 1999; Mountcastle, Posner, Kragh, & Taylor, 2007; Uhorchak et al., 2003).

Contact

The definition of a contact injury to the ACL differs between studies and between researchers. Hewett et al. (2006) explains, after extensive research of other authors perspectives, that a true contact injury is a direct blow specifically to the knee, but when a players incurs body-to-body contact with no direct blow and sustains an ACL injury, it is difficult to classify. One way is classifying this injury is explained as a non-contact injury with perturbations (Hewett et al., 2006).

Uhorchak et al. (2003) performed a longitudinal study of West Point cadets during their four-year enrollment at the military academy and found a decreased rate of contact ACL injuries. Enrollment in the academy required the cadets to be consistently physically active, and the researchers reported that there were only five contact injuries out of twenty-nine (17%) total ACL injuries over the four-year period. Other researchers have also come to similar conclusions. Boden et al. (2000) found, that only 28% of ACL injuries were from a contact mechanism. In looking at research regarding collegiate lacrosse athletes, it was found that females have a lower incidence of contact injuries overall and males have an equal incidence of contact and noncontact injuries during practice (Dick, Lincoln, et al., 2007; Dick, Romani, Agel, Case, & Marshall, 2007).

Non-Contact

Non-contact injuries are more common in the athletic population compared to contact injuries and occur from various types of athletic movements (Agel et al., 2005; Arendt et al., 1999; Hewett et al., 1999; Mountcastle et al., 2007). Contrarily, Mountcastle et al (2007) reported that male military students who played lacrosse had a larger number of non-contact injuries versus contact injuries, as well as a larger total number of ACL injuries compared to female lacrosse athletes. The differences in the findings may have been due to the subject sample as Dick et al. (2007) examined NCAA collegiate athletes and Mountcastle et al. (2007) studied recreationally active military students.

Common movements that cause non-contact ACL injuries are described as pivoting movements, sudden deceleration or stopping movements, and landing movements (Hashemi et al., 2010; Hewett et al., 1999; Ireland, 1999; Yu et al., 2005). The movements put the body in positions that include knee abduction, knee extension and a widened stance with simultaneous inefficient hip kinematics that contribute to the cause of ACL injuries (Hashemi et al., 2010; Ireland, 1999; Olsen et al., 2004; Quatman & Hewett, 2009). These movements in conjunction with delayed contraction of quadriceps and hamstrings, anatomical differences in tibial slope and plateau and variables external to the knee itself such as fatigue and ground reaction forces increase the incidence of non-contact ACL injuries (Hashemi et al., 2010).

Although, it is commonly reported that females are at a higher risk for non-contact ACL injuries and that males and females are similar in the sport of lacrosse when compared across all mechanisms of ACL injuries, in the sport of lacrosse, males are at an increased rate for non-contact injuries specifically (Mountcastle et al., 2007).

Risk Factors of Non-contact ACL Injuries

There are many risk factors associated with non-contact ACL injuries. These risk factors fall into two categories; extrinsic and intrinsic. Extrinsic risk factors include bracing and environmental/external differences, while intrinsic risk factors include anatomical, biomechanical and maturational differences (Shultz, Schmitz, Nguyen, Chaudhari, et al., 2010)

Environmental/External Risk Factors

An extrinsic risk factor relating to non-contact injuries of the ACL comes from the environment surrounding the athlete during play. Factors such as weather and surface type have shown an effect on the frequency of non-contact ACL injuries (Olsen et al., 2004; Orchard & Powell, 2003; Scranton et al., 1997). Orchard and Powell (2003) found that there was a decreased incidence of non-contact ACL injuries with colder weather compared to hot weather in outdoor stadiums in football players regardless of surface type. Athletes play on many different surfaces, and studies have been conducted to attempt to find which surface increases the risk of injury (Olsen et al., 2004; Scranton et al., 1997). Olsen et al. (2004) studied handball and surfaces associated with an artificial floor and a wooden floor. The incidence of non-contact ACL injuries was higher on the artificial surface than on a wooden surface as it is hypothesized that the wooden surface has lower friction (Olsen et al., 2004). Scranton et al. (1997) found that in football players and their associated playing surfaces, natural grass had a higher incidence of non-contact ACL injuries compared to artificial turf. They also found, that more than 95% of the non-contact ACL injuries they observed happened on turf that was dry (Scranton et al., 1997).

Another environmental risk is the effect of bracing at the knee as a factor of either helping or hindering an athlete's performance or risk of non-contact ACL injury (Baker, 1998; Pietrosimone, Grindstaff, Linens, Uczekaj, & Hertel, 2008; Wojtys, Kothari, & Huston, 1996; Yu et al., 2004). Wojtys et al. (1996) found that the six braces they tested significantly reduced tibial translation in muscle relaxed and muscle contracted tests. The braces decreased tibial translation by an average of 33.1% in muscle-relaxed tests and 80.1% in muscle-contracted tests. Although this is true, they also found that the braces decreased hamstring performance. The hamstrings functional role is to resist anterior tibial translation, which is a risk factor for non-contact ACL injury (Ahmad et al., 2006; Huston & Wojtys, 1996; Rosene & Fogarty, 1999; Rozzi, Lephart, Gear, & Fu, 1999; Wojtys et al., 1996). The braces decreased the hamstring torque by an average of 5.4 % and the quadriceps torque by an average of 2.4% (Wojtys et al., 1996). Yu, et al. (2004) studied the effects of just one specifically designed knee brace that added a constraint to knee extension. They found that with the use of this brace, athletes knee flexion on the landing of a stop jump task increased. They also found that there was no significant difference between the athlete's run speed or jump height during the test trials, with and without the brace, concluding that there is not a decrease in performance due to this specific knee brace (Yu et al., 2004). Pietrosimone et al. (2008) conducted a systematic review of the effects of the use of prophylactic knee braces to determine the relative risk reduction between the years of 1986 and 1994. They found seven articles in which the results of all were inconsistent and they deemed the effect of knee bracing inconclusive. They reported that only three of the seven articles actually benefited the athletes by wearing the brace, and the other 4 actually harmed the athletes by wearing the brace (Pietrosimone et al., 2008).

Lastly, an external factor is the arm position of certain athletes who have items to carry during play. Lacrosse players hold a lacrosse stick during play and this effects movements of the lower body that put the ACL at risk of tearing (Chaudhari, Hearn, & Andriacchi, 2005). Chaudhari et al. (2005) found that subjects who held a lacrosse stick were at higher risk for non-contact ACL tears. The subjects showed a significantly higher knee abduction moment when carrying a lacrosse stick compared to when they did not in a side step cutting task (Chaudhari et al., 2005).

Anatomical Risk Factors

An intrinsic risk factor associated with non-contact ACL injuries is the variation in individual anatomy. Anatomical factors include anterior condylar notch width, condylar and tibial width, ACL size, knee joint laxity and generalized joint laxity (Ahmad et al., 2006; Alizadeh & Kiavash, 2008; Baker, 1998; Chandrashekar, Slauterbeck, & Hashemi, 2005; DeMorat, Weinhold, Blackburn, Chudik, & Garrett, 2004; Dugan, 2005; Huston & Wojtys, 1996; Papachristou et al., 2007; Rozzi et al., 1999; Shelbourne, Davis, & Klootwyk, 1998; Stijak, Radonjic, Nikolic, Blagojevic, & Herzog, 2009; Uhorchak et al., 2003). Among those anatomical risk factors, one that has received much attention, has been the notch width index and its relation to non-contact ACL injuries (Alizadeh & Kiavash, 2008; Anderson, Dome, Gautam, Awh, & Rennirt, 2001; Chandrashekar et al., 2005; Ireland, Ballantyne, Little, & McClay, 2001; LaPrade & Burnett, 1994; Muneta, Takakuda, & Yamamoto, 1997; Souryal & Freeman, 1993; Teitz, Lind, & Sacks, 1997). The notch width index (NWI) is the ratio of the width of the anterior outlet of the femoral intercondylar notch divided by the total condylar width at the level of the popliteal groove (Souryal & Freeman, 1993). In radiographic studies of males and females tibiofemoral joints, three studies found that males had a notch width that was wider compared to females (Muneta et al., 1997; Souryal & Freeman, 1993; Stijak et al., 2009). When the femoral intercondylar notch is narrowed, it puts an individual at risk to tear their ACL as compared to individuals that do not have a narrowing of the femoral intercondylar notches (LaPrade & Burnett, 1994). Contrastingly, some studies have not found a significant difference in the NWI between genders or between patients who have and have not sustained a non-contact ACL injury (Alizadeh & Kiavash, 2008; Chandrashekar et al., 2005; Muneta et al., 1997; Teitz et al., 1997).

Uhorchak et al. (2003) observed that males who had a non-contact ACL injury had anatomical risk factors that were significantly different than those who did not sustain a non-contact ACL injury. These factors include notch width, eminence width, NWI and tibial width index (Uhorchak et al., 2003). In regards to notch width, notch height, femoral condyle height and femoral condyle width, Schickendantz and Weiker (1993) found no statistically significant difference between those who sustained either unilateral or bilateral ACL tears and those who did not sustain an ACL tear (Schickendantz & Weiker, 1993).

