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Dynamic Knee Hyperextension Screening as a Predictor of Acl Injury Potential in Competitive High School Soccer Players

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DYNAMIC KNEE HYPEREXTENSION SCREENING

AS A PREDICTOR OF ACL INJURY POTENTIAL

IN COMPETITIVE HIGH SCHOOL SOCCER PLAYERS

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ABSTRACT

Introduction: Young, active populations who play sports that include sudden cutting motions, are at heightened risk of injury to the anterior cruciate ligament (ACL). Female athletes with increased joint laxity and subsequent hyperextension of the knee, are at greatest risk of ACL injury when compared to males.

Purpose: The purpose of this retrospective study was to explore the incidence of dynamic knee hyperextension in high school soccer athletes by sex and team level, as observed through high-speed photography. This could lead to a potentially practicable screening tool for identifying high school soccer athletes at increased risk of ACL injury.

Methods: Dynamic knee extension of 87 male (n=41) and female (n=46) high school soccer athletes was captured using high-speed photography while punting a soccer ball. One photo demonstrating each athlete's maximal knee extension was assessed for degree of extension, both visually and using Kinovea, a motion analysis software program.

Results: Multinomial logistic regression regarding certainty of hyperextension with a 5-point scale by two judges showed no significant differences by sex of the player (p=.456) or team level (p=.064). Results of binary logistic regression on the presence or absence of observed hyperextension showed no significant differences by sex of the players (p=.702) or by team level (p=.191). Results of categorical data analysis showed no significant differences among six player groups consisting of freshman, junior varsity, and varsity levels for both boys and girls (chi-square=3.928, p=.560). Interestingly, there was an increased incidence of hyperextension in younger athletes. The incidence of

hyperextension among all participants of this study is not congruent with published ACL injury surveillance, confirming the multifactorial nature of ACL injuries.

Conclusion: The results indicate that with a larger sample size, a difference between team levels may emerge. Based on the agreement between visual analyzers and Kinovea measurement, visual observation of active hyperextension could potentially serve as a screening tool for ACL injury potential. More research is needed to identify the relationship between observed dynamic knee hyperextension and ACL injury.

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Chapter 1: Introduction

Background to the Problem

High school athletes who suffer anterior cruciate ligament (ACL) injuries often miss entire sport season(s) and may face lost scholarship opportunities. When considering the cost of imaging, surgery, and rehabilitation, the monetary impact of ACL injuries is over two billion dollars annually in the United States (Silvers & Mandelbaum, 2007). Thus, ACL injuries are not only costly to the healthcare industry, but also impact the individual's health, future opportunities in sport, occupational opportunity, and personal finances.

Because ACL injuries are economically costly sports injuries, they continue to be the subject of a pool of epidemiological studies. According to Joseph et al. (2013), the incidence of ACL injuries is approximately 6.5 injuries per 100,000 athlete-exposures, with an athlete-exposure defined as one athlete participating in one practice or competition. In the study by Joseph et al. (2013), certified athletic trainers from 100 U.S. high schools reported 617 ACL injuries sustained over the course of 9,452,180 athlete-exposures across nine different sports during the 2007/08-2011/12 academic years. Comparatively, approximately 250,000 ACL total injuries occur every year in the United States (Silvers & Mandelbaum, 2007). The incidence of ACL injuries - while low in overall incidence - is devastating at the individual level, and can have life-long implications to overall health and wellness.

Specific to ACL injury rates among young athletes, much research has been dedicated to the mechanisms behind such injuries. Anterior cruciate ligament injuries can be classified in one of two ways: contact (those that involve collision) or non-contact (usually involving a cutting or twisting mechanism). Research consensus approximates that 70% of ACL injuries are non-contact in nature (Boden, Dean, Feagin, & Garrett, 2000; Hewett, Myer, & Ford, 2006; McNair, Marshall, & Matheson, 1990). The most common cause of non-contact ACL injury in athletes appears to be rapid deceleration of the knee followed by a sudden change in direction (Alentorn-Geli et al., 2009). Fortunately, previous research suggests that the occurrence of non-contact ACL injuries can be reduced with specific training protocols (Agel & Klossner, 2014; Myklebust et al., 2003). On the other hand, contact injuries cannot be prevented with interventions and thus are of little interest to researchers (Agel & Klossner, 2014).

Female athletes suffer ACL injuries at a rate two to ten times that of male athletes (Arendt & Dick, 1995; Silvers & Mandelbaum, 2007). According to the 2015 survey of high school athletics (2015), the National Federation of State High School Associations reports that female sport participation has been increasing every year for the past 25 years, which puts an increasing number of female athletes at risk for ACL injury. Several researched explanations for the sex disparity of ACL injury risk include anatomical differences such as joint laxity, hormones, biomechanics, and neuromuscular control (Belanger, Burt, Callaghan, Clifton, & Gleberzon, 2013; Chandrashekar, Mansouri, Slauterbeck, & Hashemi, 2006; Hewett, Myer, & Ford, 2005; Schmitz et al., 2008; Shambaugh, Kein, & Herbert, 1991; Simon, Everhart, Nagaraja, & Chaudhari, 2010; Söderman, Alfredson, Pietilä, & Werner, 2001). Not surprisingly, current research consensus suggests that mechanisms leading to increased non-contact ACL injuries in females compared to males are most likely multifaceted (Alentorn-Geli et al., 2009; Griffin et al., 2006; Hewett et al., 2006).

In their 2007 study, Fernandez, Yard, and Comstock suggested that soccer athletes face an increased risk of lower-extremity injuries, including ACL injury, when compared to other sports. In a high school sports-related injury surveillance study, the injury rate for females was higher in soccer than that of any other sport (Fernandez et al., 2007). Similarly, the injury rate for males in soccer was second only to football (Fernandez et al., 2007). The frequent changes in speed and direction due to the nature of the sport puts soccer athletes at high risk of ACL injury.

In a study of female athletes, Myklebust and colleagues (2003) found that preventative measures such as neuromuscular training and the promotion of safer movement patterns, such as lowering the body's center of mass while turning and cutting, appears to reduce the risk of ACL injuries. This study and others like it suggest that instituting preventive training measures may reduce the incidence of traumatic ACL injuries in male and female athletes, an action which most coaches would be able to implement (Agel & Klossner, 2014; Myklebust et al., 2003). In summary, methods of preventing non-contact ACL injuries have been identified, but easily implemented methods for recognizing the athletes at greatest risk of ACL injuries who should undergo such preventive measures continues to be elusive.

One risk factor of interest in identifying athletes at greatest risk of both traumatic lower leg injuries, as well as ACL injury specifically, is generalized joint laxity and corresponding knee hyperextension (Söderman et al., 2001). Specifically, it is noted that female athletes have greater generalized joint laxity than males (Boden et al., 2000). Females who demonstrate greater levels of joint laxity (≥1 SD above the mean) have a 2.7 times higher risk of non-contact ACL injury compared to other females, as reported by Uhorchak et al. in 2003. According to Schultz et al. (2015), the effect of a greater degree of joint laxity for competitive, young adult athletes is higher risk landing mechanics. Furthermore, joint laxity also results in knee hyperextension and increased valgus knee motion (Hewett et al., 2005). A study by Ramesh, Von Arx, Azzopardi, and Schranz (2005) found that ACL reconstruction patients (those who had suffered an ACL tear) had greater joint laxity and thus, knee hyperextension. In fact, hyperextension of the knee is associated with a fivefold increase in the risk of ACL injury (Myer, Ford, Paterno, Nick, & Hewett, 2008a). It follows that screening for knee hyperextension, as an indicator of joint laxity, may be a novel method to assess young athletes for noncontact ACL injury potential.

Problem Statement

Since ACL injuries are known to occur among high school soccer athletes, it is potentially beneficial to identify which athletes are at the greatest risk of ACL injury. A screening method that could affordably be implemented by high school coaches could inform them as to which athletes may be at heightened risk of ACL injury and thus, candidates for prophylactic injury prevention training. Existing screening focuses on range of motion measurements during deceleration-related movements and requires meticulous use of expensive equipment. Unfortunately, these current screening methods for ACL injury risk are prohibitively expensive for most athletic programs, and therefore, the average coach does not have the means to screen their athletes for risk of ACL injury. Herein lies the need for a simple and effective screening test to identify knee hyperextension in the field, which may ultimately help reduce the incidence of ACL injuries.

Purpose

The purpose of this retrospective study is to explore the prevalence of dynamic knee hyperextension in high school soccer athletes while comparing this prevalence between sex and team level. This could lead to a potential cost-effective and easily employed screening tool for identifying high school soccer athletes at increased risk of ACL injury.

Research Questions

The aim of this study focused on hyperextension and ACL injury was to answer the following research questions in the sample used in the present study:

1. What is the incidence of knee hyperextension in male and female competitive high school soccer athletes during a soccer punt?
2. What is the difference in incidence of knee hyperextension during a soccer punt between males and females?
3. How does the incidence of hyperextension between male and female competitive high school soccer athletes, as viewed via high-speed photography during a soccer punt, correspond to the published rate of ACL injuries as published by Joseph et al. (2013) and Swensen et al. (2013)?

4. Is observable knee hyperextension utilizing high-speed photography during a soccer punt a viable screening method for ACL injury risk?

Significance of the Study

Anterior cruciate ligament injuries are predominant among young and active populations. Following an ACL tear, most young and active patients require surgical reconstruction (Papadakis, McPhee, & Rabow, 2015). The cost for surgical repair and physical rehabilitation following a torn ACL ranges from $17,000 to $25,000 (Hewett et al., 2005). In addition to the cost, recovery from surgery generally requires at least 6 months' time away from sport and includes the potential sequela of osteoarthritis post-reconstruction (Papadakis, McPhee, & Rabow, 2015; Lohmander, Östenberg, Englund, & Roos, 1996). In addition to majorly affecting the individual’s physical state, the long recovery time can cause athletes to miss entire seasons of their respective sports. Due to missed playing time and risk of recurrence, scholarships and professional athletic opportunities may be affected as well. The aforementioned drawbacks following ACL injury have led to research aimed at screening and prevention for those at risk of ACL injury.

Definitions of Terms

The terms used for the purposes of this study are defined as below.

- Contact ACL injury: ACL injury that occurs in the presence of player-to-player contact or contact with a fixed piece of equipment, such as a goal post.
- Dynamic knee extension: movements of the knee joint without outside assistance to the participant's musculature and synonymous with active range of motion.

- Non-contact ACL injury: ACL injury that occurs in the absence of player-to-player contact or contact with a fixed piece of equipment.
- High knee abduction moment: abnormal valgus motion of the knee joint during the impact phase of a jump-landing task (Hewett et al., 2005).
- Hyperextension: joint extension which exceeds the normal range of motion (Marieb, Willhelm, & Mallatt, 2010, p. 124). The mean values for normal range of motion at the knee, as defined by the collaborative research of the CDC and Haemophilia Treatment Center Network, for nine to nineteen year-old females and males is 2.4 degrees and 1.8 degrees, respectively (Soucie et al., 2011).
- Punt: to kick (as a football or soccer ball) with the top of the foot before the ball which is dropped from the hands hits the ground (Merriam-Webster's online dictionary, n.d.).

Chapter 2: Literature Review

Introduction

Approximately 250,000 anterior cruciate ligament injuries occur annually in the United States (Silvers & Mandelbaum, 2007). In an effort to reduce the occurrence of ACL injuries, researchers have investigated the mechanisms of ACL injury - which include intrinsic and extrinsic risk factors - that may place females at higher risk of an injury to the ACL (Agel, Arendt, & Bershadsky, 2005; Östenberg & Roos, 2005; Rozzi, Lephart, Gear, & Fu, 1999). As the number of females participating in athletics continues to rise, there is a growing need to better understand the mechanism of ACL injury and to optimize prevention strategies due to the heightened risk for female athletes (Alentorn-Geli et al., 2009; National Federation of State High School Associations, 2015). This chapter focuses on ACL injury rates, the disparity of occurrence between males and females, sex differences that may contribute to the increased risk of females, mechanisms of injury, risk factors such as joint laxity and knee hyperextension, and existing ACL injury screening protocols.

Anterior Cruciate Ligament Injury Rates

Research suggests that the rate of ACL tears vary by sex and sport (Agel et al., 2005; Alentorn-Geli et al., 2009; Boden, Sheehan, Torg, & Hewett, 2010; Silvers & Mandelbaum, 2007). Specifically, female athletes have an ACL injury rate four to six times greater than male athletes during the same sports that involve sudden cutting movements (Arendt & Dick, 1995; Myklebust et al., 2003). Among soccer players, a meta-analysis revealed a female-male incidence ratio of 2.67 (Prodromos, Han, Rogowski, Joyce, & Shi, 2007). In an analysis of 11,754,568 exposures, with each exposure defined as either a soccer practice or a game, the ACL tear rate at the collegiate level was 0.32 and 0.12 per 1,000 exposures for females and males, respectively (Prodromos et al., 2007). A 13-year review of ACL injuries occurring in basketball and soccer at the National Collegiate Athletic Association (NCAA) level revealed that 586 of the 1,268 total reported ACL injuries occurred in soccer (Agel et al., 2005). Of the 586 soccer-related ACL injuries, 394 (nearly 70%) were sustained by females (Agel et al., 2005).

