BIOMECHANICAL DIFFERENCES OF THE LOWER EXTREMITY DURING A LANDING AND JUMPING TASK IN PREPUBESCENT GIRLS AND BOYS

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Females incur non-contact anterior cruciate ligament injuries at a rate four-six times higher than their male peers. This increased incidence may be attributed to lower extremity biomechanical differences between girls and boys during landings from athletic maneuvers. While most of the published literature focuses on a postpubsent population, there is little data investigating the differences between prepubescent girls and boys. The purpose of this study was to investigate if biomechanical differences at the knee were present between prepubescent girls and boys during a landing and jumping task.

Nineteen (10 boys / 9 girls) prepubescent soccer players participated in this study. A motion analysis system and force plate was used to collect data. Knee flexion/extension angle, varus/valgus angle, vertical ground reaction forces and anterior tibial shear force were assessed during a vertical jump and landing task.

Statistical analysis revealed that there were no significant differences between genders for vertical ground reaction force, peak posterior ground reaction force, anterior tibial shear force, knee flexion/extension and varus/valgus angle at peak vertical ground reaction force and varus/valgus angle at initial contact with the force plate. There was significance between genders for the knee flexion/extension angle at initial contact with the force plate. The results of this research would indicate that the biomechanical differences of the lower extremity may emerge during or after puberty. Based upon these findings, it may be appropriate to initiate

injury prevention programs at an earlier age to aid in correcting the high risk biomechanical differences typically seen in the postpubescent population.

TABLE OF CONTENTS

PREFACE......XI

1.0 INTRODUCTION...... 1

1.1 INTRODUCTION 1

1.2 PROPOSED RISK FACTORS 2

1.3 DEVELOPMENTAL EFECTS ON BIOMECHANICAL CHARACTERISTICS 4

1.4 STATEMENT OF THE PURPOSE 7

1.5 HYPOTHESIS AND SPECIFIC AIMS 7

1.6 SIGNIFICANCE OF THE STUDY...... 9

1.7 DEFINITION OF TERMS 10

2.0 LITERATURE REVIEW 12

2.1 INTRODUCTION 12

2.2 EPIDEMIOLOGY OF ACL INJURIES...... 12

2.3 MECHANISM OF NON-CONTACT ACL INJURY 14

2.4 PROPOSED RISK FACTORS FOR NON-CONTACT ACL INJURY 15

2.5 METHODOLOGICAL CONSIDERATIONS 30

2.6 SUMMARY 31

3.0 METHODS 33

3.1 EXPERIMENTAL DESIGN 33

3.2 DATA ANALYSIS 39
3.2.1 Data Reduction 39
3.3 STATISTICAL ANALYSIS 43
4.0 RESULTS 44
4.1 SUBJECT CHARACTERISTICS 45
4.1.1 Specific Aim 1 46
4.1.2 Specific Aim 2 48
4.1.3 Specific Aim 3 49
4.1.4 Specific Aim 4 51
5.0 DISCUSSION 53
5.1 INTRODUCTION 53
5.2 KNEE ANGLES 54
5.3 GROUND REACTION FORCES 58
5.4 PROXIMAL ANTERIOR TIBIAL SHEAR FORCE 60
5.5 AGE COMPARISONS WITHIN THE SUBJECTS 62
5.6 PREVENTION PROGRAMS 64
5.7 LIMITATIONS TO THE STUDY 66
5.8 CLINICAL SIGNIFICANCE 67
5.9 CONCLUSIONS 68
5.10 FUTURE RESEARCH 69
APPENDIX A 70
APPENDIX B 71
APPENDIX C 72

BIBLIOGRAPHY **75**

LIST OF TABLES

Table 1. Participant Demographic Data 45

Table 2: Knee angles at initial contact and peak vgrf during a landing task. 46

Table 3. Knee angles at initial contact and peak vgrf during vertical jump. 47

Table 4. Peak vertical and peak posterior vgrf during landing and jumping task. 50

Table 5. Anterior shear force during a landing task and vertical jump 52

Table 6. Knee Angle Variables for landing grouped by gender and age 62

Table 7. Ground reaction force variables for landing grouped by gender and age 63

Table 8. Knee Angle Variables for vertical jump grouped by gender and age. 63

Table 9. Ground reaction force variables for vertical jump grouped by gender and age 64

LIST OF FIGURES

Figure 1. Orientation of force plate 36

Figure 2. Reflective marker placement 38

Figure 3. Knee flexion/extension angle during a vertical jump 47

Figure 4. Knee varus/valgus angle during a vertical jump 48

Figure 5. Peak vertical ground reaction force during a vertical jump 50

Figure 6. Peak posterior ground reaction force during a vertical jump 51

PREFACE

This dissertation would not have been possible without the support and assistance from many other individuals. First I would like to sincerely thank my committee for their time and guidance on this project. I would specifically like to thank my dissertation advisor Dr. Jean McCrory, who took this project on when I really needed a silver lining in my dark cloud. The guidance, support, friendship and belief that Dr. McCrory has bestowed upon me is beyond measure.

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1.0 INTRODUCTION

1.1 INTRODUCTION

Female participation in organized and recreational athletics has shown a steady increase in the United States since the Title IX act of 1972 ensured equal opportunity for women in all federally funded educational programs, including intramurals, club and varsity athletics (Lopiano, 2000). Since the inception of Title IX in 1972, female sport participation at the high school level has increased from 7% of all student athletes to 41% in 2005 (NFSHSA, 2005). In the collegiate population, female athletic participation has increased from 27.8% of all student athletes 1981 to 42% in 2001 (NCAA, 2001). The increase in high school and collegiate female athletic participation has been perpetuated by escalating numbers of children participating in organized sports, an estimated 30 million children each year (Adirim & Cheng, 2003). A potential adverse consequence of physical activity is incurred injuries. It has been estimated that athletic participation by individuals aged 5-24 result in 2.6 million emergency department visits annually (Burt & Overpeck, 2001). Furthermore, it has been reported that up to 10 million children aged 5-18 will sustain an injury that requires medical attention (Adirim & Cheng, 2003).