In relation to the notch width, the actual size of the ACL is another anatomical risk factor. Muneta et al. (1997) found that ACL size was the same regardless of notch width and therefore theorized that a narrow notch width with a normal sized ACL could lead to impingement of the ACL in rotational movements. This impingement has the potential to put the ACL in a compromised position and in turn can increase the risk of a rupture (Muneta et al., 1997). Another researcher found that the ACL size in males was larger than that in females (Stijak et al., 2009).

Another anatomical risk factor is anterior knee joint laxity. An increased anterior tibial translation (ATT) demonstrates a higher degree of knee joint laxity (Ahmad et al., 2006; Huston & Wojtys, 1996; Rosene & Fogarty, 1999; Rozzi et al., 1999). Shultz et al. (2010) found that an increased knee joint laxity and general joint laxity increased the work it took to absorb landing in a drop jump (Shultz, Schmitz, Nguyen, & Levine, 2010). Huston and Wojtys (1996) concluded that the knees of non-athletes had an increased ATT compared to athletes of the same gender. Ahmad et al. (2006) also found that there was a difference between maturity and immaturity. Maturity for males was defined as those aged 14 and higher and immaturity was defined as those aged 13 and younger. They found that mature males had the lowest ATT compared to mature females, immature males and immature females. Displaying increased anterior tibial translation can increase the risk that an individual has to sustain a non-contact ACL injury.

Joint laxity can also be determined by assessing knee hyperextension (Quatman, Ford, Myer, Paterno, & Hewett, 2008; Soderman, Alfredson, Pietila, & Werner, 2001). Quatman et al. (2008) found that as males age from pre-pubescent to post-pubescent, their knee extension laxity increased, potentially putting them at a higher risk for non-contact ACL injury after the onset of puberty. Soderman et al. (2001) observed that an increased knee hyperextension was a risk factor for sustaining any knee injury. Although these anatomical factors predispose an individual for a non-contact ACL injury, they are not the only factors that contribute to the high incidence of non-contact ACL injuries.

Biomechanical Risk Factors

The biomechanics of lower extremity movement can be a risk factor for non-contact ACL injuries. These mechanics encompass the kinetics and kinematics. Many authors have studied the risk factor of inefficient biomechanics of the lower extremity. Researchers have been searching to find which combination of these lower extremity kinetics and kinematics increase the risk of non-contact ACL injuries (Boden et al., 2000; Dempsey, Lloyd, Elliott, Steele, & Munro, 2009; Ford, Myer, Toms, & Hewett, 2005; Malinzak, Colby, Kirkendall, Yu, & Garrett, 2001; McLean, Neal, Myers, & Walters, 1999; Pollard, Davis, & Hamill, 2004; Sigward & Powers, 2006a, 2006b, 2007). It has been reported that the movements that put the ACL at risk are multi-planar in nature and typically occur in conjunction with other factors as opposed to a single factor injuring the ACL (Hashemi et al., 2010; Quatman & Hewett, 2009; Shimokochi & Shultz, 2008).

To analyze biomechanical risk factors, researchers mimic the movements that typically rupture the ACL. The most commonly analyzed movements are jump landings and side step cuts. Throughout these studies, authors have identified possible factors, which might predispose athletes to non-contact ACL injuries (Dempsey et al., 2009; Ford et al., 2005; Malinzak et al., 2001; McLean, Huang, et al., 2005; McLean et al., 1999; Pollard et al., 2004; Pollard et al., 2007; Sigward & Powers, 2006b, 2007).

As deceleration is an integral part of performing a successful landing, it has been seen as the typical time instance where athletes injure the ACL. Authors have analyzed landing mechanics from various types of jumps to identify risk factors for non-contact ACL injuries (Blackburn & Padua, 2008; Chappell, Yu, Kirkendall, & Garrett, 2002; Cortes et al., 2007; Decker, Torry, Wyland, Sterett, & Richard Steadman, 2003; Hass et al., 2003; Hewett et al., 2004; Hewett et al., 2005; Myer et al., 2009; Russell, Palmieri, Zinder, & Ingersoll, 2006; Sell et al., 2006; Swartz et al., 2005; Yu et al., 2005). These researchers have found that the biomechanical risk factors predisposing an individual athlete to a non-contact ACL injury are increased knee extension angle, knee abduction moments, ankle plantar-flexion angle, knee abduction angle, trunk extension angle, hip extension moment and knee flexion moments. Researchers have also identified decreased hip flexion and knee flexion angles as risk factors (Blackburn & Padua, 2008; Chappell et al., 2002; Cortes et al., 2007; Decker et al., 2003; Hass et al., 2003; Hewett et al., 2004; Hewett et al., 2005; Russell et al., 2006; Sell et al., 2006; Shimokochi, Yong Lee, Shultz, & Schmitz, 2009; Shin, Chaudhari, & Andriacchi, 2009; Swartz et al., 2005; Yu et al., 2005). Hass et al. (2003) disagreed in regards to hip flexion, as they found that an increased hip flexion is more of a risk factor for non-contact ACL injury and the decreased hip flexion they found within the subjects may help protect the internal structures of the knee. Hewett et al. (2005) found that a higher knee abduction moment is a greater risk factor in non-contact ACL injuries when comparing individuals with and without past injury.

Although the above information on the landing tasks helps to indicate risk factors for ACL injury, a side step cutting task, involving a pivoting movement, is also a movement pattern that can increase the risk for non-contact ACL injuries (Hewett et al., 1999; Ireland, 1999; Yu et al., 2005). When examining a side step cut, authors have examined both anticipated and unanticipated movements (Dempsey et al., 2009; Ford et al., 2005; Malinzak et al., 2001; McLean, Huang, et al., 2005; McLean et al., 1999; Pollard et al., 2004; Pollard et al., 2007; Sigward & Powers, 2006b, 2007). Studies have shown that the biomechanical risks found to predispose athletes to non-contact ACL injuries during a side-step cut are an increased knee adduction moment, knee adduction angle, hip internal rotation angle and hip adduction moment. The studies also found a decreased knee flexion moment, hip flexion angle, hip external rotation moment and knee flexion angle constitute risk factors for an ACL injury when performing a side step task (Ford et al., 2005; Malinzak et al., 2001; McLean, Huang, Su, & Van Den Bogert, 2004; McLean et al., 1999; Pollard et al., 2004; Pollard et al., 2007; Sigward & Powers, 2006b). At the knee, it has been found that the knee, in females, is in 8° of abduction and that is found to be 11° more than males. It was also found that the knee flexion angle is 8° lower in females when compared to males (Ford et al., 2005; Malinzak et al., 2001). Internal moments at the knee have been found to be .44 Nm/BW more in females compared to males for knee adduction moments and .7 Nm/BW more for knee flexion moments (Sigward & Powers, 2006b). Pollard et al. (2007) reported that females increased the hip internal rotation 8.7° and decreased the hip flexion 4.7° compared to their male counterparts during early deceleration. The internal moments were .82 Nm/BW more in females compared to males for hip adduction and 1.31 Nm/BW more for hip external rotation (Pollard et al., 2007). McLean et al. (2005) also saw an increase in females knee adduction moment reported at .21 Nm/BW compared to males (Appendix 5).

Another component of the current research is looking at time instances or phases that a non-contact ACL injury may occur. The most widely used times have been initial contact, peaks within the stance phase, and early deceleration, which is defined as the first 20 % of the stance phase (Dempsey et al., 2009; Ford et al., 2005; Malinzak et al., 2001; McLean, Huang, et al., 2005; McLean et al., 1999; Pollard et al., 2004; Pollard et al., 2007; Sigward & Powers, 2006a, 2006b, 2007). It has been shown that the early deceleration phase, or first 20% of the stance phase, is where most non-contact ACL injuries occur (Boden et al., 2000; Krosshaug et al., 2007; McLean, Huang, et al., 2005; Olsen et al., 2004).

Maturational Risk Factors

Maturation is a risk factor for non-contact ACL injuries due to the changes of the human body throughout the aging process (Davies & Rose, 2000). Many studies have looked at differences between pre- and post-pubescent subjects in attempts to understand what effect puberty has on factors relating to non-contact ACL injuries (Ahmad et al., 2006; Davies & Rose, 2000; Hass et al., 2003; Hewett et al., 2004; Quatman et al., 2006; Sigward et al., 2007; Swartz et al., 2005).

Kinetics and kinematics of the lower extremity have been widely studied in regards to differences between pre-pubescent and post-pubescent individuals.