Specific to high school soccer players, Joseph et al. (2013) conducted an epidemiologic comparison of ACL injuries by sex during the 2007/08-2011/12 academic years. One-hundred high schools across the United States were selected at random to achieve a nationally representative sample based on U.S. census geographic region and size. Nationally certified high school athletic trainers (AT) utilized the High School Reporting Information Online (RIO) program to report injury and exposure data to the aptly named National High School Sports-Related Injury Surveillance Study (Joseph et al., 2013). Athletic trainers were instructed to report only injuries that 1) occurred during an organized game or practice, 2) required physician or AT attention, and 3) resulted in at least one day away from sport.

Over the four-year span of the study, male high school soccer players sustained 44 ACL injuries in 914,551 athlete-exposures (AEs), yielding an ACL injury rate of 4.8 per 100,000 AEs. Female high school soccer players suffered 96 ACL injuries in 786,293 AEs, for an ACL injury rate of 12.2 per 100,000 AEs.

In a nearly identical study, the epidemiology of knee injuries among US high school athletes was investigated (Swensen et al., 2013). Again, ATs from 100 high schools nationwide reported knee injuries via RIO over a five-year period (Swensen et al., 2013). Similar to the findings of Joseph et al., male and female high school soccer players injured their ACLs at rates of 5 and 11.7 per 100,000 AEs, respectively (Swensen et al., 2013).

All ATs also reported data on mechanism of injury, categorized as player-player contact, player-playing surface contact, player-playing apparatus contact (ball or goalpost), no contact (rotation around a planted foot), or other. Mechanism of injury data is critical to the development of targeted injury prevention programs.

It is important to note, however, that ACL injury in high schoolers is not primarily a female-dominated problem. The distinction is that the ACL injury rate of females is higher only when analyses are limited to sex-comparable sports, like soccer. In fact, the overall occurrences of ACL injuries are similar between male and female high school athletes when sports such as football are included (Joseph et al., 2013). Finally, at all levels of high school and college play, in sex comparable sports, females have a higher ACL injury rate than their male counterparts and this increased risk does not statistically change with competition level (Beynnon, Vacek, Newell, Tourville, Smith, Shultz, Slauterbeck & Johnson, 2014).

Mechanisms of Injury and Risk Factors

Based on a comprehensive review by Hewett et al. (2006), many factors, both intrinsic and extrinsic, may be attributed to non-contact ACL injury. Extrinsic factors are typically environmental in nature, whereas intrinsic factors are divided into anatomical, hormonal, neuromuscular, biomechanical, and familial components (Hewett et al., 2006). According to several meta-analyses, a single risk factor of non-contact ACL injuries is unlikely to be isolated because the etiology of such injuries is multifactorial, involving both the extrinsic and potentially several of the intrinsic components mentioned above (Alentorn-Geli et al., 2009; Griffin et al., 2006).

Generalized Joint Laxity and Knee Hyperextension.

Of the many intrinsic factors contributing to ACL injuries, generalized joint laxity (and subsequent knee hyperextension) is thought to be one of the most influential factors (Myer et al., 2008a; Söderman et al., 2001; Uhorchak et al., 2003). Although the mechanism of ACL injury is not completely understood or agreed upon, joint laxity, as demonstrated by hyperextension of the knee is thought to play a key role.

Determining specific risk factors for ACL injury necessitates a large-scale study looking at many potential variables. Beginning in 1995, Uhorchak et al. (2003) followed 859 cadets from their entry into the United States Military Academy (USMA) and throughout their 4-year attendance at West Point. At the beginning of the study period, a broad range of data was collected for each participant in an effort to examine many of the potential risk factors for ACL injury, including body mass index (BMI), knee stability, generalized joint laxity, knee laxity, joint range of motion and flexibility, and strength of the knee extensors and flexors (Uhorchak et al., 2003). Radiographs were also obtained to assess tibial width, eminence width (estimating ACL diameter), condylar width of the femur, and femoral notch width. A high level of control was maintained throughout the study due to the similar activities and lifestyle at the military academy. Each cadet's amount and type of physical activity was recorded, including sport participation, and every subsequent injury (Uhorchak et al., 2003). Of the 859 (739 men, 120 women) qualifying cadets, 21 males and eight females sustained a Grade 3 ACL tear. All female ACL tears were non-contact in nature, and 14 of the 21 male ACL injuries were non-contact injuries (Uhorchak et al., 2003). Therefore, the incidence of ACL injury in the females was 6.6%, and 2.1% in males, approximately a 3:1 female to male ratio (Uhorchak et al., 2003).

After identifying the ACL-injured individuals, statistical analysis revealed that the following factors were most predictive of non-contact ACL injuries for both males and females, though with low sensitivity: narrow femoral notch width, higher than average BMI, generalized joint laxity, and knee laxity at 134 Newtons of pull over one standard deviation (SD) above the mean (Uhorchak et al., 2003). Perhaps most important were the risk factors identified for female participants, which included narrow femoral notch width, higher than average BMI, and generalized joint laxity (Uhorchak et al., 2003). These risk factors in female participants were highly sensitive and specific, predicted 75% of the non-contact ACL injuries, and had a mean predictive value of 98% (Uhorchak et al., 2003). Further, the females with greater knee joint laxity measured one SD or more above the mean by knee arthrometer testing were found to be at a risk of non-contact ACL tear 2.7 times greater than females with less knee joint laxity (Uhorchak et al., 2003). Specific to females, knee laxity and above-average BMI were found to be significant factors of non-contact ACL injury (Uhorchak et al., 2003). Therefore, according to this study, generalized joint laxity and knee laxity specifically held predictive value for subsequent non-contact ACL tear across the sexes (Uhorchak et al., 2003).

A study by Östenberg and Roos (2000) demonstrated that generalized joint laxity could be used as both a predictive factor and risk factor of ACL injury in soccer. Östenberg and Roos (2000) selected 123 players of skill levels ranging from non-elite to professional elite to represent five club teams in Sweden. Physical characteristics (such as age, weight, height, years of soccer experience, and BMI), generalized joint laxity, functional performance, aerobic capacity, and isokinetic muscle strength were measured during the pre-season, then analyzed alongside the injury data after the season (Östenberg & Roos, 2000). In total, 47 athletes sustained 65 injuries throughout the season, with most (n =17) injuries localized to the knee (Östenberg & Roos, 2000). Of the 17 knee injuries sustained during the season, three were ACL injuries (Östenberg & Roos, 2000). Between the injured and non-injured group, the researchers found the injured group to have significantly increased general joint laxity (p=.001), and further analysis revealed that the injured group demonstrated increased knee hypermobility (p=.05; Östenberg & Roos, 2000). Overall, generalized joint laxity was found to be a significant predictor of knee injury (OR=5.0, CI 95% 1.3-18.9; Östenberg & Roos, 2000). Östenberg and Roos (2000) suggest that general joint laxity, and potentially knee hypermobility, may be significant sources for injury risk profiles in female soccer athletes.

In an investigation focused on passive knee joint laxity, 1,558 female soccer and basketball players in both high school and collegiate levels were screened prior to sports participation between the years 2002 and 2006 (Myer et al., 2008a). Of these athletes, 15 injured their ACL while playing soccer and four occurred during basketball. Screening prior to injury included assessment of general ligament laxity and knee laxity, measured by anterior-posterior tibiofemoral translation (Myer et al., 2008a). After confirmation of complete ACL rupture by arthroscopic surgery or MRI, the injured participants were control-matched with four participants of nearest height and mass, for a total of 76 control participants for the 19 cases of ACL injury (Myer et al., 2008a). Therefore, the total case control participant number was 95. The researchers found that 47% of the athletes that tested positive for knee hyperextension subsequently injured their ACL (Myer et al., 2008a). Similarly, the risk of ACL injury was increased 5-fold in athletes with positive knee hyperextension (95% CI; Myer et al., 2008a). Therefore, passive knee hyperextension was found to be predictive of ACL injury, making it a potential measure for assessing ACL injury risk. Additionally, results indicate that passive knee joint laxity is important for knee stabilization and restraint to protect against joint injury. The study also calls for the need to determine the relationship between active and passive knee stability and the related ACL injury risk (Myer et al., 2008a).

In a study based on soccer players, Söderman et al. (2001) prospectively analyzed the risk factors for leg injuries in a total of 146 Swedish female soccer players. Specifically, the variables studied for possible significance in risk assessment were generalized joint laxity, laxity of the knee and ankle joints, age, anatomical alignment, muscle flexibility, thigh muscle torque, postural sway of the legs, recent injury, and duration of soccer exposure (Söderman et al., 2001). Overall, of the five ACL injuries that occurred during the season, two players displayed knee hyperextension, though none had generalized joint laxity according to the definition established in the study (Söderman et al., 2001). The results indicated that, when studied separately, knee hyperextension itself was found to be a significant risk factor for traumatic leg injury (Odds Ratio=2.50, p=.03; Söderman et al., 2001). A major limitation in this research is that there were not enough athletes who sustained an ACL injury to analyze with statistical power. Therefore, a larger sample size of ACL-injured athletes would be necessary to obtain more information about specific risk factors and mechanisms of ACL injury (Söderman et al., 2001).

Based on the above studies, there is strong evidence to suggest that passive knee hyperextension is a significant risk factor for ACL injury. Further, Ramesh et al. (2005) reported, "We have found sufficient evidence in the literature to suggest the final pathway of a non-contact ACL rupture could be hyperextension of the knee" (p. 802). Therefore, future research should investigate whether dynamic versus passive knee hyperextension is also a significant risk factor for ACL injury, and how dynamic hyperextension can be used to identify ACL injury risk.

Female Differences

Many potential explanations exist for the greater incidence of ACL injuries among female athletes. These explanations include excessive knee abduction, increased laxity of joints leading to increased knee hyperextension, higher estrogen and relaxin levels; and increased posterior tibial slope, intercondylar notch width, and ACL cross-sectional area (Belanger et al., 2013; Chandrashekar et al., 2006; Hewett et al., 2005; Ramesh et al., 2005; Simon et al., 2010; Söderman et al., 2001; Uhorchak et al., 2003).

Knee abduction following the landing of a jump is associated with ACL injury risk in young female athletes (Alentorn-Geli et al., 2009; Hewett et al., 2005). In a study of over 200 female soccer athletes, a high knee abduction moment, defined as an abnormal valgus motion of the knee joint during the impact phase of a jump-landing task, demonstrated 78% sensitivity and 73% specificity for ACL rupture (Hewett et al., 2005). A high knee abduction moment is believed to cause ACL injury via a valgus torque on the knee that increases anterior tibial translation and tensile load on the ACL several fold (Fukuda et al., 2003).

As previously mentioned, generalized joint laxity has been demonstrated to be a risk factor for traumatic lower leg injuries (Söderman et al., 2001). More specifically, Schmitz et al. (2008) found that females have greater knee joint laxity than males. Females with a greater degree of joint laxity have a 2.7 times higher risk of ACL injury than females with less joint laxity (Uhorchak et al., 2003). Greater joint laxity allows for greater extension of the knee, and possible hyperextension which is associated with an increased risk of ACL injury (Ramesh et al., 2005).

Similar to joint laxity, higher estrogen and relaxin levels may increase the incidence of ACL injuries in females. Greater estrogen levels reduce ACL ligament strength by binding to receptors on the ACL and inhibiting a collagen formation pathway (Hewett et al., 2006; Yu, Liu, Hatch, Panossian, & Finerman, 1999). In relation to the menstrual cycle and associated ACL ligament laxity, a 13-study meta-analysis found that evidence suggests the ACL becomes more lax during the luteal phase, though the authors also mention more research is needed in this area (Belanger et al., 2013). Specifically, menstrual timing as a risk factor may be explained by release of the hormone relaxin peaking during the luteal phase (Wreje, Kristiansson, Aberg, Bystrom, & von Schoultz, 1995). Relaxin hormone binds to female ACL tissue, where specific relaxin receptors are present (Dragoo, Lee, Benhaim, Finerman & Hame, 2003). Animal studies have shown relaxin can cause both dose-dependent release of tissue degrading enzymes and a less dense collagen structure (Kapila, Wang, & Uston, 2009). Illustrating this point, Dragoo et al. (2011) found that Division 1 female NCAA athletes with ACL tears had greater levels of relaxin than females who had not suffered an ACL tear. However, more research is needed to investigate the mechanisms and possible role of relaxin and estrogen as related to ACL injuries in females.

Another physiological difference between females and males that may contribute to risk of ACL injury is posterior tibial slope. The female's posterior tibial slope (the angle between the line representing the posterior inclination of the tibial plateau and the line perpendicular to the line through the center of the diaphysis of the tibia) is steeper on average for females as compared to males (Genin, Weill, & Julliard, 1993; Hashemi et al., 2008). In a 54-participant study, posterior lateral tibial slopes were steeper in participants who had a previous ACL injury, though notably, a posterior medial tibial slope measurement was not significantly different between previously injured and actively injured participants (Simon et al., 2010). As an explanation for posterior tibial slope contributing to ACL injury, Boden et al. (2010) hypothesized that a greater posterior tibial slope "may increase the risk that the lateral femoral condyle will slide posteriorly on the lateral tibial plateau and injure the ACL" (p.527). Larger scale studies must be completed to ascertain whether the posterior lateral tibial slope is a reliable measurement for increased ACL injury risk, and if so, confirm the mechanism of injury.