Unquestionably one of the most devastating injuries afflicting this population is an anterior cruciate ligament (ACL) tear with the majority of ACL injuries resulting from a non-contact mechanism (Agel, Arendt, & Bershadsky, 2005). It has been clearly established that females injure their ACL four to six times more frequently than male contemporaries (Agel et al., 2005; Arendt, 1999; Ferretti, Papandrea, Conteduca, & Mariani, 1992; Gwinn, Wilckens, McDevitt, Ross, & Kao, 2000; Lindenfeld, Schmitt, Hendy, Mangine, & Noyes, 1994; Myklebust, Maehlum, Holm, & Bahr, 1998). Moreover, this increased incidence has been shown notably in sports that require landing or cutting maneuvers, particularly basketball and soccer (Agel et al., 2005; Arendt, 1999; Gray et al., 1985; Lindenfeld et al., 1994). While ACL injury rates for the high school and collegiate population have been reported, there are limited data on ACL injuries in the prepubescent athlete. Andrish et al. (Andrish, 2001) found only a 0.5% incidence in ACL injuries for children under 12 years of age after reviewing 1000 case files from a Cleveland Clinic registry. A more recent study reviewed insurance claims from a company specializing in soccer coverage and found that ACL injury claims for girls and boys aged 5-18 years were 37% and 24% of total knee claims respectively (Shea, Pfeiffer, Wang, Curtin, & Apel, 2004). However, when analyzed for the prepubescent age group, boys had suffered 6 reported ACL injuries while girls had suffered none, displaying that the ACL injuries for girls did not begin until after they had entered puberty. The authors concluded their data suggests that skeletally immature females may have a higher incidence of ACL injuries compared with males with a significant increase of ACL injury after 11-12 years of age (Shea et al., 2004)

1.2 PROPOSED RISK FACTORS

A conference by a group physicians and researchers specializing in the prevention of noncontact ACL injuries grouped noncontact ACL injury risk factors while forming their consensus statement into four main categories: environmental, anatomic, hormonal and biomechanical (Griffin et al., 2000; Huston, Greenfield, & Wojtys, 2000). The panel concluded that biomechanical factors appeared to be the most responsible factor for the higher rate of ACL injuries in women (Griffin et al., 2000). Biomechanical factors include muscle strength, body movement, neuromuscular control and skill level (Griffin et al., 2000). These risk factors have been further categorized into intrinsic (not changeable), extrinsic (changeable) and combination (both) (Ireland, 2002). Biomechanical factors fall into both the extrinsic and combination categories (Ireland, 2002). Based on the panels findings and suggestions, numerous researchers have investigated the aforementioned factors in an attempt to explain the disproportionate rate of injury between the sexes in high school and collegiate cohorts, particularly the biomechanical factors (Fagenbaum & Darling, 2003; Ford, Myer, & Hewett, 2003; Hewett et al., 2005; Lephart, Ferris, Riemann, Myers, & Fu, 2002; Malinzak, Colby, Kirkendall, Yu, & Garrett, 2001; McLean, Neal, Myers, & Walters, 1999; Rozzi, Lephart, Gear, & Fu, 1999; Sell et al., 2005; Wojtys & Huston, 1994). The majority of ACL injuries occur without contact during an uncontrolled landing with the knee position near extension (Arendt, 1999; Boden, Dean, Feagin, & Garrett, 2000). It has been further reported that this mechanism is a result of deceleration prior to a change of direction or landing with the knee between full extension and 20 degrees of flexion (Boden et al., 2000). Females land with a smaller flexion angle (i.e. more extended) and wider valgus angle at the knee joint as compared to their male counterparts which may lead to increased stress upon the ACL (Chappell, Yu, Kirkendall, & Garrett, 2002; Colby et al., 2000; Lephart et al., 2002; Malinzak et al., 2001). Further research has shown that females are exhibiting greater knee flexion/extension moments upon landing from athletic tasks (Chappell et al., 2002). Additionally, vertical ground reaction forces were found to be higher in females as compared to males as a result of the "stiffer" landing at the knee (Hewett et al., 2005). Neuromuscular strategies including muscle activation and timing have also shown to be different between genders and this may contribute to altered dynamic knee stability (Huston & Wojtys, 1996; Myer, Ford, & Hewett, 2005; Rozzi et al., 1999; Wojtys, Huston, Schock, Boylan, & Ashton-Miller, 2003). Altered recruitment and timing of the muscles that contribute to dynamic knee stability could place the knee joint in an imbalanced or ill-timed position during athletic participation which may predispose the ACL to injury (Besier, Lloyd, & Ackland, 2003). Additionally, females were found to depend on their quadriceps more than their hamstrings for knee stability during landing and jumping maneuvers (Hewett, Stroupe, Nance, & Noyes, 1996; Huston & Wojtys, 1996; Malinzak et al., 2001). Altered neuromuscular strategies as mentioned above coupled with decreased flexion angles may increase result in increased strain on the ACL via increased proximal anterior tibial shear force (Huston & Wojtys, 1996; Malinzak et al., 2001; Markolf, O'Neill, Jackson, & McAllister, 2004; Renstrom, Arms, Stanwyck, Johnson, & Pope, 1986).

1.3 DEVELOPMENTAL EFECTS ON BIOMECHANICAL CHARACTERISTICS

Children begin to enter into puberty at an average age of 11 and 11.5 years for girls and boys, respectively (Malina, Bouchard, & Bar-Or, 2004). However, there is a considerable amount of individual variation for the onset of puberty having been reported to be anywhere between 8.5 to 13 years for girls and 9.5 to 13.5 years for boys. Dr. James Tanner, a pediatric endocrinologist developed a 5 stage scale to assess sexual maturation rates based on genitalia development and pubic hair growth, also known as the Tanner Scale. (Appendix A) A tanner stage of 1 is considered prepubescent and is characterized by small testes and a childlike penis in boys, absence of breast tissue and a flat areola in girls and lack of pubic hair in both sexes (Malina et al., 2004).

One of the biological characteristics that undergo change during puberty is muscular strength. Strength characteristics between genders have been shown to parallel each other during development until they begin to deviate at puberty (De Ste Croix, Armstrong, Welsman, & Sharpe, 2002; Malina et al., 2004). Boys exhibit a linear strength increase in relation to chronological age until the adolescent growth spurt at 12 to 13 years of age where there is a marked non-linear increase (Beunen, 2000). Girls, however, have an opposite presentation, while strength increases linearly with chronological age until approximately the age of 15, it then plateaus with no clear presentation of an adolescent growth spurt (Malina et al., 2004). However, it has recently been shown that peak torque during an isokinetic knee flexion test increased linearly for boys between the ages of 9 – 14, however, increases were only seen until the age of 11 in girls (Barber-Westin, Noyes, & Galloway, 2005). This is a similar finding likened to quadriceps dominance that was mentioned earlier.