Differences have been found in kinematics and kinetics of the knee, hip and ankle in both landing tasks and side-step cutting tasks (Hass et al., 2003; Hewett et al., 2004; Quatman et al., 2006; Sigward et al., 2007; Yu et al., 2005). Yu et al. (2005) found that the knee and hip flexion angles at initial contact, as well as hip flexion angle at maximum knee flexion, did not change as age increased in male athletes while performing a stop jump. Additionally they reported that the knee abduction angle at initial contact slightly increased as age increased during a stop jump. Hewett et al. (2004) studied the frontal plane and found that post-pubescent males had a slightly increased lower extremity valgus angle during a drop jump at initial contact, and a large increase in lower extremity valgus angle from pre-pubescent to pubescent stages in males. Sigward et al. (2007) also studied the frontal plane along with the sagittal plane and found that post-pubescent subjects had decreased knee flexion and adduction moments in early deceleration in a side-step cutting task. Hass et al. (2003) also studied the sagittal plane and found that post-pubescent subjects had an increased hip flexion at initial contact, and similar to Sigward et al. (2007) found an increase in knee extension within early deceleration. Both Hass et al. (2003) and Quatman et al. (2006) studied ground reaction forces (GRF) during a landing task and found that the peak GRF happened earlier in pre-pubescent subjects. Also, it was found that with maturation, the peak GRF was lower (Hass et al., 2003; Quatman et al., 2006). Lastly, Swartz et al. (2005) found that the landing patterns of pre-pubescent children increased the risk to injure the ACL than the landing patterns of adults due to the difference in hip flexion and knee abduction at initial contact as well as knee flexion, knee abduction and hip flexion angles at peak vertical GRF. The researchers concluded that with the change in development, adults had a better ability to absorb landings with improved landing mechanics (Swartz et al., 2005).

Unanticipated Side Step Cutting Task

The side step cut has been used widely in research studies because it is sports specific in nature. The side step cut has been performed in many different ways and the two most widely used cutting tasks are the box jump side step cut and the running side step cut (Besier, Lloyd, & Ackland, 2003; Cowley et al., 2006; Dempsey et al., 2009; Ford et al., 2005; Hanson, Padua, Troy Blackburn, Prentice, & Hirth, 2008; McLean et al., 2004; McLean, Huang, et al., 2005; McLean et al., 1999; Pollard et al., 2004; Pollard et al., 2007; Sigward et al., 2007; Sigward & Powers, 2006a, 2006b, 2007). The procedure that McLean et al. (1999) used has been the most widely reproduced. Their procedure required the subject to run at a speed between 5.5 m/s and 7.0 m/s starting five meters behind the force plate before the foot made contact with the force plate. The subjects were told to place their dominant foot on the force plate and cut between 35 and 55 degrees to the opposite side, which was marked with cones, putting the angle of the cut around 45 degrees. An unanticipated side step cut was achieved by giving the subject more than one task to perform and randomly cueing them before the force plate as to which task to perform (Besier et al., 2003; Dempsey et al., 2009; McLean et al., 1999; Pollard et al., 2004). Unanticipated cutting tasks are used because they are said to be representative of more real-life functional movements (Besier et al., 2003).

There have been many studies that have looked at the side step cut to determine the risk it may have on injuries to the ACL. These studies look at anticipated and unanticipated tasks, gender differences, maturational differences, task differences, muscle activation strategies and neuromuscular strategies (Besier et al., 2003; Cowley et al., 2006; Dempsey et al., 2009; Ford et al., 2005; Malinzak et al., 2001; McLean et al., 2004; McLean, Huang, et al., 2005; McLean et al., 1999; McLean, Walker, et al., 2005; Pollard et al., 2004; Pollard et al., 2007; Sigward et al., 2007; Sigward & Powers, 2006b, 2007).

Besier et al. (2003) researched muscle activation strategies and found that in an unanticipated side step cut, the knee muscles were unable to counter external loads placed on it, which increases the risk for ACL injury. Sigward and Powers (2006) also researched muscle activation strategies and found that females had a higher quadriceps activation, which could increase the tendency towards anterior tibial translation. Sigward and Powers (2006) also researched kinetics and kinematics and found a no difference in kinematics but saw increases within females in knee adduction moments and decreases in knee flexion moments when compared to males.

Other researchers have also found differences between genders in regards to kinetics during a side step cutting task. Females have been shown to have increased hip adduction moments and decreased hip extension moments when compared to males (Pollard et al., 2007). In looking at kinematics of the hip and knee, studies have researched and found different conclusions between males and females. Pollard et al. (2007) and McLean et al (2005) both found a decrease in the hip flexion angles in females when compared to males. McLean et al. (2005) found this decrease in conjunction with a decrease in knee flexion angles and an increase in knee abduction angles when comparing females to males. There are also three other studies that have found an increase in the knee abduction angle in females during a side-step cutting task (Ford et al., 2005; Malinzak et al., 2001; McLean et al., 1999) and one other study that found a decrease in knee flexion angles (Malinzak et al., 2001). Pollard et al (2004) also found the females had a decreased hip abduction angle when compared to males during a side step cutting task.

Researchers have also examined the kinetics and kinematics of a side step cut in those athletes who have already exhibited a larger knee valgus moment. These athletes have been shown to have an increased hip abduction angle, hip internal rotation angle, hip flexion angle and knee valgus angle (McLean, Huang, et al., 2005; Sigward & Powers, 2007).

Differentiation of Maturational Phase

Differences in some kinetic and kinematic variables between pre- and post-pubescent subjects exist for knee abduction angle, knee flexion angle, knee extension angle, hip flexion angle, lower extremity valgus angle, hip abduction/adduction moment, knee abduction/adduction moment, knee external/internal rotation moment, knee flexion/extension moment and ankle abduction/adduction moment (Hass et al., 2003; Hewett et al., 2004; Quatman et al., 2006; Sigward et al., 2007; Yu et al., 2005). It is important to identify these risks to better understand who is at risk for non-contact ACL injuries at a young age. The ability to recognize the subject's stage of puberty is important to be able to compare different groups.

Davies (1995) used the Pubertal Maturational Observational Scale (PMOS) to classify subjects into three groups; pre-pubescent, pubescent and post-pubescent. The PMOS scale was created using the Tanner stages of puberty and pre-pubescent males correspond with Tanner's Stage one, pubescent males fall into stages two through four, and post-pubescent males correspond to stage five. The PMOS is a non-invasive procedure to classify subjects into a pubertal group. A series of questions are asked to the subject and depending on the amount of questions the subjects answer yes to determine their pubertal stage. There is a specific checklist of questions associated with each gender. Each characteristic receives one point. If the subject receives zero to one points, they are classified as pre-pubescent, four to five points with an point in the growth spurt question is pubescent and six or more points is classified as post-pubescent. Parents are essential in the accuracy of the PMOS (Davies, 1995). Davies (2000) conducted an inter-rater reliability test and saw 100 percent agreement.

Other common scales used are Tanner's Sexual Maturation Scale (SMS) and the Pubertal Development Scale (PDS) (Marshall & Tanner, 1969, 1970; Peterson, Crockett, Richards, & Boxer, 1988). The SMS scale is not the best tool because it can be considered invasive in response to the observation that must be done by researchers of pubic hair and breast development and the personal questions that must be asked (Bond et al., 2006). The PDS was created using the SMS but instead of the invasive tasks, it is an interview based questionnaire that has been found to be reliable within females but less reliable within males (Peterson et al., 1988).

There have been many biomechanical studies related to researching ACL injuries that have use the PMOS in their differentiation of pubertal status within subjects (Hewett et al., 2004; Jackson, Garrison, Ingersoll, & Hertel, 2009; Quatman et al., 2006; Quatman et al., 2008; Sigward et al., 2007; Sigward, Pollard, & Powers, 2011). These studies range from examining the biomechanics of a side step cutting task and jumping tasks to examine differences in joint laxity, all of which compare between pubertal stages.

Summary

Anterior cruciate ligament injuries are prevalent within the population and with the increase in the number of athletes participating within youth athletics, the number of ACL injuries will continue to escalate. A majority of the literature has focused on the collegiate athlete risk of ACL injury, however further research is indicated for the adolescent population. It is important because, although not one single factor predicts non-contact ACL injuries, the ability to intervene at the right stage in life may greatly impact the incidence of non-contact ACL injuries in high school, college and even in the professional level.

CHAPTER III

METHODOLOGY

Design

A three-dimensional analysis system was used to assess the subjects' lower extremity kinetics and kinematics during an unanticipated side step cutting task. A multivariate analysis of variance (MANOVA) was used to determine the differences in the kinetics and kinematics of the knee and hip between pre-pubescent, pubescent and post-pubescent male lacrosse players. The independent variable of this study was the maturation stage with three levels: pre-pubescent, pubescent, and post-pubescent. Dependent variables included kinetic and kinematic variables. Kinetic variables included knee abduction/adduction moment, knee flexion/extension moment, hip abduction/adduction moment, hip flexion/extension moment during initial contact and the peak within early deceleration and peak vertical and posterior ground reaction forces at peak stance and the peak within early deceleration. Kinematic variables included knee abduction/adduction, knee flexion/extension, hip abduction/adduction and hip flexion/extension angles measured in degrees at initial contact and the peak within the early deceleration phase (20% of stance phase).