Additional research of anatomical properties reveals a size and mechanical discrepancy between male and female ACLs. The female's ACL is smaller in volume, cross-sectional area, and mass than the male's (Chandrashekar, Slauterbeck, & Hashemi, 2005). Additionally, cadaver testing showed female ACL ligaments had a lesser resistance pattern to strain, stress, and a lower strain energy density at failure even when controlling for ACL volume (Chandrashekar et al., 2006). These results suggest that females not only face greater risk of ACL injury because of lower ligamentous volume but also because of underlying differences in the tensile strength of the tissue itself (Slauterbeck & Hashemi, 2005).

Another anatomical concern is the quadriceps angle (Q-angle), an angle formed in the frontal plane between two line segments, one from the tibial tubercle to the middle of the patella, and the second from the middle of the patella to the anterior superior iliac spine. In a study performed on six cadavers, researchers found that by changing the Q-angle, the motion of the knee could be altered (Mizuno et al., 2001). Interestingly, female basketball players who had previous knee injuries had a larger mean Q-angle than those who did not have previous injuries (Shambaugh et al., 1991). Despite this evidence, in their study of 146 semi-pro Swedish soccer players, Söderman et al. (2001) found that Q-angle was not a predictor of ACL injury risk. Therefore, there is insufficient evidence for overall consensus on the role of the Q-angle in ACL injury (Alentorn-Geli et al., 2009). Instead of Q-angle, some researchers suggest that the ratio of pelvic width to femoral length may be a more useful measure of anatomical risk, and so, is an avenue for future research (Pantano, White, Gilchrist, & Leddy, 2005).

Unlike the Q-angle, previous research suggests that lower extremity muscle strength factors into non-contact ACL injuries (Myer et al., 2009). Since the hamstrings to quadriceps strength relationship, effectively known as the H/Q ratio, is yet another difference between the sexes, Myer and colleagues (2009) investigated the association between the strength of the quadriceps and hamstring muscles and ACL injury risk. In this study, female athletes who had a prior ACL injury were case control matched with uninjured female participants, and uninjured male participants served as a secondary comparative control (Myer et al., 2009). With isokinetic knee flexion and extension strength testing, female athletes who previously sustained ACL injury exhibited decreased hamstrings strength, but not decreased quadriceps strength as compared to both female and male controls (Myer et al., 2009). Furthermore, female athletes who did not have previous ACL injuries demonstrated decreased quadriceps strength, but not decreased hamstrings strength when compared to male control participants and female athletes of ACL injured status (Myer et al., 2009). Thus, injured female athletes displayed decreased hamstrings strength and a higher relative quadriceps strength than their uninjured female counterparts (Myer et al., 2009). Therefore, a decreased H/Q ratio by either a decrease in hamstrings strength, an increase in quadriceps strength, or a combination of a decrease in hamstring strength and increase in quadriceps strength may place female athletes at increased risk for ACL injury (Myer et al., 2009).

Joint Laxity and Knee Hyperextension Values

Apart from the aforementioned anatomical components of ACL injury, the prevalence and extent of joint laxity in young and active populations who sustain ACL injuries continues to be under investigation. In a study of 467 high school athletes, 9.8% of the participants demonstrated asymptomatic, nontraumatic unilateral hyperextension with an average prone heel-to-heel difference of 2.48 cm (Arangio, St. Amour-Myers, & Reed, 1996). Post hoc analysis in another study revealed knee joint laxity was present in 42.6% of participants with a history of ACL injuries and only 21.5% of participants without history of ACL injury (Ramesh et al., 2005). More impressively, knee hyperextension was present in 78.7% of those that had suffered ACL injuries and only 37.0% of those that had not (Ramesh et al., 2005). This evidence suggests that generalized joint laxity and knee hyperextension may put athletes at high risk of ACL injury.

Additionally, research suggests that women possess greater generalized joint laxity and knee hyperextension than their male counterparts. This statement was supported in a study that surveyed 118 active adults and collegiate athletes for specific anatomic lower extremity malalignments that are often identified as risk factors for injury: navicular drop, tibial varum, quadriceps angle, genu recurvatum (knee hyperextension), anterior pelvic tilt, and femoral anteversion (Medina McKeon & Hertel, 2009). Medina McKeon and Hertel (2009) obtained normative passive knee extension values of 5.7° ± 3.2° for women and 3.1° ± 2.5° for men. In a similar study, Trimble, Bishop, Buckley, Fields, and Rozea (2002) reported normative knee extension values of 5.8° ± 4.2° and 3.2° ± 1.5° for female and male participants, respectively. These values support that female athletes exhibit greater knee hyperextension than their male counterparts. Similarly, anterior tibial translation measured 6.05 ± 1.46 mm in healthy female athletes with no history of ACL injury and 4.80 ± 1.53 mm in their male counterparts (Rozzi et al., 1999). The difference in anterior tibial translation between male and female participants is yet another demonstration of the higher degree of knee joint laxity that promotes greater knee hyperextension among female populations (Rozzi et al., 1999).

Screening Protocols

A valid and affordable ACL injury risk screening protocol could help high school coaches determine which athletes are intrinsically at higher risk. Initial methodology for screening protocols required expensive equipment and highly trained staff, which are not economically or logistically feasible for many athletic programs. Therefore, more recent research has focused on the development of a screening methodology for ACL injury risk that requires neither expensive equipment nor highly trained staff.

The most thoroughly researched ACL injury risk screening protocol is based on the measurement of maximal knee abduction in athletes during a jump landing task. A high knee abduction moment during landing is associated with ACL injury risk in young female athletes (Hewett et al., 2005). The current gold standard screening tool was developed by Hewett and colleagues in 2005, utilizing motion tracking equipment to determine whether athletes have a high knee abduction. In this study, a high knee abduction demonstrated a 78% sensitivity and 73% specificity for future ACL rupture (Hewett et al., 2005). Although motion detection-based screening can determine high knee abduction with 90% accuracy, it requires expensive equipment and well-trained staff to implement and utilize (Myer, Ford, Khoury, & Hewett, 2010b).

To lower the cost of screening female athletes for risk of knee injury, Myer, Ford, and Hewett (2011) developed a screening method using an algorithm from multiple factors used to define knee abduction. Their methods included use of a camera and free software that yielded kinematic measurements obtained during a drop jump. Results produced a sensitivity of 77% and specificity of 71% (Myer, Ford, & Hewett, 2011). Clinically obtainable measures, including knee valgus, knee flexion, body mass, tibial length, and quadriceps to hamstring ratio were employed in this methodology as predictors of high knee abduction (Myer, Ford, Khoury, Succop, & Hewett, 2010a; Myer et al., 2011). Based on current research, this simple jump test is estimated to have a sensitivity between 61-70% and specificity between 56-61% for ACL injury, which may not be cost-effective for mass screening of athletic populations (Swart et al., 2014).

Another study utilized the tuck jump for ACL injury risk screening, evaluated by a clinician looking for valgus torque of the knee upon landing, as a more simplified methodology (Myer, Ford, & Hewett, 2008c). However, more research is needed to determine if the tuck jump is a reliable method for predicting risk of ACL injury (Myer et al., 2008c). Padua et al. (2011) developed another simplified jump-based testing protocol, called “Landing Error Scoring System - Real Time” (LESS-RE). Utilizing

LESS-RE allows well-trained clinicians to assess athletes in real-time for movements associated with lower extremity injury risk. The LESS-RE screening protocol has good interrater reliability and potentially comparable validity when compared to the “Landing Error Scoring System”, the latter being a previously developed system that is valid and reliable for identifying individuals at high risk of lower extremity injuries. The benefit of LESS-RE is that screening can be done with no equipment, although it requires well-trained staff to demonstrate good interrater reliability (Padua et al., 2011). The authors acknowledge that more research is needed to evaluate the validity of LESS-RE.

Although screening protocols for ACL injury risk have focused on analysis of a jump and land protocol, other avenues may be worth investigating. For example, posterior tibial length measurement has potential for the discovery of individuals at risk of a lower body injury (Hashemi et al., 2008). Also, intercondylar notch width may be of interest as smaller intercondylar notch width was found to be a predictor of ACL injury with a sensitivity of 74% and a specificity of 67% in a study comprised of 54 participants, with 34 being male (Simon et al., 2010). Another avenue, the focus of this study, is excessive hyperextension of the knee as a potential line of screening. Hyperextension is representative of generalized joint laxity, and individuals who exhibit the highest levels of either knee hyperextension or generalized joint laxity are at risk of ACL injury (Ramesh et al., 2005). Thus, evaluation for dynamic hyperextension of the knee is a potential screening method for ACL injury risk.

Summary

Several intrinsic mechanisms of injury place female athletes at heightened risk of ACL injury compared to their male counterparts. The disparity between the sexes is multifactorial in nature and may be attributed to anatomical, hormonal, neuromuscular, and biomechanical factors. The investigation and identification of these factors in athletes at risk may prove beneficial in reducing the incidence of ACL injury among athletes. Current screening methods are based on observation of a jumping maneuver to assess for kinematic positions that result in ligamentous susceptibility. This study explores observation of active knee hyperextension as a potential screening method for ACL injury among soccer athletes.

Chapter 3: Methodology

Introduction

The purpose of this retrospective study was to explore a potential cost-effective and easily implemented method for identifying high school athletes at increased risk of ACL injury due to knee hyperextension. Utilizing data collected by Crown College, this study aimed to identify athletes at heightened risk of ACL injury by analyzing the punt kicks of male and female high school soccer athletes. By analyzing photos previously taken with a high-speed camera by Crown College researchers, the current researchers were able to identify incidence of knee hyperextension in the soccer athletes, allowing for quantification of differences between the sexes and various levels of play. The resulting data allowed this study to answer the following questions:

1. What is the incidence of knee hyperextension in male and female competitive high school soccer athletes during a soccer punt?
2. What is the difference in incidence of knee hyperextension during a soccer punt between males and females?
3. How does the incidence of hyperextension between male and female competitive high school soccer athletes, as viewed via high-speed photography during a soccer punt, correspond to the published rate of ACL injuries as published by Joseph et al. (2013) and Swensen et al. (2013)?
4. Is observable knee hyperextension utilizing high-speed photography during a soccer punt a viable screening method for ACL injury risk?

Participants of the Crown College Study

Observations of soccer punts were conducted at Mounds View High School in Arden Hills, Minnesota. The participants of the original study were male and female high school athletes from the Mounds View High School soccer program, ages 14-18 years. The sample consisted of 87 male and female members of the Freshman, Junior Varsity (JV), and Varsity soccer teams for Mounds View High School. Of the study's participants, 19 athletes (7 males and 12 females) played at the Freshman level, 48 athletes (26 males and 22 females) at the Junior Varsity level, and 20 athletes (8 males and 12 females) at the Varsity level (see Table 1).

Table 1
Study Participants from Each Team

Sex	Freshman soccer players	Junior varsity soccer players	Varsity soccer players
Females	12	22	12
Males	7	26	8

The Bethel University Physician Assistant Student (PA-S) research team was given access to the soccer data via the Crown College Human Performance Laboratory and Stacy Ingraham, Ph.D., with Crown College IRB approval. All associated photos and data were transferred from the computers of the PA-S research team to the Crown College researchers and Human Performance Laboratory, and are stored on a password-protected computer in the lab. The data will continue to be analyzed with the intent for publication.

Instruments of the Crown College Study

The camera utilized for Crown College's data collection was a Sony Alpha 77II with a Tamron ultrasonic superdrive SP 70-200mm f/2.8 zoom lens. The camera provided the ability to produce a high-speed sequence of photos during each kick. The camera was supported on a single-leg stand which served as a stationary axis point for the photographer to stabilize the camera while following the athlete's approach and kick. A Sony video camera was also utilized to capture live-action motion, which was not used for the purposes of this study. The soccer balls used for punting met the following requirements:

- circumference of not more than 70 cm and not less than 68 cm
- weight not more than 450 g and not less than 410 g at the start of data collection
- pressure within 0.6 – 1.1 atmosphere (600 – 1100 g/cm^2) at sea level (8.5 pounds/inch^2 (PSI) to 15.6 PSI)

Procedures of the Crown College Study

Crown College data collection took place during the Fall 2015 soccer season. The athletes were asked to punt a soccer ball, with the ability to take an approach up to a seven-foot long marker, which delineated the punting area. A Sony video camera was placed on the side of the kicking area to obtain a left lateral profile of the athletes during the punt kicks. A high shutter-speed camera was placed opposite of the video camera to obtain a right lateral profile of the athletes' kicking leg during the punt kick. The camera frame rate was set to 10 frames per second.

After following their standard team warm-up, players were selected from the roster to temporarily leave the ongoing practice to participate in the study. Players were instructed to punt the soccer ball as far as possible in the punting area delineated by the seven-foot line, over which their plant leg (non-dominant leg) could not cross until the ball had been kicked. Beginning with the participant's approach, one researcher controlling the high-speed camera took a set of rapidly successive photos during each punt until the player's punting leg touched the ground. Each player kicked a total of eight qualifying kicks. Each kick distance was recorded. Once data collection was complete, all photos were transferred to the Bethel Univ. PA-S research team.

Visual Analysis for Knee Hyperextension by Bethel University PA-S Research Team

Two researchers from the Bethel Univ. PA-S research team visually assessed photographs of 87 high school soccer players (44 females and 43 males) for hyperextension during the athletes' punts, estimating anatomical landmarks as a guide. Based on the photo that demonstrated the greatest extension of the knee, each athlete was rated into one of three categories by Bethel Univ. PA-S researchers: a) lack of knee hyperextension, b) presence of knee hyperextension, or c) questionable knee hyperextension. If the lateral malleolus appeared to break the plane formed between the lateral femoral epicondyle and greater trochanter superiorly, then the athlete was considered to have hyperextended at the knee. For the purposes of this study, any athlete who displayed hyperextension one or more times was considered to hyperextend (see Figure 1). This is based on the logical assertion that if athletes hyperextend once, they have the underlying laxity to hyperextend again.