Children begin to attain the complex motor skills needed for landing and jumping movements around the age of 6 or 7 years (Malina et al., 2004). Over the next few years, motor skills continue to improve until approximately the age of 12 years when children master landing and jumping movements (Harris, 2000). Coinciding with the age that the motor skills are mastered, girls and boys begin to begin enter puberty. Puberty has been described as a transitional period between childhood and adulthood and includes the appearance of secondary sex characteristics (Malina et al., 2004). Coincidentally, this age has been shown to be associated with a 37% increase in ACL injuries of all knee injuries seen in girls, increasing from zero ACL injuries under the age of 12 years to 363 ACL injuries out of 1695 total knee injuries from 12 – 18 years of age (Shea et al., 2004). It may be theorized that the dramatic increase in

ACL injuries seen in girls may be influenced by the neuromuscular differences between girls and boys that emerge during puberty specifically the mastering of motor skills and strength differences between genders. Until recently, jumping and landing strategies had yet to be investigated in the prepubescent population. Prepubescent girls have been found to exhibit increased knee flexion angles, increased mediolateral knee joint forces and increased knee extensor moments than postpubescent females in the same study (Hass et al., 2005). Additionally, Hass et al. (Hass et al., 2005) found that prepubescent girls were landing with 11% higher ground reaction forces than their postpubescent female counter parts. The authors speculate that this was a result of the greater knee flexion angle at landing and muscle activation patterns (Hass et al., 2005) However, in a study by Swartz et al. (Swartz, Decoster, Russell, & Croce, 2005), vertical ground reaction forces were significantly higher for the prepubescent group but knee flexion angle was found to be the less than their postpubescent counterparts. Swartz et al. (Swartz et al., 2005) also found that prepubescent girls were landing from a vertical jump with greater knee valgus angle similar to that seen in the older postpubescent population. Barber-Westin (Barber-Westin, Galloway, Noyes, Corbett, & Walsh, 2005) found that prepubescent girls were landing with similar valgus alignments in drop jump tests as post-pubescent females (Barber-Westin, Noyes et al., 2005). As the previous research findings show, data on landing and jumping kinematics and kinetics in the prepubescent athletic population are limited and inconclusive. Additionally, data on anterior shear force between genders are nonexistent in this population. It still remains unclear if the biomechanical differences between genders that are proposed noncontact ACL injury risk factors in an adolescent and adult population are present for the prepubescent population.

1.4 STATEMENT OF THE PURPOSE

It has been clearly established that biomechanical differences at the knee exist between genders which may contribute to the increase in non-contact ACL injuries in the adolescent and collegiate female athlete population. Limited research has yielded mixed results on the incidence of ACL injuries in the prepubescent population with one study showing the risk being increased for the male prepubescent population. The dissimilar ACL injury incidence between prepubescent boys and girls and postpubescent boys and girls may be indicative of the biomechanical differences that become evident after the onset of puberty between genders. The purpose of this study is to determine if biomechanical differences exist between prepubescent boys and girls, particularly differences in knee flexion and varus/valgus angle, knee flexion/extension and varus/valgus moments, vertical ground reaction forces and proximal anterior tibial shear force of the dominant leg during a landing and jumping task. The landing task will consist of a drop jump onto the dominant leg while landing on a force plate. The jumping task will consist of a vertical jump for height landing on both legs, however, only the dominant leg will land on the force plate and be evaluated.

1.5 HYPOTHESIS AND SPECIFIC AIMS

Specific Aim 1: Determine the flexion and varus/valgus angles of the dominant knee at initial contact and peak vertical ground reaction force using 3-dimensional motion analysis and a force plate between 26 girls and 26 boys ages 6 -7 and 9-10 years during a landing and jumping task.

Hypothesis 1: Flexion and varus/valgus angles of the dominant knee will not be significantly different between boys and girls at initial contact and peak vertical ground reaction force.

Specific Aim 2: Determine the flexion/extension and varus/valgus moments of the dominant knee using 3-dimensional motion analysis and a force plate at peak vertical ground reaction force between 26 girls and 26 boys 6 -7 and 9-10 years during a landing and jumping task.

Hypothesis 2: Flexion/extension and varus/valgus moments of the dominant knee will not be significantly different between boys and girls at peak vertical ground reaction force.

Specific Aim 3: Determine peak vertical ground reaction force and peak posterior ground reaction force of the dominant leg between 26 girls and 26 boys 6 -7 and 9-10 years during a landing and jumping task.

Hypothesis 3: Peak vertical ground reaction force and peak posterior ground reaction force will not be significantly different between boys and girls.

Specific Aim 4: Determine proximal anterior tibial shear force at peak vertical ground reaction force of the dominant leg between 26 girls and 26 boys 6 -7 and 9-10 years during a landing and jumping task.

Hypothesis 4: Proximal anterior shear force at peak vertical ground reaction force will not be significantly different between boys and girls.

1.6 SIGNIFICANCE OF THE STUDY

Females injure their ACL at an alarmingly higher rate than their male counterparts, particularly through a non-contact mechanism. Furthermore, it has been shown through previous research that females have altered lower extremity biomechanical and neuromuscular strategies during tasks that mimic high risk positions that lead to injury. While the exact mechanism is unknown, these altered strategies have been theorized to lead to the higher incidence of injury. Additionally, these altered strategies have been displayed in the collegiate and high school population, however it is unknown exactly when they develop. There has been success with injury prevention programs which focus on exercises that may reduce the potential risk for injury. It would be of interest to investigate if the altered strategies are present in a pre-pubescent population to help further the understanding of non-contact ACL injury mechanisms, specifically those incurred by female athletes.

1.6.1 Limitations of the Study

The following are potential limitations to the study;

- Working with very young subjects may present a challenge in terms of attention span, interest and understanding the tasks.
- Motion analysis calculations are made by using external markers to predict an internal reference point. Error can be introduced through improper marker placement and movement of the markers over the skin during a task.

1.6.2 Delimitations of the Study

The following are descriptions of precautions that will be taken to minimize the limitations of the study;

- All subjects will be given a detailed explanation and demonstration of the task. Additionally they will be allowed adequate warm-up time and presented with a safe, comfortable environment.
- Motion analysis marker placement will follow the standards and recommendations set by published norms. Additionally, a "test trial" will be taken to rule out marker confusion or blending.

1.7 DEFINITION OF TERMS

Anterior Cruciate Ligament (ACL): The anterior cruciate ligament is one of four main ligaments of the knee providing rotational stability and limiting the tibia from sliding forward on the femur.

Moment: The tendency of a force to produce rotation, dependent of the magnitude of the force and the distance between the force and the line of action from the force to the axis of rotation.

Vertical ground reaction force: Force that is generated equally and in opposition to the force generated by the body upon a surface through the foot.

Isometric contraction: Muscle contraction in which there is no movement at the joint.

Kinematic: Kinematics describe the linear and angular displacement, acceleration and velocity as it relates to movement.

Kinetic: Kinetics describe the forces, both internal and external, that are used to create movement.