Subject Characteristics

Thirty-one male youth lacrosse athletes (age =11.55±1.48 years, height =153.61±13.98 cm, mass =44.73±12.12 kg) from a Hampton Roads Lacrosse Club participated in the study. An a priori power analysis showed that 11 subjects in each group would be required to achieve 80% statistical power with an alpha level of .05 (Hass et al., 2003; Hewett et al., 2004; Sigward et al., 2007; Swartz et al., 2005). Effect sizes were calculated from Hewett et al. (2004) for knee valgus angle at initial contact (d=2.0); Swartz et al. (2005) for knee valgus angle (d=1.1), knee flexion angle (d=0.61), hip flexion angle (d=0.48) and peak vertical ground reaction force (d=1.3); Sigward et al. (2007) for knee valgus moment (d=0.19-1.1) and knee flexion moment (d=0.18-1.02); and Hass et al. (2003) for knee valgus moment (d=3.1), knee flexion moment (d=1.3), knee flexion angle (d=2.4), hip flexion moment (d=1.8), hip adduction moment (d=2.6), hip flexion angle (d=0.14) and peak vertical ground reaction force (d=1.2). All effect sizes were calculated using the means and standard deviations of recorded numbers within the corresponding research studies. Participants were grouped according to their maturation stage of pre-pubescent, pubescent, and post-pubescent. Subjects completed the Pubertal Maturational Observation Scale (PMOS), which corresponds to the Tanner Stages (Davies, 1995; Davies & Rose, 2000). The PMOS scale separates subjects into three maturational groups; pre-pubescent, pubescent and post-pubescent. Pre-pubescent males correspond with Tanner's Stage one, pubescent males fall into stages two through four and post-pubescent males correspond to stage five (Davies & Rose, 2000). Subjects who had any previous lower leg injury in the previous 6 months were excluded from the study. In addition, if the subject had ever sustained a lower extremity surgery, they were excluded form the study. The subject and subject's legal guardian were required to sign an assent and informed consent form, which was approved by Old Dominion University's Institutional Review Board.

Instrumentation

An eight-camera Vicon motion capture system (Vicon Motion Systems Ltd., Oxford England) was used to obtain kinematic data at a sampling rate of 300 Hz. Forty reflective markers were placed on the lower body for calibration with thirty of those being tracking markers. Two Bertec force plates (Model 4060-10, Bertec Corporation, Columbus OH, USA) were used at a sampling rate of 1200 Hz for collecting kinetic and ground reaction force data.

During the unanticipated side step cutting task approach, a wireless Speed Trap II timing system (Brower Timing Systems, Draper UT, USA) was set up one meter before the force plates and in line with the front edge of the force plate to record the approach speed. The minimum approach speed for an accepted trial was set at 2.5 m/s. To cue the unanticipated task, a custom-made, randomization software was use to project an image, as a movement cue, onto the wall in front of the moving subject (Cortes, Blount, Ringleb, & Onate, 2011). The custom-made randomization software was triggered when the subject was two meters from the force plate. The program randomized two images that cued the subject to do one of two movements tasks (sidestep or stop jump).

Testing Procedure

Subjects reported to the Motion Analysis Laboratory wearing spandex shorts and their own athletic shoes for testing. The subjects voluntarily signed the assent form after a researcher read it aloud to them. The subjects and their parents then voluntarily signed the informed consent form and the videography/photography consent form. The subjects, with the help of their parents, were then directed to fill out the demographic and injury history form and the PMOS.

After all written forms were completed the subjects were measured for height (cm) and mass (kg). Reflective markers were then placed on specific bony landmarks. Individual markers were secured with non-toxic contact cement, surgical tape and in the case of the hip markers, a cohesive elastic tape. The marker clusters were secured using pre-wrap, cohesive elastic tape and white athletic tape. Special shoe clusters were created for each foot and secured to the shoes of the subject using white athletic tape. Forty reflective markers were placed on specific landmarks with ten being removed after calibration, creating thirty tracking markers (Appendix 6). A standing static trial and a standing dynamic trial to calculate the hip joint center were used for calibration.

The subjects were then given instructions for the static and dynamic calibration captures. To complete the static calibration trial, the subjects were instructed to stand with their feet in the middle of each force plate with their hands across their chest as still as possible. The dynamic calibration trial consisted of 3 circular hip rotations counterclockwise. To calculate functional hip joint centers the standing trial with circular motion was used (Begon, Monnet, & Lacouture, 2007). After the static and dynamic calibration, ten markers were removed for the dynamic capture.

Verbal and visual instructions were provided regarding how to complete a side step task and a stop jump task. The stop jump task was used to allow for unanticipated movement and was not analyzed within the confines of this study. The side step cutting task instructions were the same for each subject (Appendix 7). The subjects made a cut away from their dominant limb only, which was determined by the limb they kick a ball with. The dominant limb was the plant foot. The plant foot was the foot placed on the force plate and cut away from. White floor tape placed on the floor in front of the force plates in order to channel the subjects to make a cutting maneuver between 35 and 55 degrees (Pollard et al., 2007). Prior to data collection, the participants had five practice trials or until they felt comfortable with the task. For the trials to be accepted, four requirements had to be met: the foot had to make contact within the boundaries of the force plate, the subject had to be traveling above the minimum speed, the appropriate task had to be performed and the subject had to successfully place their second step in between the white tape lines placed on the floor. They had to complete 5 successful trials of each task.

Data Analysis

Kinetic data were normalized across subjects. Moments were normalized to body height (m) and mass (kg), and ground reaction forces were normalized to body weight (N). To process the data, Visual 3D (C-motion, Rockville MD, USA) and Matlab (The Math Works Inc., Natick MA, USA) were used. Visual 3D was used to create a lower limb biomechanical model for each subject. Custom made software created for Matlab was used to reduce kinetic and kinematic data. These data were then exported it into a Microsoft Excel spreadsheet for further data analysis. Case-wise diagnostics were performed to assess data normalcy.

Statistical analysis was completed using SPSS version 16 (SPSS Inc, Chicago IL, USA). A multivariate analysis of variance (MANOVA) was conducted for the dependent variables, which consisted of kinetics and kinematics of the knee and hip in the sagittal and frontal planes. The level of significance was set *a priori* at $p \leq .05$.Tukey post-hoc HSD were utilized to further assess the significant differences between the three levels of maturation. A *post-priori* analysis was completed for the dependent variables of interest through G*power (Faul, Erdfelder, Lang, & Buchner, 2007).

CHAPTER IV

RESULTS

Demographics

There was a statistically significant difference between pubertal levels for height ($p<.0001$; pre-pubertal=137.3±8.8 cm, pubertal=153.6±10.7 cm, post-pubertal=165.6±5.9 cm), mass ($p=.0002$; pre-pubertal=32.7±7.1 kg, pubertal=44.7±10.9 kg, post-pubertal=53.4±8.7 kg) and age ($p<.0001$; pre-pubertal=9.9±1.1 years, pubertal=11.4±0.9 years, post-pubertal=12.9±0.7 years) (Appendix 8). The mean approach speed to the side-step cutting task across all subjects was 3.2±.5 meters/second (Appendix 9).

Initial Contact

At initial contact, there were no statistically significant differences found between any levels of puberty within the dependent variables (Appendix 10).

Peak Stance

There were no statistically significant differences at peak stance between groups for the peak vertical ground reaction force (pre-pubertal= 2.58±0.25 N/BW, CI=2.21-3.08; pubertal= 2.70±0.52 N/BW, CI= 2.38-3.08; post-pubertal= 2.42±0.76 N/BW, CI= 2.05-2.79;$p=0.457$) or peak posterior ground reaction force (pre-pubertal= 0.83±0.19 N/BW, CI= 0.62-1.03; pubertal= 1.00±0.27 N/BW, CI= 0.86-1.20; post-pubertal= 0.87±0.28 N/BW, CI= 0.69-1.04;$p=0.249$).

Early Deceleration

There was a statistically significant difference in the hip extension moment between pre-pubertal and pubertal subjects ($p=.033$) as well as pubertal and post-pubertal subjects ($p=.015$). There was a significant increase in the hip extension from pre-pubescent (-1.85±0.28 Nm/kgm) to pubescent (-2.28±0.40 Nm/kgm) subjects and a significant decrease from pubescent (-2.28±0.40 Nm/kgm) to post-pubescent (-1.84±0.34 Nm/kgm) subjects (Appendix 11).

There were no other statistically significant differences in any other variables between groups (Appendix 12). A post-priori power analysis was completed for all variable of interest within early deceleration (Appendix 13).

CHAPTER V

DISCUSSION AND CONCLUSION

The purpose of this study was to determine if there were lower extremity biomechanical differences between pre-pubescent, pubescent and post-pubescent male lacrosse players during an unanticipated side-step cutting task. We hypothesized that post-pubescent subjects would demonstrate a smaller internal knee adduction moment and internal hip extension moment within the early deceleration phase than pre-pubescent individuals. We also hypothesized that the post-pubescent subjects would have an increased internal knee extension moment and internal hip adduction moment within the early deceleration phase. Our findings do not support the majority of our hypotheses, as there were limited differences found within any of the variables in our study. Our primary finding revealed that maturation levels presented a difference in the internal hip extension moment within the early deceleration phase as initially hypothesized. Specifically, there was an increase in the hip extension moment from pre-pubescent to pubescent subjects and a decrease from pubescent to post-pubescent subjects during the early deceleration phase.