Figure 1

Lateral View of a Soccer Punt Demonstrating Hyperextension

Kinovea Software Analysis

Following the visual analysis, visual scores were compared to scores obtained via angle measurement using Kinovea, a software-based motion analysis program. In order to determine the presence or absence of knee hyperextension from high-speed photography using Kinovea software, the angle between the landmarks of the greater trochanter and lateral malleoli, with the knee joint as a midpoint, was measured at the point of maximal knee extension of each athlete's kick. The angle determined by these landmarks was measured using Kinovea software version 0.8.15, which has previously been utilized for measurement of joint angles from a 2D image plane (Damsted, Nielsen, & Larsen, 2015). A power calculation estimated eighteen photos would be needed (with each photo demonstrating maximal extension for that athlete) from each visual evaluator, which were selected at random, totaling 36 photos for Kinovea analysis. The investigator carrying out Kinovea angle measurement analysis was blinded to the visual results.

The objective for the Kinovea evaluator was to determine presence or absence of hyperextension based on the determined angle of extension as described above. Based on previous research in which passive range of motion was measured while eliciting maximal knee extension, hyperextension was defined as 2.4° (1.5° - 3.3°) for females and 1.8° (0.9° - 2.7°) for males ages nine to nineteen (Soucie et al., 2011). Since there is not yet a consensus in existing literature for normal knee extension angles versus knee hyperextension with dynamic range of motion, any angle beyond 0.0° was rated hyperextension for the purposes of this study (see Figure 2).

Figure 2
Kinovea Software Utilized to Measure Joint Hyperextension

Research Design

This study is defined as a quantitative, retrospective study targeting competitive high school soccer athletes. Two analyses were performed to answer the research questions outlined above. A binary logistic regression and a multinomial logistic regression were conducted to assess the difference, if any, in the incidence of hyperextension between the sexes and across team levels.

Statistical Methods

The independent variables explored in this study were sex and skill (team level, while presence or absence of hyperextension were the dependent variables. A binary logistic regression was performed, grouping the visual analysis data into two categories:

presence or absence of hyperextension. This allowed the incidence of hyperextension in relation to sex and team level to be compared. A categorical data analysis was then performed to explore the results of another approach with a chi-squared analysis.

For a second analysis, a scale rating the expectation of hyperextension from -2 to +2 was developed to reflect the agreement of the judges on their observations of presence or absence of hyperextension. The four resulting categories of judgments were categorized using a multinomial logistic regression to compare players by sex and sex-team combinations because the requirements for an ordinal logistic regression model were not met.

Chapter 4: Results

Overview of Research Methods

Photos of 87 high school athletes including females (*n* = 46) and males (*n* = 41) were evaluated for evidence of hyperextension during soccer kicks by two independent raters, who judged kicks separately. Photos of eight kicks were taken of each athlete. Raters selected a photo of a kick for visual analysis using the process outlined in the methodology section above to assess players for evidence of hyperextension. Judges selected one photo for each athlete that demonstrated the highest degree of knee hyperextension. In this study, judges rated the same kick by 43 players and different kicks for 44 players, meaning, in 43 cases they selected the same photo as the greatest representation of hyperextension for that athlete. Of the kicks performed by these 87 players, the kicks of 77 players produced scores that were valid for analysis. Kicks were removed from analysis if neither judge could provide a determination of the angle of the kick (i.e., both judges rated the kick as questionable, *n*= 5) or where raters made opposing judgments, effectively cancelling the score of the other judge, *n*= 5).

To assess how well the judges' observations correlated with Kinovea software, each judge randomly selected 18 player's kicks that were considered to be the most extreme angle produced by the player. No questionable kicks were included in this comparison. Each set assessed by the judges contained kicks from 14 unique players; kicks from four players were judged by both raters. Fourteen kicks were drawn from different players, one player was in both sets but a different kick was used, and three identical kicks were assessed by both judges, producing 36 ratings: 30 from different kicks and three from identical kicks that were assessed twice, one by each rater. The judgments regarding the presence or absence of hyperextension were compared to angle analysis values produced by Kinovea. The correlation between judgments by the two visual analyzers and the angle assessment by Kinovea was 100%. In other words, the judgments by each rater regarding the presence or absence of hyperextension were verified with results from Kinovea. In these sets, each judge found evidence of hyperextension in the kicks of 12 players and no hyperextension in the kicks of 6 players. These ratings were verified by angles assessed by Kinovea. Likewise, as the judges reported, Kinovea confirmed that knee angles failed to meet criteria for hyperextension in the most extreme kicks of 6 randomly selected players, but concurred with the judges' determination of the presence of hyperextension in the most extreme kick of 12 players.

Descriptive Statistics

This study involved 44 female soccer players and 43 male soccer players from 11 teams, consisting of varsity players (female n = 12; male n = 8), female junior varsity A squad (n = 14), female junior varsity B squad (n = 8), male junior varsity white team (n = 13), male junior varsity green team (n = 9), male junior varsity B squad (n = 4), and freshman teams (female n = 12; male n = 7), as shown in Table 2 below.

Table 2
Participants

Team Level	Female	Male
Varsity	12	8
Junior Varsity Total	22	26
Junior Varsity Divisions		
JV – A Squad	14	0
JV – White		13
JV – Green		9
JV – B Squad	8	4
Freshman	12	7
Total Participants	46	41

Judges rated one photo for each participating athlete and designated each with one of the following: a) no hyperextension, b) hyperextension, or c) questionable hyperextension. Results are summarized in Table 3 below.

Table 3
Visual Analysis Results

Sex/Team Level	Not Hyperextended		Hyperextended		One Yes/One No Rating for Kick	Both Raters Uncertain
	Both raters	One rater	Both raters	One rater		
Female Total	13	12	12	4	2	3
Varsity	5	3	2	1	0	1
JV – A Squad	4	5	2	0	1	2
JV – B Squad	1	3	2	2	0	0
Freshman	3	1	6	1	1	0
Male Total	13	7	8	8	3	2
Varsity	2	2	1	2	0	1
JV – White	3	3	0	4	3	0
JV – Green	3	1	2	2	0	1
JV – B Squad	2	1	1	0	0	0
Freshman	3	0	4	0	0	0

Participants from the male JV – B Squad were combined with male JV Green due to low levels of participation in each group.

Data Analysis

Responses were categorized as a binary response (presence or absence of hyperextension) and as a 5-point scale for likelihood of hyperextension. Each outcome will be presented separately.

Binary Prediction of Odds of Hyperextension

- Hyperextension

In the first method of assessment, if both judges viewed hyperextension (Y+Y) in the photo, the kick was rated as hyperextension. If one judge rated a photo as hyperextension and the other rated the photo as questionable (Y+Q), the kick was also rated as hyperextension, indicating hyperextension or likely hyperextension. If one or both judges deemed that hypertension had occurred, the athlete was rated "yes" in Figure 1.

- Not Hyperextended

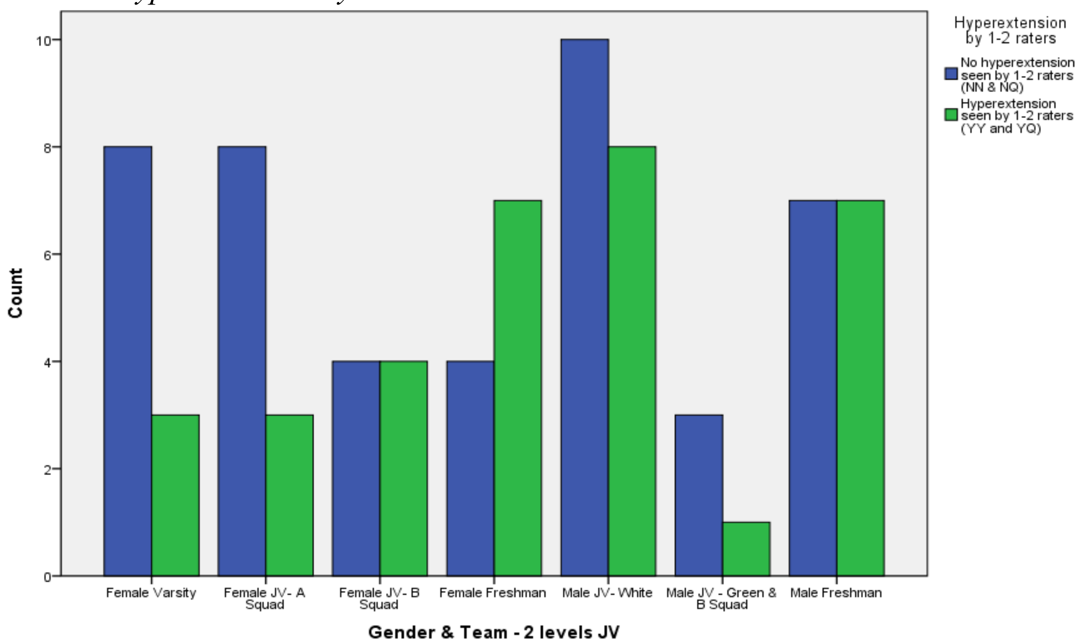
Similarly, if both judges did not view hyperextension (N+N) in a photo, the kick was rated as no hyperextension. If one judge viewed no hyperextension and the other was questioning (N+Q), the kick was also rated as no hyperextension, indicating no hyperextension or likely no hyperextension. If one or both judges deemed that no hyperextension had occurred, the athlete was rated “no” in Figure 1.

- Questionable ratings

If a judge was unable to make a firm determination regarding the presence or absence of hyperextension, the kick received a questionable rating. Questionable ratings were assigned when the angle of the knee was occluded or the judge was uncertain about the angle of the knee. Kicks that received questionable judgments from both judges (Q+Q, $n = 5$) and kicks that judges disagreed whether hyperextension did or did not occur (Y+N, $n = 5$) were not included in the analysis, leaving 77 valid cases for further examination. The distribution of responses for each sex-team combination is shown in Figures 3 and 4.

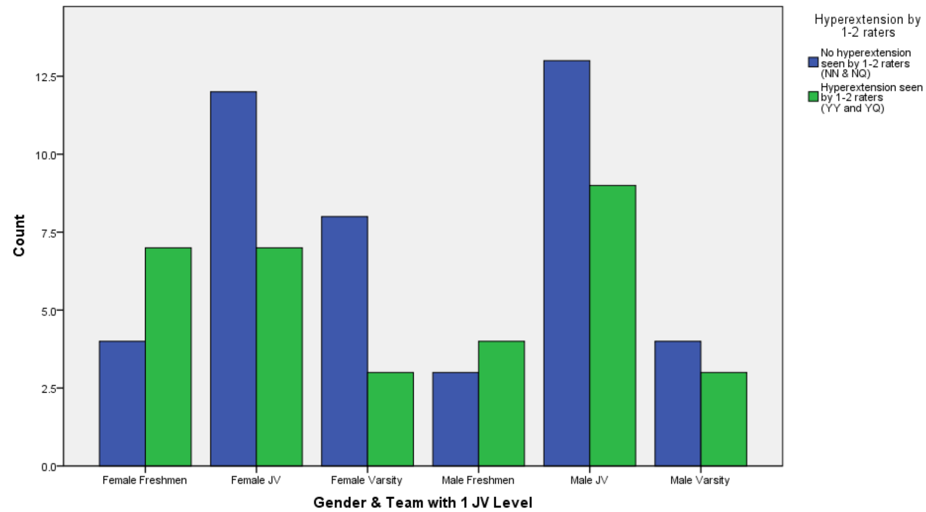
Figure 3

Observed Hyperextension by Sex and Team Level



When the JV levels are combined into a single level, a picture emerges of hyperextension being most common in freshman teams for both females and males, with a majority of kicks found to be not hyperextended in JV and varsity players.

Figure 4
Observed Hyperextension by Sex and Team Level with JV Teams Combined



Binary logistic regression was used to assess these data, using sex of the player and team level for each sex (varsity, two JV levels, and freshman teams) as independent variables, and presence or absence of hyperextension or probability of the presence or absence of hyperextension, as defined above, as dependent variables. In logistic regression, the results are interpreted as odds of the dependent variable. Since more cases were found to have no hyperextension and probable no hyperextension, absence of hyperextension was used as the reference for comparison. As indicated above, male JV - Green and JV - B Squad teams were merged due to small numbers in each set.

Binary Prediction of Odds of Hyperextension in Regard to Sex and Team Level

Next, the binary prediction of odds was completed with both sexes and four team levels (Varsity, JVA (female) and JV White (male), JVB (female) and JV Green and B (male) and Freshman) as main effects. The variation in the dependent variable (hyperextension and probable hyperextension) based on the main effects model as indicated by Nagelkerke R^2 is 6.9%, suggesting that the added variables provided little additional information to the basic model of assuming that no hyperextension occurred, using the response categories listed above. The Hosmer and Lemeshow test of goodness of fit was not statistically significant (p = .987), indicating that the model is an adequate fit.

The classification table shows that 84.1% of cases overall could be correctly classified by simply assuming that all cases were classified as "no hyperextension or probable no hyperextension." However, with the independent variables of sex and team level added, the model correctly classified 62.3% of cases overall indicating that the addition of the independent variables does not improve the overall prediction of cases into the two categories of the dependent variable hyperextension and probable hyperextension versus no hyperextension and probable hyperextension. The model correctly predicted that 33% of the athletes displayed hyperextension.