2.0 LITERATURE REVIEW

2.1 INTRODUCTION

Females were first permitted to participate in the Summer Olympic games of 1912. This milestone contributed to an increase in female athletic participation until the Title IX educational amendments act of 1972 ensuring equal opportunity for men and women in federally funded programs. Title IX created numerous opportunities for young girls and women and as a result female participation in organized sports increased considerably (NCAA, 2001; NFSHSA, 2005). An unfortunate yet unavoidable consequence of physical activity is the potential to sustain an athletic related injury. It has been estimated that individuals between 5-24 years of age generate 2.6 million emergency room visits annually for sports related injuries (Burt & Overpeck, 2001). While any injury can be severe and ultimately career threatening, much attention has focused on injuries of the knee, specifically non-contact anterior cruciate ligament injuries and the disproportionate incidence of these injuries between males and females. Second section

2.2 EPIDEMIOLOGY OF ACL INJURIES

It has been widely reported that females injure their ACL during athletic participation at a much higher rate than their male counterparts (Agel et al., 2005; Arendt, 1999; Ferretti et al., 1992; Gray et al., 1985; Gwinn et al., 2000; Ireland, 1999; Lindenfeld et al., 1994; Myklebust et al., 1998; NCAA, 2001; Powell & Barber-Foss, 2000; Viola, Steadman, Mair, Briggs, & Sterett, 1999). Gwinn et al. (Gwinn et al., 2000) evaluated the relative risk of ACL injuries between male and female midshipman participating in intercollegiate basketball, soccer and rugby. Data from ACL injuries incurred during practice and competition were collected over a six year span. The authors found that women had an overall relative injury risk of 3.96 compared to men participating in the same sports (Gwinn et al., 2000). Additionally, it was noted that when analyzing sports separately, women soccer players had a relative risk greater than 9 times their male counterparts (Gwinn et al., 2000). While studying injury rates of male and female basketball and soccer players in the NCAA, Arendt and Dick (Arendt & Dick, 1995) found that female collegiate soccer and basketball athletes had significantly higher rates of ACL injury regardless of the mechanism over a five year span. Agel et al. (Agel et al., 2005) conducted a similar yet more comprehensive study examining ACL injuries that were reported to the National Collegiate Athletic Association Injury Surveillance System (NCAA ISS) over a 13 year span from 1990 - 2002. The authors found that the trends reported earlier by Arendt and Dick had persisted, showing that female collegiate athletes were still injuring their ACL significantly more than their male counterparts in the same sports (Agel et al., 2005). The trend of increased female ACL injury has also been shown with high school aged athletes.

While ACL injury rates and statistics have been established for the high school and collegiate population, it has only recently been explored in the pediatric population. Shea et al. (Shea et al., 2004) studied over 8,000 insurance claims submitted to an insurance company specializing in coverage for youth soccer leagues across the United States. ACL injuries accounted for 37% of total knee injury claims for females and 24% of total knee injury claims for males with an overall claim percentage of 31 for all knee injury claims submitted (Shea et al., 2004). While the first claim for an ACL injury was a 5 year old male, ACL injuries didn't begin to steadily increase until the age of 11 for both genders. Additionally, between the ages of 11 and 18, the female ACL injury rate was almost twice that of males (Shea et al., 2004). Lastly, Andrish et al. (Andrish, 2001) found a .5% incidence of ACL injury in children under the age of 12 after reviewing 1000 ACL injury files from a Cleveland Clinic registry. While ACL injuries in the pediatric population have been reported, the true incidence may yet to be discovered considering the small number of studies that exist.

2.3 MECHANISM OF NON-CONTACT ACL INJURY

It has been generally accepted by the medical community that the majority of ACL injuries are non-contact in nature occurring with the lower extremity in a poorly or awkwardly aligned position. This consensus has been established by either analysis of video of the injury while it was occurring or through athlete recall with specifically designed questionnaires. The majority of ACL injuries have been found to occur without contact during an uncontrolled landing with the knee position near extension (Arendt, 1999; Boden et al., 2000). Through observations of non-contact ACL injuries, Ireland (Ireland, 1999) has described this position as a "position of no-return" where the athlete is landing with their knee in an extended, valgus position with the tibia externally rotated, foot pronated and upper body flexed forward over the hips and center of gravity. The mechanism of injury has further been analyzed by Boden (Boden et al., 2000) through interviewing and distributing questionnaires to athletes that had sustained ACL injuries. While recall questionnaires may sometimes be biased conditional to the persons' memory, they found similar outcomes in that a non-contact nature accounted for 72% of all ACL injuries where the athletes' knee was close to full extension during footstrike (Boden et al., 2000). The researchers further reported that through video tape analysis of 27 non-contact ACL injuries, they found the mechanism was a result of deceleration or a landing maneuver with the knee between full extension and 20 degrees of flexion. With the establishment of a common mechanism of injury for non-contact ACL injuries, researchers then began to investigate possible risk factors that may predispose a female athlete to an injury of this nature.

2.4 PROPOSED RISK FACTORS FOR NON-CONTACT ACL INJURY

Numerous risk factors have been proposed for non-contact ACL injuries, however researchers have yet to isolate any one that is specifically involved or of more importance. The proposed risk factors have been categorized into either intrinsic (not changeable) or extrinsic (changeable) in nature. Intrinsic factors include but are not limited to ACL and femoral notch size, hormonal influences, and increased hamstring flexibility. Extrinsic factors include joint position and forces, muscle strength and muscle firing rate and patterns. As previously mentioned, no one factor has emerged as the most important in determining risk of a non-contact ACL injury. In an attempt to understand the proposed risk factors more thoroughly a detailed discussion follows with an emphasis on the extrinsic factors that are related to this study.

2.4.1 Intrinsic Risk Factors

Quadriceps Femoral Angle

The quadriceps femoral angle, or Q-angle, is found by measuring the angle between an imaginary line that connects the anterior superior iliac spine and midpoint of the patella and the line connecting the tibial tuberosity and the same midline of the patella (Hungerford & Barry, 1979). Research has reported normative Q-angles between 8 and 17 degrees for men and women, however, women typically have a greater angle (Horton & Hall, 1989; Hvid, Andersen, & Schmidt, 1981). Furthermore, a clinically abnormal Q-angle has been reported to be greater than 15 degrees and 20 degrees for men and women respectively (Hvid et al., 1981). An increased Q-angle has been hypothesized to lead to a greater lateral pull on the quadriceps muscle, thus increasing medial stress on the knee. This has further been hypothesized to increase predisposition to an ACL injury. Shambaugh et al. (Shambaugh, Klein, & Herbert, 1991) found that recreational athletes who had sustained knee injuries had statistically significant differences between their Q-angle and those who did not sustain an injury. While the exact role that Q-angle may play in ACL injury is still unknown, it has been clearly established that an anatomical difference between genders exists which may predispose female athletes for an increased risk of injury.

Intercondylar Notch Width and ACL Size

Anatomically speaking, the size of the ACL will be dictated by the space allowed for it by the femoral notch. Smaller notches have been associated with an increase in ACL injury regardless of gender. It has been theorized that a smaller notch width corresponds to a smaller ACL thus an increased risk of ACL rupture regardless of gender (Shelbourne, Davis, &

Klootwyk, 1998). Anderson et al. (Anderson, Dome, Gautam, Awh, & Rennirt, 2001) investigated the notch width of 50 male and 50 female high school basketball players through magnetic resonance imaging. They found that while the notch width index was not statistically significant, when corrected for height and body weight, females exhibited a statistically smaller ACL than their male counterparts. Conversely, Rizzo et al. (Rizzo, Holler, & Bassett, 2001) found through investigation of 26 fresh frozen cadaveric knees that while there was not a statistical difference between genders in regards to the femoral intercondylar notch (FIN) widths, there was a statistical difference between both ACL widths and ACL:FIN width ratios. The authors hypothesized that while it was of importance that females had smaller ACL widths, of more importance was the finding that females had smaller ACL:FIN width ratios and that this may be the predisposition to non-contact ACL injury. A limitation of this study may have been the older population that served as subjects (mean ages of 63.9 and 69.9 years for males and females respectively) compared to other MRI studies using younger, more active populations. Femoral notch width size and ACL size research has yielded mixed results and further research in this area is warranted to pinpoint which aspect is more significant in regards to non-contact ACL injury.