Overall, all three groups used similar movement strategies to successfully perform the side step cutting maneuver. The increased hip extension moment within the pubescent group is of interest, however the increase (.43 Nm/kgm) may not represent a clinically significant change especially when it is proposed that the ACL would have to endure a load of over 2000 N in the sagittal plane to rupture (Woo, Hollis, Adams, Lyon, & Takai, 1991). Pollard et al (2007) suggests that greater hip extension moments may infer that these individuals have a greater ability to engage the hip extensors in order to control the deceleration phase of the cutting maneuver. They found that females had decreased hip extensor moments as compared to males, however their moments were higher than those we reported (3.21 Nm/kgm females, 3.73 Nm/kgm males).

There were no significant differences in any other of the sagittal plane kinetics or kinematics of the knee and hip at initial contact or within early deceleration. Comparison against other studies is difficult because of the minimal research that has been previously done in this area. For example, DiStefano et al. (2011) conducted a study in which they used a sidestep cutting task in youth athletes, yet the movement they chose was different than ours in that it was an anticipated side-step maneuver following a drop from a 30cm box, therefore our values would be expected to be different because our subjects are only contacting the ground with one leg during stance phase while their subjects performed a drop jump first and contacted the force plate with two legs. In addition, Sigward et al. (2007) used very similar methods as we did, but the only published work is in abstract form only. When comparing to adults, the comparison is easier to make because there are many more studies done within that population.

The kinetics of the knee has been shown to have contrasting results throughout the literature. Sigward et al. (2007) found a difference within female youth athletes in the knee flexion moment with larger knee flexor (1.05 and 1.14 vs 0.67 Nm/kgm) and adductor (1.43 and 1.31 vs 0.84 Nm/kgm) moments in pre-pubescent and pubescent females compared to post-pubescent. Our knee flexor moments were smaller, at an average of 0.90 Nm/kgm across maturation phases, suggesting that the values of males may just be lower overall during this unanticipated task, or that our combination of tasks (side-step and stop-jump) may have affected our outcomes. In addition to this finding, it was found in the knee extension moment of adults for this task are very similar to our findings of 1.33 Nm/kgm and 1.38 Nm/kgm, respectively (O'Connor, Monteiro, & Hoelker, 2009). Although our values are similar to O'Connor et al. (2009), they recorded peak values across the entire stance phase while we recorded the peak only within the first 20% of the stance phase. This finding demonstrates an inconsistency within the knee extensor moments throughout maturity and may need further evaluation and research to determine the true change, if any, throughout maturation.

Sagittal plane hip and knee kinematic findings in our study were similar to the findings of others. Our early deceleration phase findings, or lack of findings are similar to those seen within this specific population (Sigward et al., 2007). In addition, our values (57.9°) are also similar, and even slightly larger, when compared to adults (50.1°) (McLean, Walker, et al., 2005; Pollard et al., 2007). It appears as if the hip flexion angle is in a consistently larger flexed position throughout our study as well as others researching many different levels of maturation (children or adults). This may suggest that our subject population has sagittal plane hip kinematics that do not increase their risk for ACL injury. Many theories have been suggested to explain non-contact ACL injuries, one of which is altered patterns in the sagittal plane, specifically a decrease in the flexion angle at the knee or hip (Chappell et al., 2002; DeMorat et al., 2004; Malinzak et al., 2001). It has been suggested that a decrease in the knee and hip flexion angles can increase the risk of a non-contact ACL tear as it places an increased anterior tibial shear force on the ACL because of the increased action of the quadriceps (Pandy & Shelburne, 1997).

These previous findings suggest that the sagittal plane can increase the likelihood of ACL rupture. Discordantly, McLean et al. (2004) reported that sagittal plane biomechanics cannot solely injure the ACL during a side step cut because it does not place a large enough load on the ACL to cause a rupture. The frontal plane was found to be a more detrimental to the ACL according to McLean et al. (2004). Recently, researchers have agreed that the injury is multifactorial in nature, and due to a combination of factors from various planes (e.g., sagittal, frontal, transverse) (Shultz, Schmitz, Nguyen, Chaudhari, et al., 2010).

Our study found no statistically significant differences in the frontal plane at any maturation level within the kinetics and kinematics of the knee and hip at any time instance. Sigward et al. (2007) found a difference within the knee adduction moment when examining the side step cutting task with post-pubescents having a decreased knee adduction moment in early deceleration. They suggested that the decreased moments exhibited by post-pubertal subjects might decrease their chance of injury to the ACL combined with other factors. Our knee adduction moments were similar to their post-pubertal group but the difference in findings may be due to the difference in the population selected, as Sigward et al. (2007) studied female soccer players and we examined male lacrosse players, and it has been well established in the literature that sex maybe a risk factor per se (Shultz, Schmitz, & Nguyen, 2008; Shultz, Schmitz, Nguyen, Chaudhari, et al., 2010). In looking at the frontal plane kinetics of the hip, Pollard et al. (2007) found a difference within the hip adductor moment between male (-.49 Nm/kgm) and female (-1.01 Nm/kgm) adults. While our study results did not find a significant difference between maturation levels, we did not have a gender comparison to examine.

Although this is true, the values across our maturational levels, from pre to post pubescent, were found to be in between (0.73±0.25; 0.67±0.29; 0.80±0.43 Nm/kgm) the values that Pollard et al. (2007) recorded for males and females. In addition, it is important to note the methodological difference between studies as Pollard et al. (2007) used slightly different testing protocols (anticipated versus unanticipated tasks).

In theory, it is believed that frontal plane support is primarily due to passive structures, with the ACL being a secondary passive stabilizer to this movement (Lloyd & Buchanan, 1996). Through examination of the kinematics of the knee, many researchers have found that females, when compared to males, exhibit larger knee abduction angles across the stance phase of a side step cutting task within the post-pubescent and adult populations (Ford et al., 2005; McLean, Walker, et al., 2005; Pollard et al., 2007). We found higher values across maturation phases when compared to the males in the previous mentioned studies, with a slight increase from pre-pubescent to post-pubescent subjects. Hewett et al. (2005) found that an increased knee valgus angle can be a predictor of ACL injury. In examining the kinematics of the hip, Pollard et al. (2004) found that females exhibited significantly less hip abduction than males, yet never reached hip adduction during the side step cutting task. This is interesting because, as Pollard et al. (2004) stated, hip adduction can contribute to increased knee abduction. Our subjects never reached hip adduction, and also exhibited larger hip abduction angles than adults which is a better position for our subjects to be in (McLean, Walker, et al., 2005; Pollard et al., 2004). Although, there was little to be found in the differences between kinetics and kinematics at the knee and hip during a sidestep cutting task, there have been differences seen across maturation phases in the examination of drop jumps in regards to lower extremity biomechanics, but the movement task is not able to be compared to a side step cutting tasks that our subjects completed (Hass et al., 2003; Hass et al., 2005; Sigward et al., 2011; Swartz et al., 2005; Yu et al., 2005).

Limitations

The study was limited in that the population cannot be generalized to all youth sports and cannot be translated to female athletes. The study researched participants without injury and it cannot be assumed that because we found no differences that these individuals are not at risk for ACL injury. The researchers could not control for outside activity of the subjects prior to data collection and there is the possibility that the subjects may have already been fatigued from other physical activity encountered in the same day. Lastly, the subjects completed the tasks empty handed, when normally in the game of lacrosse, the participants hold lacrosse sticks.

Conclusions

Overall, our study did not find significant differences between maturation levels for the side-step cutting task. The only exception was the hip extension moment, yet this study was not cause and effect and therefore the results do not show significant findings for the overall risk of ACL injury. Clinically, this is important to note because it suggests that the increased risk of ACL injuries in male youth lacrosse players may not be due to risky biomechanical changes throughout puberty while performing a side step cutting task.

Although there were minimal differences found within males, future studies should focus on maturation phases within females because of the high incidence of ACL injuries in this population and possibly introduce fatigue into the protocol. Future studies should also strive to make the unanticipated movement as life-like or game-like as possible as this will provide more information about the true biomechanical factors of the lower extremity during play.

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INFORMED CONSENT DOCUMENT

OLD DOMINION UNIVERSITY

PROJECT TITLE: Effects of a 8-week Augmented Feedback Intervention on Lower Extremity Kinematics and Kinetics during Athletic Tasks in Pubescent Athletes

INTRODUCTION

The purpose of this form is to give you information that may affect your decision whether to say YES or NO to your child's participation in this research, and to record the consent of those who say YES. The name of the research project is "Effects of 8-week Augmented Feedback Intervention on Lower Extremity Kinematics and Kinetics during Athletic Tasks in Pubescent Athletes". The data collection will take place in the Motion Analysis Lab, Room 1007, in the Student Recreation Center on the Old Dominion University campus.