The results of the model including sex of player and four team levels showed no significant differences by sex of the player (p = .753) or by team levels when compared to the reference group (Varsity), as shown in Table 4. The Freshman team (p = .099) was marginally statistically different from the Varsity team, but the level consisting of Female JV A-Squad and Male JV White Squad (p = .984) and the level consisting of Female JV B-Squad and Male JV Green and B Squad (p = .498) were not statistically different in terms of hyperextension from the Varsity Team.

Table 4

Comparison of Hyperextension with JV Levels Separated

Sex/Team Level	B	S.E.	Wald	df	p-value	Exp(B)	95% C.I.for EXP(B)	
							Lower	Upper
Sex of Player	-.152	.481	.099	1	.753	.859	.334	2.208
Teams - 2 JV Levels Each			3.829	3	.281			
Freshman	-1.147	.696	2.714	1	.099	3.148	.804	12.316
JV – A and White	-1.160	.672	2.981	1	.984	.987	.259	3.764
JV – Green and B	-.686	.669	1.049	1	.498	1.586	.418	6.010
Constant	.545	.568	.921	1	.298	.548		

a. Variable(s) entered on step 1: Sex of player, Teams with Varsity, two JV Levels, and Freshman

Similar results were obtained when all JV levels were collapsed into one level, leaving only comparisons among varsity, JV and freshman teams, as shown in Table 5.

Table 5

Comparison of Hyperextension with JV Levels Combined

Sex/Team Level	B	S.E.	Wald	df	p-value	Exp(B)
Sex of Player	-.183	.478	.147	1	.702	.833
Teams - 1 JV Level			3.315	2	.191	
JV Level	.220	.598	.135	1	.713	1.246
Freshman	1.147	.696	2.715	1	.099	3.150
Constant	-.583	.576	1.023	1	.312	.558

a. Variable(s) entered on step 1: Sex of player, Teams (Varsity, JV and Freshman)

The results of the model showed no significant differences by sex of the player (p = .702) or by team level when compared to the reference group (Varsity). The Freshman team (p = .099) was marginally statistically different from the Varsity team, but the combined JV teams were not statistically different regarding hyperextension when compared to the reference group, the Varsity Team (p = .713). In other words, the odds of hyperextension showed no statistically significant differences across groups.

Binary Prediction of Odds: Interaction of Sex and Team Levels (Varsity, JV, and Freshman)

Creating six levels of data with a combination of sex-team levels (Female Varsity, Female Junior Varsity, Female Freshman, Male Varsity, Male Junior Varsity, Male Freshman) did not change the overall assumption that the odds of hyperextension were lower than the odds for no hyperextension in the current sample of 77 kicks. Sex of the athlete was not statistically significant (p = .585), and none of the teams were statistically significantly different from one another regarding hyperextension, as shown in Table 6.

Table 6

Comparison with the Breakdown of Sex and Team Level

Sex/Team Level	B	S.E.	Wald	df	p-value	Exp(B)	95% C.I.for EXP(B)	
							Lower	Upper
Sex			3.756	5	.585			
Female Freshman	.847	.988	.735	1	.391	2.333	.336	16.180
Female JV	-.251	.900	.078	1	.780	.778	.133	4.536
Female Varsity	-.693	1.021	.461	1	.497	.500	.068	3.696
Male Freshman	.575	1.080	.284	1	.594	1.778	.214	14.767
Male JV	-.080	.878	.008	1	.927	.923	.165	5.162
Constant	-.288	.764	.142	1	.706	.750		

Categorical Data Analysis of Binary Response

A categorical data analysis was performed to evaluate the binary outcomes of hyperextension/no hyperextension as another approach to the research question. Evaluating a varsity team, two JV teams, and a freshman team for both female and male players (Female Varsity, Female JV – A, Female JV – B, Female Freshmen, Male Varsity, Male JV - White, Male JV Green and B, and Male Freshmen) resulted in non-significant differences among groups (χ^2 = .610). Collapsing the JV teams into one category, leaving three team levels per sex did not change the results significantly (χ^2 = .560).

Analysis of Judges' Ratings on a 5-Point Scale (Expectation of Hyperextension)

In order to refine the categorization of the ratings made by the two judges, a 5-point scale of hyperextension certainty was developed as follows: a) -2: 2 ratings, no hyperextension; b) -1: one judge rated the kick as exhibiting no hyperextension but the second judge judged the kick as questionable; c) 0: both judges regarded the kick as questionable, or one judge observed hyperextension but the second judge did not, cancelling the rating; d) 1: one judge rated the kick as exhibiting hyperextension but the second judge rated the kick as questionable; and e) both judges rated the kick as exhibiting hyperextension. This system is detailed in Table 7 below.

Table 7
Score Assignments for Judges' Ratings (Scale: Expectation of Hyperextension)

Points assigned	**-2**	**-1**	**0**	**1**	**2**
Judges' ratings	No hyperextensi on observed by both judges	First judge: no hyperextension; second judge: questionable	Both judges: questionable or opposite ratings	First judge: hyperextension; second judge: questionable	Hyperextension observed by both judges

Since the model violated the assumption of proportional odds required for ordinal logistic regression, multinomial logistic regression was used to compare the players by sex and sex-team combination.

Distribution of ratings over the 5-point scale for player sex and team level, using one level for JV for both males and females. Seventy-seven valid cases were analyzed as distributed in the categories shown in Table 8 below.

Table 8
Distribution of Ratings with 5-Point Scale for Sex and Team Level

		N	Marginal Percentage
Hyperextension Certainty Score	Two NN	25	32.5%
	NQ	19	24.7%
	YQ	11	14.3%
	Two YY	22	28.6%
Sex & Team - 1 Level JV	Female Freshmen	11	14.3%
	Female JV	19	24.7%
	Female Varsity	11	14.3%
	Male Freshmen	7	9.1%
	Male JV	22	28.6%
	Male Varsity	7	9.1%
Valid		77	100.0%
Both QQ or One N, One Y per Kick (i.e., invalid)		10	
Total		87	
Subpopulation		6	

A multinomial logistic regression was used to analyze presence or absence of hyperextension in different team categories, using one JV level for all players to increase numbers in team categories. Sex of player was not considered in these categories.

Model fitting information revealed that the addition of player sex and team level to the model did not improve the model (p = .223). In other words, given these sample data, sex of player accounting for team level did not affect the prediction which players would have hyperextension (see Table 9).

Table 9

Distribution of Ratings for 5-Point Scale for Athlete Sex and Team Level

Model Fitting Criteria	Likelihood Ratio Tests		
-2 Log Likelihood	Chi-Square	df	p-value
58.249			
39.453	18.796	15	.223

Following these results, player sex and player team level (3 levels: Varsity, JV, and Freshman) were analyzed separately to increase the number in each category.

Differences between Sexes on 5-Point Presence/Absence of Hyperextension Scale Using Multinomial Logistic Regression

Using multinomial regression of the effect of the sex of the player on the judges' ratings showed no significant effects ($p = .456$), meaning that the sex of the player had no impact on the ratings of the presence or absence of hyperextension on the 5-point scale described above, as shown in Table 10.

Table 10

Difference Between All Males and All Females Based on a 5-Point Hyperextension Scale

Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	p-value
Intercept-Only	21.458[a]	.000	0	
Final	24.064	2.606	3	.456

The chi-square statistic is the difference in -2 log-likelihoods between the final model and a reduced model. The reduced model is formed by omitting an effect from the final model. The null hypothesis is that all parameters of that effect are zero.

Results of the multinomial logistic regression on sex are presented in Table 11. No significant differences between sexes for any scoring category for presence or absence of hyperextension was found.

Table 11

Multinomial Logistic Regression on Sex

Score on Expectation of Hyperextension Scale		B	Std. Error	Wald	df	p-value	Exp(B)	95% confidence interval	
								Lower bound	Upper bound
No hyperextension observed by both judges	Intercept	.368	.434	.719	1	.396			
	Female	-.448	.590	.576	1	.448	.639	-.448	.590
	Male								
One judge: no hyperextension; second judge: questionable	Intercept	-.251	.504	.249	1	.618			
	Female	.171	.644	.071	1	.790	1.187	.171	.644
	Male								
One judge: hyperextension; second judge: questionable	Intercept	-.251	.504	.249	1	.618		-.251	.504
	Female	-.927	.762	1.480	1	.224	.396	-.927	.762
	Male								

Differences between Team Levels on 5-Point Presence/Absence of Hyperextension Scale Using Multinomial Logistic Regression

Finally, team levels were compared regarding the ratings given by judges on the 5-point scale for presence of absence of hyperextension. The model with the added variable of team level is marginally significant, shown in Table 12.

Table 12

Team Level and Ratings

Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	p-value
Intercept-Only	Intercept-Only	38.596		
Final	Final	26.669	11.927	.064

Assuming that the marginal significance points to a trend, the following results may be relevant, as shown in Table 13. No ratings were obtained for the five kicks where both judges were unable to make a determination regarding the presence or absence of hyperextension or for the five kicks where judges made opposite determinations. The low number of members in two categories for the Freshman team made further analysis impossible. However, note that except for two players, Freshman team members were observed as clearly not hyperextending or clearly hyperextending. An increase in the number of players may yield a significant result.

Table 13

Expectation of Hyperextension Scale

Team Level	No hyperextension observed by both judges	One judge: no hyperextension; second judge: questionable	One judge: hyperextension; second judge: questionable	Hyperextension observed by both judges	Totals
Freshman	6	1	1	10	18
JV	12	13	7	9	41
Varsity	7	5	3	3	18
Totals	25	19	11	22	77

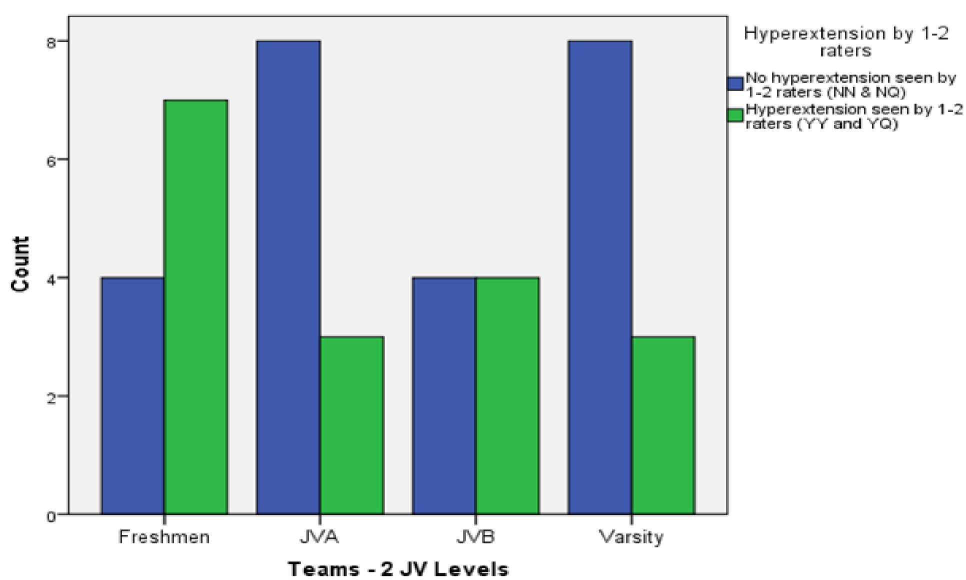
Odds of hyperextension were compared to male and female athletes. There were no significant differences for hyperextension by sex of the player or team level. The small number of valid Male Varsity and Male Freshman cases affected the results that were obtained.

Discussion

Small numbers of some player categories such as Male Varsity and Male Freshmen may have impacted the results that showed no differences by sex or team level regarding observed hyperextension. Refining the categories of ratings and combining team levels did not produce statistically significant differences. However, Figures 3 and 4 here, suggest some areas for intervention.

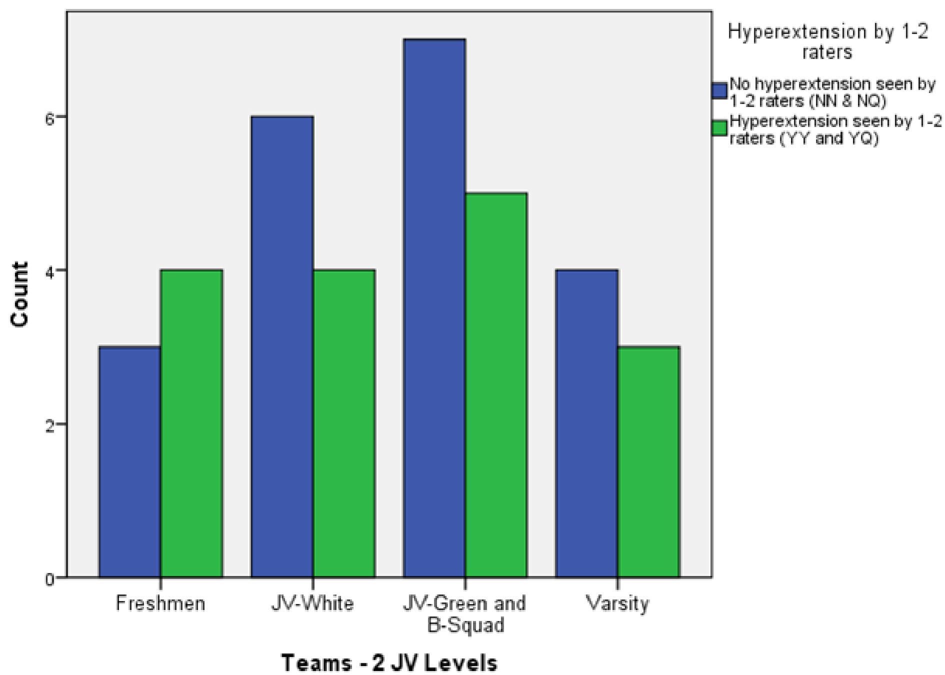
For female players, the less experienced players showed hyperextension as shown in the plot below. The freshmen and JV-B teams showed more hyperextension than the JV-A team and Varsity team. Even though the differences did not rise to the level of statistical significance, this finding may guide coaches in working with younger and less experienced players (see Figure 5.)