Hormonal Influences

A risk factor unique to female athletes are differences in circulating hormones, namely the sex hormones estrogen, progesterone and relaxin. These hormones have cyclic effects and differing levels during the phases of the menstrual cycle. The menstrual cycle begins with menses, followed by the follicular phase (days 1-9), ovulatory phase (days 10-14) and luteal phase (days 15-28). Estrogen peaks just before ovulation where it then declines with ovulation. Additionally, ovulation occurs in a much shorter time period than the 4 days allowed, typically within 24-36 hours. However, it is unknown when those hours occur during the 4 day time frame. Sex specific hormones and non-contact ACL injury have received attention due to the presence of estrogen receptor sites on the ACL and the effect of estrogen and relaxin in decreasing ligament strength. In an attempt to explore this effect, numerous researchers have investigated the rates of injury during different phases of the menstrual cycle (Myklebust et al., 1998; Slauterbeck et al., 2002; Slauterbeck & Hardy, 2001; Wojtys, Huston, Boynton, Spindler, & Lindenfeld, 2002). Findings of these studies have shown mixed results, reporting increases in non-contact ACL ligament injury in differing phases of the menstrual cycle. Wojtys et al. (Wojtys, 2000; Wojtys, Huston, Lindenfeld, Hewett, & Greenfield, 1998) studied 28 female athletes who reported an ACL injury and met the inclusion criteria for their study. The injured athletes provided information pertaining to the mechanism of injury, previous history of injury, oral contraceptive use and menstrual cycle. Through subject recall, the authors reported a trend toward an increase in injury during the ovulatory phase of menstruation and fewer injuries occurring during the follicular phase (Wojtys, 2000; Wojtys et al., 1998). The authors continued their work in this area and reported a more detailed study a few years later (Wojtys et al., 2002). The latter study examined 69 female athletes who had sustained an ACL tear documenting the mechanism of injury, oral contraceptive use, menstrual cycle details, history of previous injury and a urine sample for performance of hormone assays to obtain menstrual cycle stage. Similar to their previous findings, this study found that there was a significant increase in injuries during mid-cycle or the ovulatory phase and a decrease in reported injuries during the luteal phase. Furthermore, the researchers found that use of oral contraceptives diminished the significance between ACL tears during the ovulatory phase. Another study performed by Slauterbeck et al. (Slauterbeck et al., 2002) analyzed 37 female athletes over a 3 year period. Saliva samples were obtained in 31 subjects within 72 hours of injury to determine menstrual phase via radioimmunoassay. Additionally, of the 31 subjects, 21 also completed menstrual histories to complement the saliva samples and an additional 6 completed menstrual histories only. Saliva samples and self reported menstrual histories showed a correlation of 95 percent so the authors analyzed the menstrual cycle phase at time of injury for all 37 subjects as one cohort regardless of saliva sample or menstrual history only status. The researchers found a statistically significant difference in phases, with 25 athletes injured during the follicular stage, 11 during the luteal stage and 1 during the ovulatory stage (Slauterbeck et al., 2002). This is in contrast to the findings by Wojtys et al. However, when the 27 athletes who self reported time of menstrual cycle at injury were analyzed, 10 of the subjects reported injury immediately prior to or 1-2 days after menses commenced, showing similarity to Wojtys' study. Hormones and the role they play in female ACL injury remain a mystery, although it would appear from the previous research that there is a tendency toward injury during the follicular phase.

Hamstring Flexibility

Lastly, another proposed intrinsic risk factor that has been identified is a greater amount of hamstring flexibility that females tend to exhibit. The hamstring muscles are just one of the soft tissues that act as a dynamic stabilizer of the ACL. Dynamic stabilizers are considered skeletal muscles that cross a joint and obtain information from either feed forward or feedback mechanisms (Riemann & Lephart, 2002). Additionally, the dynamic stabilizer is only as effective as its biomechanical and physical properties allow (Riemann & Lephart, 2002). The hamstring muscles apply a posterior force on the proximal tibia, offering protection to the ACL by counteracting anterior displacement. Boden et al. (Boden et al., 2000) found that 52 percent of 89 injured athletes exhibited excess hamstring laxity stating that athletes with increased hamstring flexibility may have been predisposed to an ACL injury. This increased laxity may become an important factor when considering injury rate differences by gender. During and after puberty, flexibility decreases with age and maturation in boys, however this is not seen in girls. Girls actually show an increase in hamstring flexibility after puberty (Malina et al., 2004). This increase may play a role in the dynamic stabilization system of the knee, particularly in regards to timing of the hamstring muscle activation and co-contraction of the hamstring and quadriceps muscles. While this proposed risk factor most likely does not completely explain the disproportionate rate of ACL injury between genders, it may play a small part and merits further investigation.

To summarize, the proposed intrinsic risk factors discussed in this section are unchangeable and have a strong theoretical basis with research to both support and debunk the statements made by the investigators. Intrinsic risk factors are numerous, as well as are challenging to assess and only a few select ones were discussed. Many studies of intrinsic risk factors employ research techniques and instruments that are continuously evolving. Others are very hard to measure directly due to the in vivo nature of the characteristic being studied. The proposed intrinsic risk factors should continue to be studied in an attempt to isolate and focus upon those which may be of more importance in determining risk for a non-contact ACL injury.

2.4.2 Extrinsic Risk Factors

The proposed extrinsic risk factors for non-contact ACL injuries are considered to be biomechanical and neuromuscular in nature and include joint position and forces, muscle firing rate and patterns and muscle strength. These risk factors receive considerable attention and research due to their modifiable nature. Several studies have shown that through proper training, these extrinsic risk factors can be modified and potentially decrease the risk of non-contact ACL injury in female athletes (Caraffa, Cerulli, Projetti, Aisa, & Rizzo, 1996; Cerulli, Benoit, Caraffa,

& Ponteggia, 2001; Hewett, Lindenfeld, Riccobene, & Noyes, 1999; Hewett et al., 1996; Lephart et al., 2005; Myklebust, 2003). The following discussion will attempt to focus on each factor separately and identify its importance in non-contact ACL injury risk.