RESEARCHERS

Dr. Bonnie Van Lunen, Ph.D., Associate Professor, Responsible Project Investigator
Crystal Sullivan, B.S., Graduate Student, Human Movement Sciences Department
Julie Bamberg, B.S., Graduate Student, Human Movement Sciences Department
Ashley Brawford, B.S., Graduate Student, Human Movement Sciences Department
Eric Greska, M.S., Doctoral Student, Human Movement Sciences Department

DESCRIPTION OF RESEARCH STUDY

There have been numerous studies that have analyzed the high occurrence of anterior cruciate ligament (ACL) tears in non-contact sports. Research has shown that females are at approximately 4-6 times more likely to sustain an ACL injury when compared to males participating in the same activities. Most studies have looked at the knee joint and how it contributes to this type of injury. There is still a lack of knowledge on how these injuries occur in relation to the knee joint. More recently, research has demonstrated that lower limb mechanics begin to decline at about the onset of puberty. Other studies have suggested that various forms of feedback of athletic tasks can improve mechanics on athletic tasks. The purpose of this study is to determine the effects of various forms of feedback on lower limb mechanics during various athletic tasks in adolescent lacrosse and soccer players.

If your child decides to participate, then your child will join a study involving research of different landing techniques that are related to hip, knee and ankle motion patterns and forces during the stop-jump phase. The study data will be collected in a single session. Your child will be asked to repeat the testing sequence after an 8-week period as desired to evaluate the effects of your child's personal exercise program on physical performance. Your child will report to the Motion Analysis Laboratory, wearing spandex shorts and running shoes, as well as a sports bra for females. You and your child will fill out a questionnaire with questions about your child's history of injury and athletics experience. The testing will take approximately two hours to complete.

- Your child will have a 10-minute warm-up period that will consist of cycling and/or self-directed stretching. After the warm-up period and stretching, measurements will be taken to assess your child's body composition, postural control, strength, and functional movement.

Dynamic Sport Specific Tasks

- Sixteen (16) reflective markers will be placed on specific body landmarks and there will be a short period of time to familiarize your child with the athletic tasks. The three athletic tasks that will be performed consist of a drop-jump task, running stop-jump task, and a running side-step cutting task. All athletic tasks will be randomly performed 5 times each. Following the completion of the three tasks, your child will then perform an aerobic capacity assessment test.

Aerobic Capacity Assessment Testing

- Aerobic fatigue capacity: During the maximum aerobic capacity test your child will be fitted with a chest strap heart rate monitor, a facemask and a head support for the collection of the exhaled. Your child will then run on a treadmill that increases in speed and grade every two minutes. Safe guards are in place on the treadmill with a red STOP button and testers will be within arm's reach of your child. Your child will be instructed to continue to run until he/she voluntarily stops. During the treadmill test, your childs heart rate, breathing, distance traveled, and oxygen consumption will be measured. Your child will rest for five minutes followed by 20 minutes of interval jogging and running.
- After completing the 20-minute run, your child will return to the Motion Analysis Laboratory and repeat the drop-jump task, running stop-jump task, and running side-step cutting task.

- Your child will be asked to return 8-weeks later to retest the entire protocol.

The drop-jump task will be videotaped, this will allow the investigator to insure the landing techniques and athletic tasks are performed correctly. If you and your child do not consent to be videotaped, your child will be excluded from the test. If you and your child say YES, then your child's participation will last for approximately 2.5 hours at the Motion Analysis Lab. Subjects will consist of 60 females and 60 males.

EXCLUSIONARY CRITERIA
Your child will be excluded from the study in the case that you and your child do not consent to be videotaped/photographed.

Your child will be excluded from the study if he/she does not meet specific age requirements described in the questionnaire.

Your child will be excluded if he/she has suffered a traumatic lower extremity injury within the past 12 months.

RISKS AND BENEFITS
RISKS: If you decide to participate in this study, then you may face a risk of ankle sprain, knee injury, muscle pain, and muscle soreness. Ankle sprains can be compared as stepping off the curb, muscle pain and muscle soreness can be compared as the same sensation you might have after workout. The researcher tried to reduce these risks by provided clear directions on how to perform each athletic task and landing technique. You could also experience muscle injury, inappropriate changes in blood pressure or heart rhythm, a heart attack, stroke or death during the maximal fatigue exercise tests. The risk of these events is very low in individuals who are physically active and apparently healthy, such as yourself. The risk is likely no greater than what you experience during your normal training. An automated external defibrillator will be in the laboratory during testing, and available for use if needed. Phone access to EMS is available in the testing room. Finally, as with any research, there is some possibility that you may be subject to risks that have not yet been identified.

BENEFITS: The main benefit to you for participating in this study is that you will learn your aerobic capacity, your body fat percentage and other indicators of your fitness. The results of the study may be useful in determining more appropriate training strategies for you and other physically active individuals.

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

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

CONFIDENTIALITY
All information obtained about you in this study is strictly confidential unless disclosure is required by law. The researchers will take reasonable steps to

insure confidentiality is upheld. The researchers will store all questionnaires, videotapes, and laboratory findings in a locked file cabinet prior to and after processing. The results of this study may be used in reports, presentations and publications, but the researcher will not identify you.

WITHDRAWAL PRIVILEGE

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

COMPENSATION FOR ILLNESS AND INJURY

If you say YES, then your consent in this document does not waive any of your legal rights. However, in the event of harm and/or injury arising from this study, neither Old Dominion University nor the researchers are able to give you any money, insurance coverage, free medical care, or any other compensation for such injury. In the event that you suffer injury as a result of participation in this research project, you may contact Dr. Bonnie Van Lunen, at 757-683-3516, Eric Greska, at 757-683-5676, Dr. George Maihafer, the current IRB chair, at 757-683-4520, or the Old Dominion University Office of Research, at 757-683-3460, who will be glad to review the matter with you.

VOLUNTARY CONSENT

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

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

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

Parent/Legal Guardian of Subjects' Printed Name & Signature	**Date**

Subject's Printed Name & Signature	Date

INVESTIGATOR'S STATEMENT

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

Investigator's Printed Name & Signature	Date

ASSENT FORM

Effects of a 8-week Augmented Feedback Intervention on Lower Extremity Kinematics and Kinetics during Athletic Tasks in Pubescent Athletes

My name is Crystal Sullivan. I work at Old Dominion University.

I am asking you to take part in a research study because I am trying to learn more about movement patterns of youth lacrosse and soccer players. I want to see how movement patterns change as you become tired.

If you agree, you will be asked to complete some physical tasks. You will be tested for height, weight, muscle strength, and movement control. You will also be asked to run and make movements as though you were chasing a rolling ball. You will be asked to run on a treadmill for as long as you can, and then run for another 20-minutes. After completing the run, you will be asked to make the movements as though you were chasing a rolling ball again. These tasks will take about 2 hours to complete.

You do not have to be in this study. No one will be mad at you if you decide not to do this study. Even if you start, you can stop later if you want. You may ask questions about the study.

If you decide to be in the study I will not tell anyone else what you say or do in the study. Even if your parents or teachers ask, I will not tell them about what you say or do in the study.

Signing here means that you have read this form or have had it read to you and that you are willing to be in this study.

Signature of subject____

Subject's printed name ____

Signature of investigator____

Date__________________________

INFORMED CONSENT DOCUMENT FOR USE OF PHOTO/VIDEO MATERIALS

STUDY TITLE: Effects of an 8-week Augmented Feedback Intervention on Lower Extremity Kinematics and Kinetics during Athletic Tasks in Pubescent Athletes.

DESCRIPTION:

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

CONFIDENTIALITY:

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

VOLUNTARY CONSENT

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

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

Parent/Legal Guardian of Subjects' Printed Name & Signature	**Date**
Subject's Printed Name & Signature	**Date**
Investigator's Printed Name & Signature	**Date**

DEMOGRAPHICS/HISTORY QUESTIONNAIRE

Age:__________ Gender: Male Female | Weight:___________kg |
Height:________cm

Ethnicity: Hispanic or Latino Not Hispanic or Latino Unknown

Race: American Indian/Alaska Native Asian Native Hawaiian/Other Pacific Islander

Black or African American White More than one race Unknown

Dominant Leg: Left Right
This is the leg in which you would kick a soccer ball as far as possible with

How many years have you been playing soccer?__________

Injuries:
Have you had any ankle sprains? Yes No

If yes, which leg? Right Left Both

If yes, when?_________________________ (month/year)

Have you had an ACL injury? Yes No

If yes, which leg? Right Left Both

If yes, when?_________________________ (month/year)

Have you had any surguries (ankle and/or knee)? Yes No

If yes, which leg? Right Left Both

If yes, when?_________________________ (month/year)

Do you presently have any physical impairment that would limit you from performing a jump-landing task?

Yes No

Have you been exercising at least 30 minutes per day, 3 times per week, for the past 6-months?