Figure 5
Observed Female Hyperextension by 1-2 Judges with JV Levels Split



For males, Freshmen players exhibited more hyperextension than proper extension. Interestingly, nearly half of the Male Varsity exhibited hyperextension. However, the small size of this group makes this result unreliable (see Figure 6).

Figure 6
Observed Male Hyperextension by 1-2 Judges with JV Levels Split



Summary

In this study, 87 soccer players (males = 41 and females = 46) were evaluated for hyperextension. Each judge rated one kick from each player for presence or absence of hyperextension. Of the 87 athletes, kicks from 77 athletes were used in the analysis. Five ratings were removed due to no clear judgment (both judges rated the kick as questionable), and five were removed due to observer disagreement.

Due to small numbers for some teams, the JV teams were combined so that each sex was rated on two JV teams, presumably a higher-skilled and lower-skilled team. In some analyses, the JV teams were combined into one category to increase power for the analysis.

For the first analysis, a binary logistic regression was performed, grouping the judgments into two categories: no hyperextension, or hyperextension. No statistically significant differences were found for sex or for team level regarding presence or absence of hyperextension for teams that included two JV levels or were combined into a single JV level. A categorical data analysis was performed to explore the results of another approach, but a χ^2 analysis showed no significant differences between female and male players or across team levels.

For the second analysis, a scale rating the expectation of hyperextension from -2 to +2 was developed to reflect the agreement of the judges on their observations. Four categories of judgments were analyzed: 1) both judges agree no hyperextension was observed; 2) one judge observed no hyperextension, but the second judge rated the kick as questionable; 3) one judge observed hyperextension, but the second judge rated the kick as questionable; 4) both judges agree that hyperextension was observed.

A multinomial logistic regression was used for this categorization because the model did not meet the assumptions for an ordinal logistic regression. None of the judges' ratings were significantly different statistically across sexes or team levels. These results aligned with results from a categorical data analysis which revealed no statistically significant differences between groups.

The lack of statistical differences across groups may be attributed to lack of power due to small sample sizes in the different sex, team, and response categories.

However, the plots show a possible explanation by revealing that teams with younger, less experienced players tend to exhibit higher percentages of kicks with hyperextension. This finding, although not statistically significant, may provide direction for future research.

CHAPTER 5: DISCUSSION & CONCLUSION

Summary

An aim of this study was to quantify the incidence of knee hyperextension in male and female competitive high school athletes during a soccer punt and explore the difference in incidence, if any, between the sexes. Additionally, incidence of knee hyperextension was compared to the rates of ACL injury, as published by Joseph et al. (2013) and Swensen et al. (2013), to assess any relationship between the incidence of observable, dynamic knee hyperextension and ACL injury in the same sport. Understanding the relationship between incidence of observable, dynamic knee hyperextension and ACL injury will assist in determining if high-speed photography used to capture observable, dynamic knee hyperextension during a soccer punt is a viable screening method for ACL injury risk among high school soccer athletes.

In this study, the incidence of hyperextension for females and males across all skill levels was approximately 16/41 (39%) and 16/36 (44%), respectively. In another study exploring the incidence of asymptomatic, non-traumatic unilateral knee hyperextension among high school athletes, only 46/467 (9.8%) demonstrated hyperextension (Arangio et al., 1996). While the incidence of hyperextension between the two studies does not directly correspond, Arangio et al. (1996) did not consider sex, range of motion was assessed using an isokinetic rehabilitation system, and participating athletes played all sports instead of soccer only. Compared to the Joseph et al. (2013) study that demonstrated ACL injury rates of approximately 96/786,293 (0.012%) and 44/914,551 (0.004%) respectively for female and male high school soccer players, the incidence of hyperextension among all participants of the current study does not directly correspond with the published rate of ACL injuries. Likewise, the respective ACL injury rates of 11.7 and 5 per 100,000 athlete-exposures for female and male high school soccer players, as published by Swensen et al. (2013), do not correlate with the incidence of hyperextension observed in either sex in the current study. This difference may be a result of the multifactoriality of ACL injury. Hyperextension is but one of the intrinsic risk factors associated with ACL injury. This likely explains the disparity between rates of hyperextension in the current study and published rates of ACL injury among high school soccer players.

The literature on ACL injuries led to our expectation that high school female athletes in the current study would hyperextend more frequently than their male counterparts. However, no significant differences were found for sex regarding presence or absence of hyperextension for any team at any skill level. Again, the lack of difference in hypermobility between males and females further substantiates current research that risk of ACL injury is multifactorial. Hyperextension alone almost certainly does not explain the difference in the incidence of ACL injury between male and female athletes. This leads to speculation regarding other easily measurable causes of ACL injury and other opportunities for investigation.

The lack of statistical difference in knee hyperextension between female and male high school soccer players during a soccer punt in this study does not match the sex disparity in occurrence of ACL injuries as reported in the literature. Existing literature is in strong agreement that the rate of ACL injury is higher among females. Yet the overwhelming abundance of literature supporting this claim may exaggerate that ACL injury is primarily a female-dominated problem. Thus, it is important to make the distinction that the ACL injury rate is higher only when analyses are limited to sex-comparable sports. The gap in ACL injury rates between the sexes narrows when considering all sports (Joseph et al., 2013). However, because this study assesses only individuals who play soccer, a sex-comparable sport, the ACL injury rate is anticipated to be greater among female athletes. Again, the surprising result of evenly distributed occurrence of hyperextension between the sexes found in this study points to additional factors as well as an over-simplified analysis. Other impacting factors, in addition to hyperextension, putting females at greater risk for ACL injury over males in similar sports, could include; more severe hyperextension, decreased H/Q ratio, hormonal influences, and tibial translation differences.

Degree of hyperextension. One important factor not addressed in this study is severity of hyperextension and the role it may play in ACL injury risk. In this study, athletes that hyperextended at all were categorized as such. No distinction was made between obviously identifiable hyperextension and marginal hyperextension. The authors of this study hypothesize that if athletes with a severe degree of hyperextension were considered a separate, higher risk group, the comparisons may yield a different result.

H/Q ratio. Another possible factor affecting knee laxity and observed hyperextension may be hamstring and quadriceps muscle strength. In muscle recruitment for protection against anterior tibial translation, female athletes exhibit quadriceps dominance, a decrease in the recruitment of the hamstrings relative to the quadriceps, as evidenced by Huston & Wojtys (1996). This heavy dependence on the quadriceps for knee stabilization may be due to an electromechanical delay to maximal torque generation of the hamstring muscles (Huston & Wojtys, 1996). Thus, high-risk females may benefit from injury-prevention programs that promote hamstrings stabilization of the knee and improved neuromuscular response, compensating for any deficits and minimizing the likelihood of ACL injury.

Incidence of male joint laxity. This study revealed a higher-than-expected incidence of males exhibiting knee joint laxity by means of hyperextension. Along this line, it is important to note that because previous research focused on passive range of motion to identify joint laxity, many males who did not show passive joint laxity but still had enough laxity to dynamically hyperextend at the knee joint may have remained unidentified through passive range of motion screening measures. The current study bridges this gap and allows for identification of those who have enough laxity to hyperextend when in motion versus only identifying passive laxity.

Younger teams. Although there was no statistical difference in the incidence of hyperextension across team levels, this study illustrates an increased incidence of hyperextension in younger teams compared to older, more skilled teams. This is in contradiction to the body of research that states that the higher the level of competition, from high school to college, the greater the incidence of ACL injuries (Beynnon et al, 2014). This statement is true of both sexes; both males and females have increased rates of ACL injury with higher levels of competition, but the overall ratio of females having a greater risk of ACL injury remains consistent even as competition levels increase (Beynnon et al, 2014).

Several factors may account for increased hypermobility in younger teams, including limited sample size for different sex, team, and response categories; maturation phase; hyperextension categorization; and coaching. An obvious solution to the lack of significance potentially due to sample size is to repeat a similar study with more participants and a stronger response distribution across team levels and sexes. Exploring the importance of the degree of hyperextension, as mentioned earlier in the chapter, could also have an important on influence on these results. The researchers of this study recommend utilizing a sample size three to four times larger for a future study to gain power for analysis and a more robust categorization of hyperextension.

Maturation phase. Another important factor that may have contributed to a lack of significance across teams is maturation phase. The participants in this study ranged from freshman to varsity, approximately ages 14 through 18. Absence of thelarche by age 13 or menarche by age 16 constitutes delayed puberty in females (Castro, Rogol, & Shulman, 2013). Thus, most – if not all - of the female participants had likely gone through at least early puberty by the time of their participation in this study (median pubertal onset is approximately 9 years of age in females, with menarche beginning within 2-2.5 years post-pubertal onset; Biro & Chan, 2017). In their 2004 study, Hewett, Myer, and Ford demonstrated that female's neuromuscular control worsens beginning early to late puberty as a result of a change in height, weight, bone length, and lack of natural neuromuscular adaptation to their new physiology. Conversely, the same study showed that towards late puberty (median age 15.8 years), male soccer and basketball athletes showed increased neuromuscular control (Hewett, Myer, and Ford, 2004). A possible explanation contributing to lack of statistical difference between teams is that the athletes of the male teams were at varying levels of pubertal maturation and associated neuromuscular control due to their later onset of puberty, while all the female athletes/teams were likely late pubertal/post-pubertal and already experiencing the corresponding depressed neuromuscular control and hormonal influences leading to joint and ligament laxity associated with female puberty. Less neuromuscular control is thought to be an intrinsic risk factor for ACL injury by predisposing athletes to joint mechanics associated with a higher ACL injury risk (Myer, Chu, Brent, & Hewett, 2008b). Since males' risk for ACL injury based on neuromuscular factors does not decrease until late/post-puberty, reducing their risk - and that of the females' risk throughout puberty and post-puberty - of ACL injury by teaching athletes early on how to properly turn and cut could help reduce injury to the ACL before they are even at heightened risk.

Training and coaching. In 1996, Huston and Wojtys observed male and female athlete's knee laxity to be less than the knee joint laxity of the non-athletic male and female control groups, indicating that a level of training may improve laxity. Additionally, results showed significantly greater knee laxity for females than males, leading to the hypothesis that male athletes had tighter knee joints because they also demonstrated better control of anterior tibial translation with more effective hamstring muscle activation for protection against tibial translation (Huston & Wojtys, 1996). Due to its presence among male athletes and a few female athletes, and the lack thereof amongst non-athletic controls and female athletes who recruit other muscles initially, protective hamstring muscle activation is seemingly a response pattern resulting from training and conditioning (Huston & Wojtys, 1996). The authors concluded that with the limited knee laxity of the male athletic sample, the current training and conditioning programs appeared successful at preventing excessive strain on the ACL for males, whereas females were not as well served by current training and conditioning programs due to their complex neuromuscular function (Huston & Wojtys, 1996).

The results of the research by Huston and Wojtys, and the incidence of hyperextension in both male and female high school athletes in this study may point toward two avenues of necessary prevention: one for stabilization of the joint and the other for avoiding excessive joint mobility. There is evidence to show that neuromuscular training and conditioning through exercises such as balancing and safe planting/landing procedures can effectively prevent ACL injuries (Myklebust et al., 2003). Regarding hypermobility, stretching increases flexibility through improved range of motion (Smith, 1994; Zakas, Grammatikopoulou, Zakas, Zahariadis, & Vamvakoudis, 2006). The increased flexibility and subsequent improved range of motion about a joint represents an increased muscle/tendon unit length and permanent connective tissue lengthening of the muscles/tendons and connective tissue supporting the joint (Jacobson & Speechley, 1990). Therefore, the authors of the current study recommend against intentionally enhancing mobility by way of static stretching warm-ups, particularly for athletes already at risk of ACL injury due to hypermobility (joint laxity) of the knee, as evidenced by observed dynamic hyperextension during a punt kick.

Additionally, the increased incidence of hyperextension in younger athletes found in the current study suggests that, if found to be significant in future studies, may point towards a need for more coaching education. Contrary to the norm of the most qualified and experienced coaches leading the varsity teams, the results of this study indicate that less experienced teams with younger athletes may actually be in most need of the highest level coaches who can identify the athletes at heightened risk of non-contact ACL injury and direct them in neuromuscular training and conditioning, and teach proper form in cutting and turning maneuvers specific to lowering center of mass at the point just prior to a change-in-direction cut beginning from an early age, to reduce the preventable risk of ACL injury.