Muscular Strength and Recruitment Patterns

Muscular strength, recruitment and activation are all important factors in knee stability, particularly during the movements that may predispose females to non-contact ACL injuries. Prior to puberty, strength differences are minimal between the sexes; however, at onset of puberty and the increase in secondary sex hormones that accompanies this phase, strength characteristics begin to diverge. Static strength in boys increases linearly with chronological age until the age of 12 or 13 when a significant increase in strength occurs (Beunen, 2000; Malina et al., 2004). This pattern is not seen in girls, as girls show a slow steady increase in strength until the age of 15 without the marked acceleration seen in boys (Beunen, 2000; Malina et al., 2004). This trend is repeated in explosive strength. Explosive strength measured through a vertical jump or standing long jump increases linearly in both sexes between the ages of 6 to12 or 13, when it then levels off for girls but continues to increase at an even greater rate in boys (Malina et al., 2004). It is hypothesized that these differences are a result of the increased release of testosterone associated with the onset of puberty in boys. Lastly, it has been demonstrated that adolescent females have significantly less relative lower extremity strength than their male counterparts, specifically in regards to their quadriceps and hamstring muscles (Anderson et al., 2001; Hewett et al., 1996; Huston & Wojtys, 1996; Lephart et al., 2002). These strength deficits in females may potentially contribute to non-contact ACL injury. Additionally, females may have altered neuromuscular activation strategies when preparing for or responding to specific physical activities, particularly those that imitate positions related to non-contact ACL injury.

The altered neuromuscular activation coupled with imbalanced quadriceps and hamstrings may further predispose the female athlete to injury.

Quadriceps and hamstring strength play an important role in the restraint of the ACL during athletic tasks. The quadriceps muscle group produces an anterior translation of the tibia during knee flexion and counteracts the ACL. The peak ACL strain occurring as a result of eccentric quadriceps contraction has been reported to occur between 10 and 25 degrees of knee flexion (Durselen, Claes, & Kiefer, 1995). The quadriceps muscle has been reported to elicit forces as high as 5000N between 15 and 30 degrees of knee flexion during dynamic eccentric contractions (Woo, Hollis, Adams, Lyon, & Takai, 1991). Much of this force may be transmitted to the ACL, which may fail at only 2000N. This may further illustrate that a non-contact mechanism for ACL rupture is possible when tensile forces are high enough. Recall that Boden et al. (Boden et al., 2000) reported that the majority of non-contact ACL injuries occurred between full extension and 20 degrees of knee flexion. Huston and Wojtys (Huston & Wojtys, 1996) found that female athletes displayed quadriceps dominance when reacting to an anterior tibial translation, meaning when presented with tasks that produced anterior translation, females contracted their quadriceps muscles first as opposed to their hamstrings (hamstring dominance). This may contribute to the strain on the ACL. Conversely, the hamstrings have been found to decrease anterior translation between 15 and 30 degrees of knee flexion by acting in concert with the ACL and producing a posterior translation (Renstrom et al., 1986). Additionally, it has been recently reported by Markolf et al. (Markolf et al., 2004) that during flexion angles greater than 60 degrees, the action of the hamstrings has the ability to cancel out the anterior force from the ACL. Lastly, it has been shown through cadaveric studies that the greatest strain on the ACL occurs during a combination of flexion, valgus and internal rotation moments at the knee (Markolf et al., 1995). Athletic males and non-athletic females displayed hamstring dominance, contracting their hamstrings first in response to the translation. Hamstring dominance was further demonstrated by Rozzi et al. (Rozzi et al., 1999) with interesting findings. Rozzi found that during a landing task women actually activated their hamstrings first, similar to men. However, these women were also found to have decreased proprioception and increased knee joint laxity. The authors concluded that this activation finding may have been a compensatory stabilizing mechanism in response to the laxity and proprioception findings (Rozzi et al., 1999) Myer et al. (Myer et al., 2005) analyzed a movement that depicted a high risk ACL injury position which required the subject to "sway" back and forth until their knee reached 30 degrees of flexion with both feet planted and turned slightly outward. The authors found that females had decreased medial quadricep activation coupled with increased lateral quadriceps and lateral hamstrings activation. They further hypothesized that the increase in lateral activation together with a decrease medially would produce an increased valgus stress on the knee, ultimately leaving the knee in an injury prone situation.

During athletic competition however, most non-contact ACL injuries occur during active play and are a result of unplanned activities or a reaction. Besier and colleagues (Besier et al., 2003) examined the muscle activation patterns of 11 males during preplanned and unplanned cutting and running, two activities highly associated with non-contact ACL injury. The investigators found that during preplanned activities, the men employed activation strategies that allowed for an increase medial muscle recruitment and co-contraction. However, men had lower medial muscle activation and very general co-contractions during the same activity in an unplanned manner. The authors to concluded that there is an increase in medial muscle activity and co-contraction activity during a valgus force at the knee during the preplanned activity condition (Besier et al., 2003). Furthermore, Sell et al. (Sell et al., 2006) found findings similar to Rozzi while analyzing both males and females during planned and reactive tasks. During reactive tasks and planned tasks to the left (medial to the right knee) females were found to have greater hamstring activity as well as co-contraction values than males. Additionally, this data coincided with a decreased knee flexion angle, which may lead to an increased risk of injury for athletes (Sell et al., 2006).

The findings from preplanned and reactive task studies may be related to the feed-forward and feedback mechanisms of motor control. Feed-forward mechanisms are trained through repetition of an activity. This allows the muscles to stiffen or contract prior to the activity in an attempt to decrease the stress on the ligament through better force absorption. Feed backward mechanisms allow the joint to respond or react to the task after ligament loading. However, feed-forward mechanisms are of particular interest due to their preventative nature and ability to be learned over time. Proper neuromuscular training may assist in developing better feed-forward and feed-back activation strategies, especially if it is employed in very young

Joint Position, Forces and Moments

Measurement of human motion can be achieved through biomechanics, the application of mechanical principles to physical activity or movement. Through biomechanics we are able to assess joint position, forces and resultant moments. Joint positions are simply described as the mechanical angle of a specified joint during a specific movement. Joint resultants are the sum of all forces associated with a moment at the joint. Resultant forces and moments can be found by isolating the separate joint forces. Joint forces and moments occur as a result of resistance applied through gravity, another object, vertical ground reaction force or forces of the muscles pulling on the skeleton. Moments are referenced as either internal or external. For example, during a landing task an athlete will encounter the ground, causing an external knee joint flexion moment. To counteract that external flexion moment, the knee will also produce an internal extension moment in an attempt to buffer the landing.

As previously described, non-contact ACL injuries have been reported to occur between 0 and 20 degrees of knee flexion (Boden, 2000). Female athletes have been observed to land in a "stiffer" position, attributed to a lower flexion angle at the knee than that commonly seen in males (Colby et al., 2000; Ireland, 1999; Malinzak et al., 2001). This observation and general theory led researchers to investigate the knee flexion/extension and varus/valgus angle differences between men and women (Chappell et al., 2002; Fagenbaum & Darling, 2003; Ford et al., 2003; Ford, Myer, Toms, & Hewett, 2005; Hewett et al., 1999; Huston, Vibert, Ashton-Miller, & Wojtys, 2001; Huston & Wojtys, 1996; Lephart et al., 2002; Sell et al., 2006; Yu et al., 2005). Additionally, the more extended landing position has been associated with higher vertical ground reaction forces that occur quicker than in males (Derrick, 2004). The differences seen in flexion and valgus angles coupled with altered neuromuscular strategies may increase susceptibility of females to non-contact ACL injuries.