Yes No

PUBERTAL MATURATION OBSERVATIONAL SCALE

Female Characteristic Checklist

_____ The adolescent has grown 3 to 3.5 inches in the past 6 months or is past this growth spurt.

_____ The adolescent has begun breast development.

_____ The adolescent has begun menarche.

_____ The adolescent has evidence of darker underarm hair or shaves.

_____ The adolescent has evidence of darker hair on her legs or shaves.

_____ The adolescent's calves are becoming defined.

_____ The adolescent has evidence of acne.

_____ There was evidence of sweating after physical activities.

Male Characteristic Checklist

_____ The adolescent has evidence of darkening of facial hair or shaves.

_____ The adolescent's voice has gotten deeper or is currently breaking.

_____ The adolescent has grown 3 to 4 inches in the past 6 months or is past the growth spurt.

_____ The adolescent has darker hair on his legs.

_____ The adolescent's biceps are becoming defined.

_____ The adolescent's calves are becoming defined.

_____ The adolescent has evidence of acne.

_____ There was evidence of sweating after physical activities.

_____ There is darkened underarm hair.

KEY: + characteristic is present - characteristic is absent

SCORING CRITERIA FOR MALES AND FEMALES

STAGES	NUMBER OF "+"
Prepuberty	1 or less
Midpubertal	4 or 5; growth spurt essential
Postpubertal	at least 6; growth spurt completed

DIFFERENCE IN LOWER EXTREMITY ANGLES AND MOMENTS BETWEEN GENDERS

Table 1. Difference in angles and moments during side step cutting tasks between genders. All numbers represent the difference between males and females. *= increased in females; † = increase in males.

	Knee Abduction Angle	Knee Flexion Angle	Knee Adduction Moment	Knee Flexion Moment	Hip Internal Rotation Angle	Hip Flexion Angle	Hip Adduction Moment	Hip External Rotation Moment
Ford, 2005 and Malinzak, 2001	*11°	†8°						
Sigward and Powers, 2006b			*.44 Nm/BW	*.7 Nm/BW				
Pollard, 2007					*8.7°	†4.7°	*.82 Nm/BW	*1.31 Nm/BW
McLean, 2005			*.21 Nm/BW					

MARKER PLACEMENT

Specific Bony Landmarks

40 Markers for Calibration placed bilaterally on:

Posterior superior iliac spine (PSIS),
Apex of the iliac crests
Greater trochanters
Medial knee joint lines
Lateral knee joint lines
Medial malleoli
Lateral malleoli
Posterior Calcanei
Lateral Calcanei
Base of the 5^{th} metatarsal
Head of the 5^{th} metatarsal
Head of the 2^{nd} metatarsal
A plate with four markers that was placed on the thigh
A plate with four markers that was placed on the shank

30 Markers for dynamic trials that were left in place included (bilateral):

Posterior superior iliac spine (PSIS),
Apex of the iliac crests
Posterior Calcanei
Lateral Calcanei
Base of the 5^{th} metatarsal
Head of the 5^{th} metatarsal
Head of the 2^{nd} metatarsal
A plate with four markers that was placed on the thigh
A plate with four markers that was placed on the shank

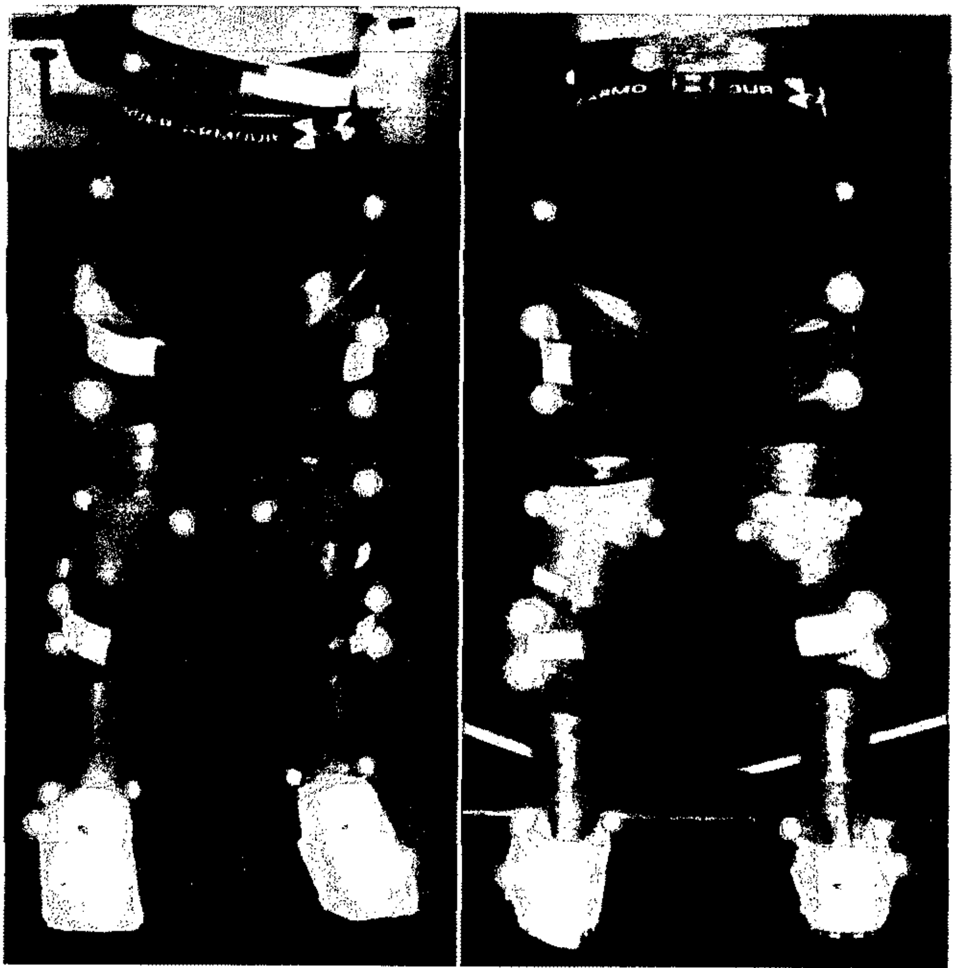

Figure 1. Marker placement for static and dynamic calibration

INSTRUCTIONS TO SUBJECT WHEN PERFORMING MOVEMENT TASKS

1. Calibration:
    a. Dynamic Hula- "Please stand with each foot in the middle of a force place, arms across your chest, look straight forward and move just your hips in 3 circular motions, like a hula-hoop motion, to the left first. "
    b. Static- "Please stand with each foot in the middle of a force plate, arms across your chest and look straight forward."
2. Anticipated Tasks:
    a. Stop-Jump- "You are going to run full speed, land with both feet at the same time in the middle of a force plate and jump straight up as high as you can. You will complete 5 successful trials."
    b. Side-Step- "You are going to run full speed; land with your dominant foot in the middle of the force plate and then step diagonally to your non-dominant side in between the lines placed on the floor in front of you. You will complete 5 successful trials."
3. Unanticipated Tasks:
    a. "You will be performing a combination of stop-jumps and side-step tasks. The projector in front of you will tell you which task to perform when you get within 2 meters of the force plates. The projector will show a blank green screen at the beginning of each trial. Once you pass the 2 meter mark, a big blue arrow pointing you in the direction of the cutting motion will mean a side-step cut is required and a big red stop sign will mean a stop-jump task is required."

GROUP DEMOGRAPHICS

Table 2. Group Demographics.

		Mean±SD
Age	Pre-pubescent (n=8)	9.88±1.13 years
	Pubescent (n=12)	11.42±0.90 years
	Post-pubescent (n=11)	12.91±0.70 years
Height	Pre-pubescent (n=8)	137.25±8.76 cm
	Pubescent (n=12)	153.58±10.73 cm
	Post-pubescent (n=11)	165.55±5.93 cm
Mass	Pre-pubescent (n=8)	32.74±7.12 kg
	Pubescent (n=12)	44.74±10.91 kg
	Post-pubescent (n=11)	53.44±8.71 kg

APPROACH SPEED

Table 3. Approach Speed.

Group	Mean±SD
Pre-pubescent	2.85±0.22 meters/second
Pubescent*	3.36± 0.48 meters/second
Pos-pubescent*	3.35± 0.40 meters/second

* Significantly different from pre-pubescent subjects (p=.018)

DEPENDENT VARIABLES AT INITIAL CONTACT BETWEEN SUBJECT GROUPS

Table 4. Means, Standard Deviations and Confidence Intervals (CI) of each dependent variable at IC for each group with corresponding significance level and power for each variable. Moments are measured in Nm/kgm and angles are measured in degrees.

		Mean±SD	CI (Lower-Upper)	Significance
Knee Flexion(-)/Extension(+) Moment	Pre-Pubescent	0.22±0.24	0.09–0.36	0.503
	Pubescent	0.29±0.19	0.18–0.41	
	Post-Pubescent	0.20±0.16	0.08–0.32	
Knee Adduction(+)/Abduction(-) Moment	Pre-Pubescent	0.04±0.08	-0.05–0.12	0.431
	Pubescent	0.10±0.09	0.04–0.17	
	Post-Pubescent	0.09±0.16	0.02–0.17	
Hip Flexion(+)/Extension(-) Moment	Pre-Pubescent	0.42±0.45	0.20–0.64	0.736
	Pubescent	0.51±0.26	0.33–0.69	
	Post-Pubescent	0.43±0.20	0.24–0.62	
Hip Adduction(+)/Abduction(-) Moment	Pre-Pubescent	-0.06±0.14	-0.21–0.09	0.723
	Pubescent	0.01±0.22	-0.11–0.13	
	Post-Pubescent	-0.03±0.22	-0.16–0.10	
Knee Flexion Angle	Pre-Pubescent	-24.15±5.80	-29.82–-18.48	0.356
	Pubescent	-27.84±7.38	-32.47–-23.21	
	Post-Pubescent	-25.28±7.85	-28.15–-18.48	

Continued from Table 4.