A final speculative consideration from these results is whether dynamic range of motion elicited by a punt kick is reflective of injury risk in a unique way when compared to the risk profile associated with passive range of motion. It is established that passive knee hyperextension can increase risk of ACL injury 5-fold in young female athletes. At this time, it is unknown how dynamic and passive range of motion compare in relation to risk of injury. Questions concerning this new method of assessing for hyperextension include: What is a normal dynamic range of motion for knee extension? Does dynamic range of motion have a stronger association with ACL injury risk than passive range of motion? Did the use of dynamic knee range of motion in this study, versus passive range of motion as utilized in other studies, impact how the results of this study compared with the known difference of ACL injury risk in the literature?

Research question #1: What is the incidence of knee hyperextension in male and female competitive high school soccer athletes during a soccer punt? In the current study, the incidence of hyperextension for females and males across all skill levels was approximately 16/41 (39%) and 16/36 (44%), respectively.

Research question #2: What is the difference in incidence of knee hyperextension during a soccer punt between males and females? By both multinomial logistic regression and categorical data analysis, there was no statistical difference in the occurrence of knee hyperextension between males and females.

Research question #3: How does the incidence of hyperextension between male and female competitive high school soccer athletes, as viewed via high-speed photography during a soccer punt, correspond to the published rate of ACL injuries as published by Joseph et al. (2013) and Swensen et al. (2013)? Compared to the Joseph et al. (2013) study that demonstrated ACL injury rates of approximately 96/786,293 (0.012%) and 44/914004%) for girls' and boys' high school soccer, the incidence of hyperextension among all participants of this study does not directly correspond with the published rate of ACL injuries.

Research question #4: Is observable knee hyperextension utilizing high-speed photography during a soccer punt a viable screening method for ACL injury risk? It is unclear if this methodology of visualizing hyperextension during soccer punts is a viable screening method for ACL injury risk. However, this methodology is reliable in identifying athletes who demonstrate active knee hyperextension and thus, joint laxity.

Limitations

Several limitations affect the results of this study. One limitation is the clothing of the participants, some of whom were wearing pants and/or shin guards on the days of data collection. This made it considerably more difficult to identify the anatomical landmarks necessary to accurately assess and measure knee extension. Left-footed kickers also present a limitation as their bodies obstructed, to varying degrees, the view of their kicking legs. Additionally, researchers were unable to assess extension based on viewing of anatomic landmarks used to assess right foot-dominant kickers since the photographic view was of the right lateral leg (a left foot-dominant kicker's plant leg) instead of switching to left lateral view. The angle of the camera capturing the punt may not always present a perfect lateral view of the athletes' kicking leg for other reasons as well. For example, photographs of athletes of differing heights may result in distorted angles which would affect analysis, or athletes kicking in different planes would also affect reliability of both visual and angle measurement analysis. An example of a kick in different plans would be an athlete who makes contact with the ball while adducting the leg and flexing the hip rather than simply flexing the hip in one plane. It should also be noted that anatomic landmarks were not physically marked for data collection. Subsequent analysis was performed by estimating anatomic landmarks unless able to visualize, such as the lateral malleolar prominence. Therefore, dress code and absence of photographic equipment modifications were limitations of the previous study which affect the current study.

Finally, each participating athlete followed their team's normal warm-up routine, which was not universal across all teams. Athletes were called in small groups to participate in the study while the rest of the team continued with practice. This resulted in some athletes photographed nearer to the beginning of practice and others nearer to the end of practice. With the time disparity between participants' trials, varying degrees of fatigue may have been a confounding factor. Greater levels of fatigue may result in an increase in the incidence of hyperextension if the fatigued musculature is less capable of resisting hyperextension immediately following a punt.

Areas for Future Research

A logical next step for a follow-up study would be to observe for knee hyperextension with the additional distinction between 'marginal' and 'obvious' hyperextension. Those players with the most drastic, easily identifiable hyperextension would be placed into an 'obvious' category, and those with less appreciable hyperextension would be placed into the 'marginal' category. Athletes exemplifying 'obvious' hyperextension may hold the highest risk for ACL injury as compared to the 'marginal' or 'no hyperextension' or 'questionable' categories. More research is needed to identify whether athletes with the greatest degree of hyperextension more closely match ACL injury rates between males and females in existing literature.

Additionally, existing literature on knee hyperextension focuses on passive range of motion. Previously, degrees of passive laxity/extension have been measured in laboratories using goniometry. To the current researchers' knowledge, this study is the first of its kind to explore dynamic knee hyperextension in the field using a punt kick. Since this has not been explored before, it is unclear whether dynamic hyperextension carries new relevance in regards to ACL injury risk in non-contact injuries over passive hyperextension. The current researchers suspect that observing dynamic – over passive – knee range of motion will be most helpful for identifying risk of non-contact ACL injury because the majority of non-contact ACL injuries results from dynamic movements such as sudden acceleration-deceleration and cutting motions. Passive range of motion is allowed by joint laxity but dynamic hyperextension of the knee may be more heavily influenced by additional factors due to its dependence on muscle activation. For example, an athlete may fail to fully extend during a kick due to lack of effort – lack of muscle activation; or, an athlete may compensate with antagonist muscle activation to prevent excess knee extension. One such protective mechanism of compensation could be activation of the hamstring muscles as a 'recoil' of the lower leg, causing protective flexion at the knee following knee extension during a soccer punt. This concept of hamstring-activated 'recoil' of the leg as a protective mechanism against hyperextension presents another avenue for future research.

In this study, anatomical landmarks were visually approximated. The application of stickers or markers to the center point of the following bony landmarks may yield more accurate results in future studies by allowing for more accurate angle measurement: greater trochanter, lateral tibiofemoral joint space or midpoint of the lateral knee joint, and lateral malleolus. Similar to the current study, the resulting data could be analyzed both visually and by angle measurement software such as Kinovea. The addition of anatomic landmarks for more precise Kinovea angle measurement could subsequently achieve a stronger basis for reliability of visual analysis in identifying hyperextension.

Specific to data collection, a larger sample size would likely be helpful in producing results that carry significance either between teams or between the sexes. The analysis for level of extension was originally thought to be impacted by participants wearing pants or other attire obscuring their true anatomy (for example, shin guards). Surprisingly, there was 100% agreement between Kinovea analysis and visual analysis, indicating that agreement on level of extension is still possible even without a clear picture of the anatomy. However, there is still a question of accuracy with concealing clothing. In future research, specifications regarding clothing may be given to participants ahead of time, requesting they refrain from wearing pants, shin guards, or any clothing that may obstruct the view of the athletes' kicking leg on days of data collection. These specifications may become part of inclusion/exclusion criteria.

The camera angle relative to the athlete's position and their kicking leg in the frame may limit future analysis of the angle at the knee. Using this methodology, a permanent limitation may be inability to capture a true lateral profile view of an athlete who adducts their leg as they flex their hip to kick the ball, creating a plane difficult to capture using one camera. Subsequently, the opportunity for 3-D photography may reveal angles not clear in the current research.

Finally, potential confounding factors, such as specific parameters identifying hyperextension and female hormonal influences, were not considered. An accepted definition of dynamic hyperextension or "normal" active range of motion has not been firmly established in existing literature on which to base the current researcher's parameters for identifying dynamic hyperextension. This is further confounded by lack of standardization of knee extension during a soccer punt. Varied definitions of hyperextension may yield results different from this study, so this limitation must be considered. Establishing normal values for dynamic extension would be helpful for future research.

Conclusion

No difference in incidence of observed hyperextension in males and females or between the teams again lends support to the multifactorial nature of ACL injuries. In high school, younger, less experienced athletes may be at greater risk of ACL injury compared to older, more experienced athletes, but additional research is necessary to confirm this hypothesis. Preventive interventions in such groups may be warranted. It appears that visual analysis may be an accurate method for identifying the presence of knee hyperextension in high school soccer athletes, but more research is required to explore the link between observable, dynamic knee hyperextension and ACL injury.

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Appendix A

Consent Form

Parental Consent Form

Your child is invited to participate in a research study to measure the kinematics of the knee in a long ball punt in competitive soccer players. Your child was selected because they are part of a Mounds View Soccer team, a population sample of convenience. We ask that you read this form and ask any questions you may have before agreeing to have your child in this study.

The study: The purpose of this study is to compare the differences of extension in the knee between males and females. If you agree to have your child in this study, your child will be asked to complete a short questionnaire including their current playing level, height and weight, birth date, menstrual period for females, and previous knee and ankle injuries. To assess the kinematics of each player's punt, they will punt a soccer ball eight times as far as they can. While they punt, they will video-taped, and have rapid speed pictures taken. These recording and pictures will be used to analyze the kinematics of the punt. All recording angles are wide shots, with no deliberate identifiable close-ups of any players.

Risks/benefits: There are minimal risk when partaking in this study. The risk is the same as participating in a soccer practice. The benefit of having this information includes an ability to compare the differences of knee movement between different athletes. There are no known other risks to participation in this study beyond that normally found in soccer participation. There is no direct benefit to subjects who participate in this study. The information gained from this study will be used to further educate coaches about the differences in knee kinematics between the different sexes.

Confidentiality: The records of this study will be kept private. All the information asked for on the questionnaire will be used in the data interpretation phase of this study. Names will be used to identify players in early stages of the research, but only by the research team. When the data is collaborated, before publication, the athlete's names will be taken out in the interest of confidentiality. Consent forms will be kept securely along with results for 7 years after completion of this study.

Voluntary nature/questions: Your decision whether or not to participate will not affect your current or future relations with Crown College or with your sport team. If you decide to allow your child to participate, you are free to withdraw your child at any time without affecting your relationship with Crown College or your sport team. Furthermore, your child may also discontinue participation at any time. The researchers conducting this study are Daniel Hanson, William Newhouse, Sarah Ingraham, Zoe Randall, and Molly Fennig, under the direction of, Dr. Stacy Ingraham, Ph.D. You may ask any questions you have at this time. If you have additional questions at any time, you may contact us at ingrahams@crown.edu.

Parent; I authorize use of my child's picture for clinical presentation use with no personal identifiers of her / him. Circle one; YES NO

In order to use any of the photography for presentation use, "Yes" must be circled by both parent and athlete on both the child assent and the parent consent.

Signature of Parent ______________________________ Date _____________

Signature of Investigator ____________________________ Date _____________

Example of Long Ball Punt

Appendix B

Children's Assent Form

Children's Assent Form

We are conducting a study to measure the kinematics of the knee in a long ball punt in competitive soccer players. The investigators are asking you to assist us in acquiring this information because there is limited information about the kinematics of the knee in long ball punts.

If you agree to be in this study, we are going to ask you to punt a soccer ball eight times. It will be measured for distance, video-taped, and have rapid-motion pictures taken. The video tapes and pictures will help capture the movement of the knee. Sometimes players don't like to be videotaped, yet the video tape will be focused on the athlete's knee. The investigators are simply using live time to precisely capture movement. Once the movements have been analyzed, only randomized subject numbers will be associated with the data from that point forward.

We will also be recording self-reported height and weight measurements, along with day of menstrual cycle (Female Only), as well as injury history. This information will help us analyze differences in the kinematics of the knee.

You may ask questions at any time about this study. Also, if you decide at any time not to finish or to withdraw, you may do so without judgment or penalty. Remember, this is not a test. There is no right or wrong way to do it. Participating or choosing not to participate will have no bearing on your position on your current team or in the future.

Signing this paper means that you have read this or had it read to you and that you want to be in the study. If you don't want to be in the study, don't sign the paper. Remember, being in the study is up to you, and no one will be upset or disappointed if you do not participate or even if you change your mind later in the process.

Athlete; I authorize use of my picture for clinical presentation use with no personal identifiers of me. Circle one; YES NO

Signature of Participant ________________________________ Date ____________

Signature of Investigator ________________________________ Date ____________

Appendix C

Pre-Trial Questionnaires

Athlete Questionnaire - Female

1. Athlete's Full Name:____
2. Athlete's Email:_______________________________________
3. Parent's Email:____
4. Athlete's Sex:______________________
5. Athlete's Age:__________________
6. Date of Birth: ____/_____/_______
7. Athlete's Height:__________________
8. Athlete's Weight:__________________
9. Team (Circle one): Varsity JVA JVB Freshman
10. Main Position (Circle one): Goalie Defense Midfield Forward
11. Secondary Position (Circle one): Goalie Defense Midfield Forward
12. Dominant Leg (left / right): ________________
13. Dominant Hand (left / right) :_________________
14. Previous Injuries (Knee, Ankle, Hip) (designate right or left):_______________
    ____
15. Current Injuries (Knee, Ankle, Hip) (designate right or left): ________________
    ____
16. Surgical Repairs (Knee, Ankle, Hip) (designate right or left): _________________
    ____
17. Athletes Day of Menstrual Cycle (Day 1 is first day of bleeding): _____________

Athlete Questionnaire - Male

1. Athlete's Full Name:____
2. Athlete's Email:______________________________________
3. Parent's Email:______________________________________
4. Athlete's Sex:____________________
5. Athlete's Age:_________________
6. Date of Birth: ____/_____/_______
7. Athlete's Height:_________________
8. Athlete's Weight:_________________
9. Team (Circle one): Varsity JV Green JV White JVB Freshman
10. Main Position (Circle one): Goalie Defense Midfield Forward
11. Secondary Position (Circle one): Goalie Defense Midfield Forward
12. Dominant Leg (left / right): _______________
13. Dominant Hand (left / right) :________________
14. Previous Injuries (Knee, Ankle, Hip) (designate right or left):______________