Malinzak et al. (Malinzak et al., 2001) studied male and female recreational athletes during running, cutting and side-stepping tasks. The researchers found that in all tasks, females exhibited decreased knee flexion and increased knee valgus angles when compared to the males in the study, particularly during the cutting tasks. Additionally, they found that females activated their quadriceps muscles to a greater extent and hamstrings to a lesser extent, opposing the activation strategies of the males. The authors concluded that the altered variables acting together may predispose the female athlete to higher anterior tibial shear forces which may ultimately predispose them to a higher risk of ACL injury. Chappell et al. (Chappell et al., 2002) found similar findings when evaluating stop-jumps in recreationally active males and females. Like Malinzak, the authors hypothesized that anterior shear forces may be higher due in fact to the decreased flexion angle, increased valgus angle and greater peak knee extension moments. This work was further supported by Lephart et al. (Lephart et al., 2002) whose research with 15 varsity female and 15 recreationally active male athletes showed females exhibited a decreased knee flexion angle and shorter time to peak knee flexion during a landing and hopping task. The authors further speculated that the shorter time to peak flexion coupled with a greater extension angle may lead to a faster absorption of force, again predisposing the female athlete to undue injury. On the contrary, Fagenbaum and colleagues (Fagenbaum & Darling, 2003) assessed the biomechanical characteristics of 8 female and 6 male collegiate basketball athletes when landing from 25.4 and 50.8 centimeter boxes. These authors reported findings dissimilar to those of the previous studies. They found females to exhibit greater knee flexion angles (10%-14% higher) than the males in the study. Additionally, they found females and males to have comparable knee muscle activation patterns. The authors deduced that due to this odd finding, factors other than those investigated must play a significant role in ACL injury incidence in females.

Recently, investigators have added a new approach to their research by utilizing both planned and unplanned or reactive tasks when investigating knee biomechanics (Besier, Lloyd, Ackland, & Cochrane, 2001; Ford et al., 2005; Sell et al., 2006). By collecting data during a reactive task, one might be better able to capture findings that are more indicative of those seen during real-time physical activity or sport. Of particular note is the work done by Sell et al. (Sell et al., 2006) incorporating planned and reactive 2-legged stops in three different directions (vertical, medial and lateral). Eighteen female and 17 male high school basketball players were subjects in this study, which looked at ground reaction forces, EMG, and joint kinetics and kinematics. After data analysis, the authors found that females exhibited lower knee flexion angles and greater maximal valgus angles during the reactive jumps and jumps to the medial aspect. Additionally, the findings show that the medial jumps created the lowest flexion angles, highest vertical and posterior ground reaction forces, valgus and flexion moments and proximal anterior shear forces (Sell et al., 2006). Finally, there was also an effect seen between the two types of tasks, either planned or reactive. Reactive tasks produced less knee flexion at the time of peak posterior ground reaction force as well as greater knee flexion and valgus moments and higher maximal knee flexion angles as compared to the planned tasks. This finding may indicate a difference in performance between the conditions under which subjects are tested. Lastly, Yu et al. (Yu et al., 2005) examined 30 male and 30 female soccer players between the ages of 11-16 years. The subjects were grouped according to age to isolate any gender or age effects on knee biomechanics during stop-jump tasks. He found that again, females displayed decreased knee flexion angles during the landing phase and that this occurred in females after the age of 12 and increased steadily with age until 16 years (Yu et al., 2005). This may be attributable to physical characteristic changes that occur during the adolescent years.

The aforementioned research was conducted on men and women during adolescence or adulthood. While the findings and trends are similar, there is some disparity. This disparity may be due to numerous factors including sample size, protocols, tasks utilized for assessment, and skill level. While it remains clear that there are significant biomechanical and neuromuscular differences between genders, this has only recently begun to be investigated in girls and boys prior to puberty. Could the disparities between genders be due to maturational factors? If so, could it be possible to prepare young athletes through proper preventative training programs to respond physically to ACL injury mechanisms in a better manner prior to the onset of maturation?

While it is impossible to pinpoint an exact moment that maturation begins, typically, it begins around the age of eleven in girls and thirteen boys and is characterized by an increase in secondary sex hormones, pubic hair growth, and the adolescent growth spurt. Prior to maturation, girls and boys demonstrate similar physical activity patterns with distinct changes in neuromuscular and biomechanical between genders. This has prompted researchers to begin focus attention on biomechanical ACL injury risk factors in the prepubescent athlete.

The effect of maturation status and neuromuscular and biomechanical ACL injury risk characteristics has been investigated. Hass et al. (Hass et al., 2003; Hass et al., 2005) addressed this between 16 recreationally active prepubescent (prior to growth spurt and menarche) and 16 postpubescent females through a drop landing followed by either a vertical jump, lateral jump or static stance. They found that the postpubescent girls landed in all cases with less knee flexion, 30% greater knee extension moment, greater anterior/posterior forces and greater medial/lateral resultant forces. The peak knee extensor moment was greater in the prepubescent group in all cases as well. Interestingly, the postpubescent group landed with an 11% lower average vertical ground reaction force (Hass et al., 2005). This is an unusual finding because the prepubescent group landed with a more flexed knee, hence one would assume better dissipation of forces and a lower ground reaction force. The authors hypothesized that this may be due to the subject modifying the activity of the lower extremity before contact to dissipate forces that they otherwise would not have the reaction time to address (Hass et al., 2005). In a similar study, Swartz (Swartz et al., 2005) explored the biomechanics of the knee between 30 prepubescent girls and boys and 28 postpubescent men and women. Pubescence was determined by the onset of the adolescent growth spurt, which has been shown to accompany the onset of maturation (Tanner, 1986). Swartz used a vertical jump protocol that incorporated a target suspended at 50% of their predetermined maximal vertical jump height. His findings were in contrast to Hass' (Hass et al., 2003; Hass et al., 2005) in that the prepubescent group displayed greater knee valgus angles at initial contact and peak vertical ground reaction forces, decreased knee flexion angles and greater vertical ground reaction force and time to peak (Swartz et al., 2005). There were no differences between genders for the prepubescent group. Hewett and colleagues (Hewett, Myer,