		Mean±SD	CI (Lower-Upper)	Significance
Knee Abduction Angle	Pre-Pubescent	-1.83±2.09	-4.31–0.66	0.236
	Pubescent	-4.30±3.53	-6.32–-2.27	
	Post-Pubescent	-4.26±4.00	-6.37–-2.14	
Hip Flexion Angle	Pre-Pubescent	57.27±16.39	44.85–69.69	0.234
	Pubescent	62.53±15.05	52.39–72.67	
	Post-Pubescent	50.03±19.65	39.44–60.62	
Hip Adduction Angle	Pre-Pubescent	-13.97±4.12	-17.53–-10.42	0.797
	Pubescent	-13.71±5.66	-16.62–-10.81	
	Post-Pubescent	-15.04±4.78	-18.07–-12.01	

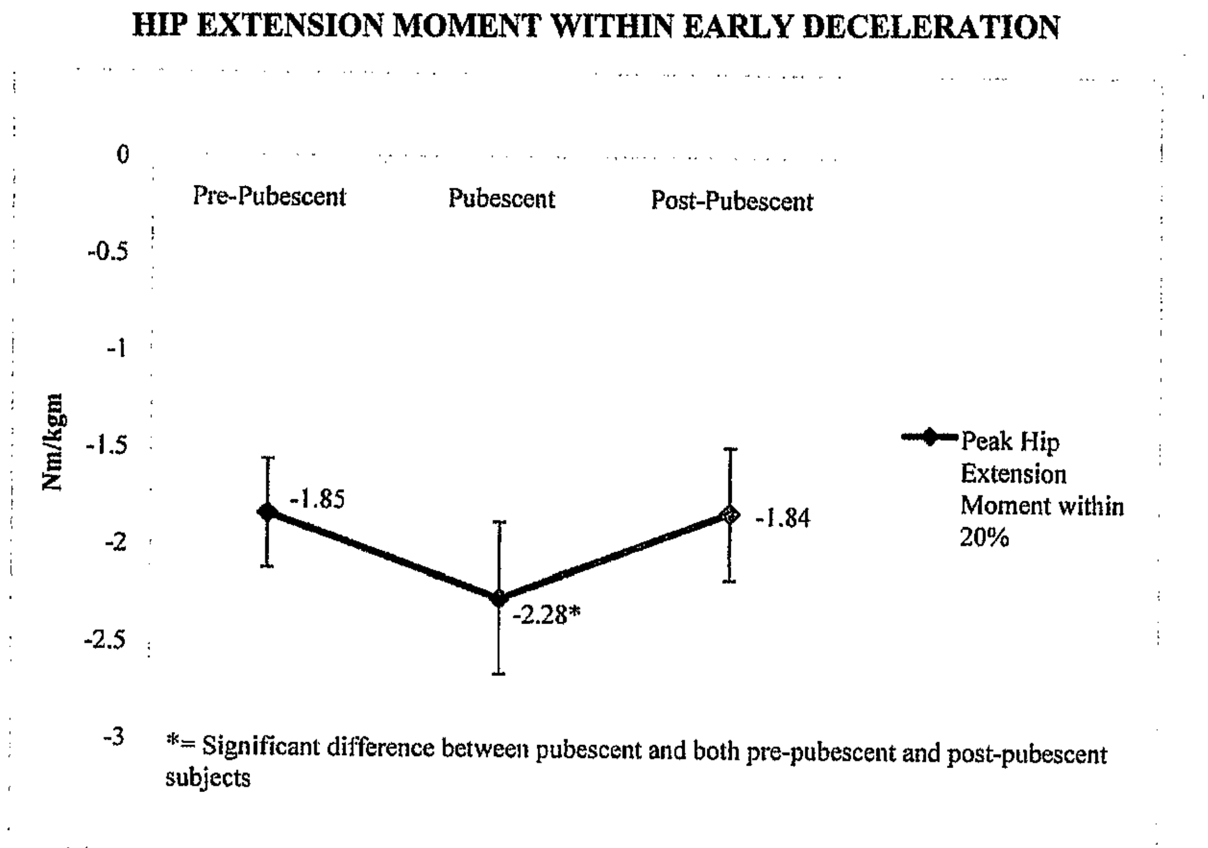

Figure 2. Peak hip extension moment within the first 20% of the stance phase (early deceleration). Significant difference found between pre-pubescent and pubescent as well at post-pubescent and pubescent

DEPENDENT VARIABLES WITHIN EARLY DECELERATION BETWEEN SUBJECT GROUPS

Table 5. Means, Standard Deviations (SD) and 95% Confidence Intervals of each dependent variable within early deceleration for each group with corresponding significance level and power for each variable. Moments are measured in Nm/kgm, angles in degrees and GRFs in N/BW.

		Mean±SD	CI (Lower-Upper)	Significance
Knee Flexion Moment	Pre-Pubescent	-0.08±0.17	-0.22–0.05	0.608
	Pubescent	-0.07±0.17	-0.18–0.04	
	Post-Pubescent	-0.004±0.16	-0.12–0.11	
Knee Extension Moment	Pre-Pubescent	1.36±0.27	1.12–1.60	0.714
	Pubescent	1.45±0.31	1.25–1.64	
	Post-Pubescent	1.34±0.38	1.14–1.55	
Knee Abduction Moment	Pre-Pubescent	-0.20±0.07	-0.31–-0.08	0.223
	Pubescent	-0.25±0.21	-0.35–-0.15	
	Post-Pubescent	-0.13±0.15	-0.23–-0.03	
Knee Adduction Moment	Pre-Pubescent	0.60±0.23	0.38–0.82	0.554
	Pubescent	0.61±0.33	0.43–0.78	
	Post-Pubescent	0.73±0.31	0.54–0.91	
Hip Flexion Moment	Pre-Pubescent	1.11±.050	0.71–1.51	0.558
	Pubescent	1.23±0.65	0.90–1.56	
	Post-Pubescent	0.97±0.48	0.63–1.32	

Continued from Table 5.

		Mean±SD	CI (Lower-Upper)	Significance
Hip Extension Moment*	Pre-Pubescent	-1.85±0.28	-2.11--1.60	0.009
	Pubescent	-2.28±0.39	-2.48--2.10	
	Post-Pubescent	-1.84±0.34	-2.05--1.62	
Hip Abduction Moment	Pre-Pubescent	-0.44±0.37	-0.66--0.23	0.952
	Pubescent	-0.45±0.28	-0.63--0.28	
	Post-Pubescent	-0.41±0.26	-0.60--0.23	
Hip Adduction Moment	Pre-Pubescent	0.73±0.25	0.48-0.97	0.656
	Pubescent	0.67±0.29	0.47-0.87	
	Post-Pubescent	0.80±0.43	0.59-1.01	
Knee Flexion Angle	Pre-Pubescent	-40.85±5.31	-46.03--35.66	0.507
	Pubescent	-41.01±6.09	-45.24--36.77	
	Post-Pubescent	-42.20±9.11	-46.62--37.77	
Knee Abduction Angle	Pre-Pubescent	-2.94±2.44	-5.93-0.05	0.177
	Pubescent	-5.26±4.02	-7.70--2.83	
	Post-Pubescent	-6.62±5.08	-9.17--4.07	

Continued from Table 5.

		Mean±SD	CI (Lower-Upper)	Significance
Hip Flexion Angle	Pre-Pubescent	58.04±16.44	45.76–70.31	0.298
	Pubescent	63.49±14.98	53.46–73.51	
	Post-Pubescent	52.23±19.20	41.76–62.70	
Hip Abduction Angle	Pre-Pubescent	-16.55±4.71	-20.48–-12.63	0.919
	Pubescent	-15.69±6.71	-18.90–-12.49	
	Post-Pubescent	-16.49±4.12	-19.81–-13.14	
Peak Vertical Ground Reaction Force	Pre-Pubescent	2.54±0.30	2.20–2.87	0.752
	Pubescent	2.66±0.54	2.39–2.93	
	Post-Pubescent	2.52±0.45	2.24–2.81	
Peak Posterior Ground Reaction Force	Pre-Pubescent	0.80±0.18	0.62–0.98	0.369
	Pubescent	0.97±0.30	0.82–1.11	
	Post-Pubescent	0.89±0.23	0.74–1.05	

* Found to be statistically significant between groups

POST-POWER ANALYSIS

Table 6. Post-Power Analysis on Dependent Variable of Interest with corresponding effect sizes

Dependent Variable @ Early Deceleration	Effect Size	Power
Knee Adduction Moment	.18	.21
Knee Extension Moment	.13	.13
Hip Adduction Moment	.13	.13
Hip Extension Moment	.54	.96
Knee Adduction Angle	.28	.45
Knee Flexion Angle	.07	.07
Hip Abduction Angle	.06	.07

VITA

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