    ____
15. Current Injuries (Knee, Ankle, Hip) (designate right or left): _______________

    ____
16. Surgical Repairs (Knee, Ankle, Hip) (designate right or left): ________________

    ____

Appendix D

Trial Day Questionnaires

Test Date ______________________Subject Number: ________

Temperature:_____________Wind (mph): ____________ Rain: drizzle, damp, steady

Athlete Questionnaire - Female

1. Athlete's Full Name:_____________________________________
2. Athlete's Email:____________________________________
3. Parent's Email:_____________________________________
4. Athlete's Sex:____________________
5. Athlete's Age:_________________
6. Date of Birth: ____/____/______
7. Athlete's Height:_________________
8. Athlete's Weight:_________________
9. Team (Circle one): Varsity JVA JVB Freshman
10. Main Position (Circle one): Goalie Defense Midfield Forward
11. Secondary Position (Circle one): Goalie Defense Midfield Forward
12. Dominant Leg (left / right): _______________
13. Dominant Hand (left / right) :________________
14. Previous Injuries (Knee, Ankle, Hip) (designate right or left):______________

    ____
15. Current Injuries (Knee, Ankle, Hip) (designate right or left): _______________

    ____
16. Surgical Repairs (Knee, Ankle, Hip) (designate right or left): ________________

    ____
17. Athletes Day of Menstrual Cycle (Day 1 is first day of bleeding): ____________

Test Date ______________________ Subject Number: ________

Temperature:______________Wind (mph): ____________ Rain: drizzle, damp, steady

Athlete Questionnaire - Male

1. Athlete's Full Name:____
2. Athlete's Email:_____________________________________
3. Parent's Email:______________________________________
4. Athlete's Sex:____________________
5. Athlete's Age:_________________
6. Date of Birth: ____/_____/_______
7. Athlete's Height:_________________
8. Athlete's Weight:_________________
9. Team (Circle one): Varsity JV Green JV White JVB Freshman
10. Main Position (Circle one): Goalie Defense Midfield Forward
11. Secondary Position (Circle one): Goalie Defense Midfield Forward
12. Dominant Leg (left / right): _______________
13. Dominant Hand (left / right) :________________
14. Previous Injuries (Knee, Ankle, Hip) (designate right or left):______________

    ____
15. Current Injuries (Knee, Ankle, Hip) (designate right or left): _______________

    ____
16. Surgical Repairs (Knee, Ankle, Hip) (designate right or left): ________________

    ____

Appendix E

Crown College IRB Approval

CROWN COLLEGE
Graduate School

Application for Review of Research Involving Human Subjects Integrated Research Projects

Federal regulations and Crown College's Institutional Review Board (IRB) policy require that all research involving humans as subjects be reviewed and approved by the University's IRB *before research begins*. This form has been designed for faculty research applications to the IRB Committee. Please type your answers in the fields provided, and submit it via email to the IRB Committee Chair.

1. Title of Project: **The Difference in Kinematics of a Long Ball Soccer Punt in Male & Female Competitive Youth Soccer Players**

2. **Principal Investigator's Name:** Stacy Ingraham

   Campus or Mailing Address: W301

   Phone Number: 651-226-7671

   Crown College e-mail: ingrahams@crown

   Has PI completed human subjects (CITI) training? ☒ Yes ☐ No

3. **Co-Investigator's Name** (if any): **Daniel Hanson**

   Status: ☐ Crown Online Adjunct Faculty
   ☐ Crown Online Full-time Faculty/Staff
   ☒ Other (specify) High School Research Team

   Phone Number: 612-210-5219

   Crown College e-mail:

   Has co-investigator completed human subjects (CITI) training? ☒ Yes ☐ No

4. **Co-Investigator's Name** (if any): Sarah Ingraham

   Status: ☐ Crown Online Adjunct Faculty
   ☐ Crown Online Full-time Faculty/Staff
   ☒ Other (specify) High School Research Team

   Phone Number: 651-717-5554

   Crown College e-mail:

   Has co-investigator completed human subjects (CITI) training? ☒ Yes ☐ No

5. **Co-Investigator's Name** (if any): William Newhouse

   Status: ☐ Crown Online Adjunct Faculty
   ☐ Crown Online Full-time Faculty/Staff
   ☒ Other (specify) High School Research Team

   Phone Number: 651-639-0778

   Crown College e-mail:

   Has co-investigator completed human subjects (CITI) training? ☒ Yes ☐ No

6. **Co-Investigator's Name** (if any): Molly Fennig

   Status: ☐ Crown Online Adjunct Faculty
   ☐ Crown Online Full-time Faculty/Staff
   ☒ Other (specify) High School Research Team

   Phone Number: 651-408-4053

   Crown College e-mail:

   Has co-investigator completed human subjects (CITI) training? ☒ Yes ☐ No

7. **Co-Investigator's Name** (if any): Zoe Randall

   Status: ☐ Crown Online Adjunct Faculty
   ☐ Crown Online Full-time Faculty/Staff
   ☒ Other (specify) High School Research Team

   Phone Number: 651-398-8226

   Crown College e-mail:

   Has co-investigator completed human subjects (CITI) training? ☒ Yes ☐ No

8. Vulnerable Populations: Indicate the categories of participants in this study. Check ALL that apply.

   a. ☐ Decisionally impaired
   b. ☐ Decisionally impaired and institutionalized
   c. ☒ Minors (under age 18 – give age ranges)
   d. ☐ Patients (including pregnant/lactating women or persons with HIV/AIDS)
   e. ☐ Prisoners
   f. ☐ Students
   g. ☐ Existing/Secondary Data
   h. ☐ Other vulnerable population (specify)
   i. ☐ Volunteers not known to be part of a vulnerable population

9. Number of participants to be: Recruited 200 Enrolled

10. Risk Level: Indicate which of the categories listed below accurately describes this protocol:
    a. ☒ Not greater than minimal risk (i.e., risk encountered in daily life)
    b. ☐ More than minimal risk, but with the prospect of direct benefit to individual participants
    c. ☐ Greater than minimal risk, no prospect of direct benefit to individual participants, but likely to yield generalized knowledge about the topic
    d. ☐ Research not otherwise approvable which presents an opportunity to understand, prevent, or alleviate a serious problem affecting the health and welfare of participants
11. Does this research involve past, present, or future physical or mental health or condition of subjects; provision of health care to subjects, or the past, present, or future payment for the provision of health care to subjects?
    a. ☐ Yes - see HHS policy on HIPAA: http://www.hhs.gov/ocr/hipaa/
    b. ☒ No
12. Does this research involved identifiable information from students' educational records?
    a. ☐ Yes – see FERPA guidelines: http://www.ed.gov/policy/gen/guid/fpco/ferpa/index.html
    b. ☒ No
13. Does this research involve *minors* in which any of the following information will be ascertained: political affiliations or beliefs of the student or student's parent; mental and psychological problems of the student or the student's family; sex behavior or attitudes; illegal, anti-social, self-incriminating, or demeaning behavior; critical appraisal of others with whom respondents have close family relationships; legally recognized privileges or analogous relationships (e.g., lawyer, physician, minister); religious practices, affiliations, or beliefs of the student or student's parent; or income?
    a. ☐ Yes - see PPRA guidelines: http://www.ed.gov/policy/gen/guid/fpco/ppra/index.html
    b. ☒ No
14. Are you collecting data at your place of employment or internship?
    a. ☐ Yes. If yes, what is your role in relation to the potential subjects?
    b. ☒ No
15. Is this a web-based survey?
    a. ☐ Yes – what is the URL and password (if applicable)?
    ☒ No

The information I have provided about my research on this form is complete and accurate. No changes will be made without advance approval of the Internal Review Board. I understand that additional forms may be needed if data from Crown College is to be accessed.

PI Signature: ______________________________ **Date:** __________

(Continued on the next page)

Overview of the Project

Write a concise statement of purpose and objectives of the research. Use straightforward, non-technical language.

This research study will attempt to analyze the kinematics of the knee in a long ball punt in competitive soccer players and to quantify the differences between high school males and females.

Where will the research be conducted?

Mounds View High School, Arden Hills, MN

Who will conduct the research and how many investigators will be involved?

Stacy Ingraham and the Mounds View High School Research Team (5)

What is your research training? Describe your competence to carry out this research. Include graduate-level research classes you have taken, other research studies you have conducted or participated in, and so on.

See attached Vita

Data Collection

Describe the data gathering instruments that will be used. Attach copies of all questionnaires, interview prompts, or other data collection instruments. All measures should be submitted in Word or as .jpg files.

Survey and player punt results on data sheet

Will videotape or audiotape be used to collect data? ☒ Yes ☐ No

If no, describe your process of note-taking or data collection. How will you insure that you are accurately recording what participants are saying or how they are responding?

If no, how will you safely store the data that you collect and how will you safely destroy it when the research is concluded?

If yes, describe the procedures that will be used to maintain confidentiality during taping.

Once the data has been coded with the personal data, the names of the subjects will be removed and will only be identified with a subject number.

If yes, describe how tapes (or digital recordings) will be stored and when they will be disposed of.

All recordings will be analyzed on a password protected computer. They will be disposed of 2 years after the completion of the data collection.

If yes, who will have access to the tapes (or digital recordings) and who will make the transcriptions?

Only the listed researchers on this project will have access to the tapes.

If yes, describe the procedure used during transcription to remove identifying information.

once the movement analysis software is complete, all identifying information will be removed.

If yes, describe any plans to use the recorded information for purposes other than this research.
no

How much time will be required from each participant? Include the number and length of times of participation (e.g., two sessions lasting 30 minutes each).

1 information session (approx 15 minutes). 1 testing session (apprx. 8-10 minutes)

Participants

How many participants do you estimate will participate in your study? 180

Describe the expected ages, gender, ethnic backgrounds and health status of subjects.

14-18

If any of the participants will be children, cognitively impaired, prisoners, pregnant women and/or fetuses, or individuals from other vulnerable groups, please provide a rationale for their participation.

This is the population that needs to be studied to provide insight to common injuries in soccer.

Will data collection be done in a classroom setting? ☐ Yes ☒ No

If yes, explain what students who do not participate in the research will be doing.

How will participants be selected or recruited?

From the high school soccer programs at Mounds View High School at a parent-athlete meeting.

NOTE: Attach any advertisements, flyers, cover letters, or scripts to be used in recruiting subjects.

Will participants receive any compensation or reward for their participation? ☐ Yes ☒ No

If yes, please provide details. If extra credit is utilized for compensation, please provide information on what alternative method will be available for those who choose not to participate to earn the extra credit.

As participation must remain voluntary, explain how the researcher will minimize any possibility of perceived coercion to participate.

The researchers receive nothing in exchange for the subject participation. The research is not related to participation in the sport of soccer. The coaches will not be privy to any of the details of the data collection, only the results. The results will not reveal individual results.

Is the researcher a teacher and/or supervisor of potential subjects? ☐ Yes ☒ No

If yes, coercion should be specifically addressed both here and in the consent form. For example, in the consent form, you might write something like "Although I am your teacher, I will not know who participated in this project and your relationship with me and your performance in this class will not be affected by participation or non-participation."

NOTE: Attach a letter giving approval from any agencies or schools involved with the data collection.

Currently waiting for approval from the athletic director, Bob Madison. Will submit email of approval.

Benefits and Risks

What are the potential benefits of this research (e.g., to participants, to generalizable knowledge, to community or society)?

This information could potentially be used as a qualifier as a field test for ACL risk.

Does the proposed study pose a risk to participants? Be sure to consider physical, psychological, social, legal, or economic risks. ☐ Yes ☒ No

If yes, describe the risk and your strategies for protecting the participant from this risk.

Confidentiality

Describe the precautions that will be taken to ensure the privacy of subjects and confidentiality of information by answering the following questions. Be explicit if the data are sensitive.

Once data has been collected, it will only be identified with randomized subject numbers. All personal identifiers will be removed for analysis. The only place any of the original information will be housed will be on a pass-protected Crown College laptop.

Appendix F

Bethel University IRB Approval

5/30/2017 Bethel University Mail - Bethel IRB Approval

BETHEL UNIVERSITY Jessica Schindler <jes49766@bethel.edu>

Bethel IRB Approval

Wallace Boeve <w-boeve@bethel.edu> Thu, Mar 9, 2017 at 12:28 PM
To: David McGehee <dam93336@bethel.edu>, Jessica Schindler <jes49766@bethel.edu>, Jon-Paul Ciszewski <joc22983@bethel.edu>
Cc: Stacy Ingraham <ingrahams@crown.edu>, Lisa Naser <l-naser@bethel.edu>, Peter Jankowski <p-jankowski@bethel.edu>

March 9, 2017

David, Jessica, and Jon-Paul;

After careful discussion with the Bethel University IRB Chair, we have agreed that your study in fact does meet Bethel's Level 3 approval. Therefore, as granted by the Bethel University Human Subjects committee as the program director, I write this letter to you in approval of Level 3 Bethel IRB of your project entitled: "Knee Hyperextension Screening as a Predictor of ACL Injury Potential in Competitive High School Soccer Players." This approval is good for one year from today's date. You may proceed with data analysis. I remind you, as with any human subjects research, but especially with this pediatric population, that you handle the data with the strictest confidentiality. Please let me know if you have any questions.

Sincerely;

Wallace Boeve, EdD, PA-C

Program Director

Physician Assistant Program

Bethel University

w-boeve@bethel.edu

651 308-1398 cell

651 635-1013 office

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http://gs.bethel.edu/academics/masters/physician-assistant

CC: Bethel IRB Chair, Peter Jankowski

Faculty Chair Advisor, Stacy Ingraham

PA Program Research Coordinator, Lisa Naser