& Ford, 2004) undertook an ambitious study segregating 180 subjects by either a prepubescent, early pubescent or late/post pubescent status. Eighty girls and 100 boys completed a 31 centimeter drop jump followed immediately by a vertical jump to assess biomechanical and neuromuscular traits. Hewett found that when compared to boys, prepubertal girls exhibited no difference in medial joint motion, early pubertal girls exhibited similar medial joint motion and post-pubertal girls exhibited significantly different medial joint motion when compared to boys when landing from the drop jump. Additionally he found interesting findings when evaluating the muscles responsible for knee flexion and extension. Girls showed no increase in hamstring torque across the 3 pubertal stages and an overall lower torque than the boys while the boys increased their hamstring torque over the stages (Hewett et al., 2004). When the quadriceps were analyzed, Hewett found that the boys again increased their peak quadriceps torque across the stages while the decreased peak quadriceps torque was still evident in the girls ranging from 11 to 18 percent lower when compared to the boys (Hewett et al., 2004). This finding may that there is altered developmental neuromuscular control seen in girls that is not evident in boys. Finally, Quatman et al. (Quatman, Ford, Myer, & Hewett, 2006) undertook a two year study that involved following 16 girls and 17 boys from a pubertal to post-pubertal stage while assessing biomechanical characteristics from a 31 centimeter drop jump. Over the 2 years and transition into post-puberty, boys were found to have increased their vertical jump height and decreased their vertical ground reaction forces. Alternatively, girls were found to have no change in vertical jump height, no change in vertical ground reaction forces during landing and a decrease in vertical ground reaction forces during take-off (Quatman et al., 2006). This may be an effect of the increases in explosive strength seen in boys but not girls of this age. Unfortunately, knee flexion angles were not collected to correlate with the vertical ground reaction forces.

Additionally, it would be of interest to conduct this study starting with pre-pubescent children to follow through into adulthood.

2.5 METHODOLOGICAL CONSIDERATIONS

Video data analysis combined with force plate data provides invaluable information pertaining to joint kinematics and kinetics including joint angles, moments, and forces. This is accomplished through an inverse dynamics procedure described by Vaughn et al. (Vaughn, Davis, & O'Conner, 1992). These calculations are based upon the movements of the two dimensional reflective markers to create three dimensional coordinates.

Perhaps the most challenging portion of a research study is creating relevant and productive tasks to assess the outlined variables. Two tasks will be used in this study including a landing task from a specified height and vertical jump. Prior to testing leg dominance will be determined by asking the participant which leg they would use to kick a soccer ball. While this is an simple assessment it has been utilized widely in similar testing situations (Fagenbaum & Darling, 2003; Ford et al., 2003; Ford et al., 2005; Hewett et al., 2005; Yu et al., 2005). A box height of 20 centimeters has been chosen in order to provide a significant drop while not creating a height that would prove to be too challenging to the participants. Additionally a drop from this height is similar to heights seen in playtime activities. Previous research utilizing drop jumps have reported heights between 20 cm and 31 cm for an adolescent population (Ford et al., 2003; Hewett et al., 2005; Lephart et al., 2002; Quatman et al., 2006; Rozzi et al., 1999). The vertical jump will be no different than a vertical jump that would occur in a sporting activity or playtime.

Lastly, data collection with children can prove to be as challenging as it is rewarding. Utilizing children as subjects in testing situations such as those presented in this study is relatively novel. Due to the age and maturity level of the participants in this study, problems may be encountered in terms of attention span, understanding of the tasks and influence to perform if parents or guardians are observing the test. Special attention must be considered to ensure that each participant understands the tasks to be performed and feels both safe and comfortable with the test administers and situations. Extreme effort will be made to ensure that the testing environment is both productive and comfortable for the participant.

2.6 SUMMARY

It has been unquestionably established that females incur more ACL injuries than males, specifically those of a non-contact nature. Furthermore, these injuries are thought to be a result of several proposed intrinsic and extrinsic risk factors. Considerable attention has been given to the extrinsic factors, specifically those considered biomechanical, due to their significant impact and potentially modifiable nature. In general, adolescent females have demonstrated lower knee flexion angles, increased knee valgus angles and poor muscular activation patterns during landing and cutting tasks that closely resemble movements found to dispose them to injury. This has not been clearly established in the pediatric population. Few studies have investigated these extrinsic factors in a prepubescent population, while those that have are showing mixed results. Focusing on the prepubescent population is of importance in order to isolate those biomechanical and neuromuscular changes that occur during puberty. Once those changes are found, prevention programs may be further designed for the pre-pubescent female athlete which focuses on increasing strength, muscular recruitment patterns and coordination that may decrease the likelihood of incurring a non-contact ACL injury.

3.0 METHODS

3.1 EXPERIMENTAL DESIGN

This descriptive study evaluated the biomechanical characteristics of the lower extremity between two cohorts of prepubescent children based on gender. The independent variable were gender and the dependent variables were knee joint kinematics and kinetics and vertical ground reaction forces. The specific dependent biomechanical variables will include the following:

1) Knee flexion and varus/valgus angle of the dominant limb at initial contact and peak vertical ground reaction force (degrees) of the dominant leg during a landing and jumping task.
2) Flexion/extension and varus/valgus moments at peak vertical ground reaction force [Nm/(bw x bh)] of the dominant limb during a landing and jumping task.
3) Proximal tibial anterior shear force at peak vertical ground reaction force (N/Bw) of the dominant limb during a landing and jumping task.
4) Peak vertical ground reaction forces and peak posterior ground reaction force (N) and time to peak posterior ground reaction force (ms) during a landing and jumping task.

3.1.1 Subject Characteristics

Healthy active children between the ages of six and ten years of age who had experience in organized athletics were participants in this study. A power analysis was performed a priori to determine appropriate sample sizes. Effect sizes were calculated from published literature with methods that closely resembled this study (Swartz et al., 2005). Based on an alpha level of $\alpha = 0.05$, power of $P = 0.80$, and a large effect size, 26 subjects per group were targeted to be recruited. Participants were recruited via informational flyers distributed to local elementary school and community athletic coaches and organizations. Additionally recruitment advertisements were placed in local newspapers and community magazines. All participants met the following criteria for inclusion in this study.

3.1.1.1 Inclusion Criteria

- Girls and boys who have experience in organized soccer, basketball or volleyball.
- Ages 6 -10 years
- Lower extremity is injury free at the time of testing
- Tanner stage 1

3.1.1.2 Exclusion Criteria

- Girls who have experienced either thelarch or menarche.
- Pubic hair growth.
- Boys with genital enlargement.
- History of serious lower limb musculoskeletal injury.

- History of neuromuscular disease or disorders.
- Previous experience with jump training.

3.1.2 Instrumentation

3.1.2.1 Eagle Digital 3D Optical Motion Capture System

The Eagle Digital 3-dimensional optical motion capture system (Motion Analysis Corporation, Santa Rosa, CA) was used to gather kinematic data via six high speed (120 Hz) digital optical cameras (Hawk-i, Motion Analysis Corporation, Santa Rosa, CA) that were mounted on tripods surrounding the force plate where the tasks were performed. Calibration was performed prior to testing utilizing a calibration volume that was representative of the subjects' movement and the volume in which the movement occurred. The capture volume for the tasks was approximately 1 m wide, 1 m long and 2 m high. Calibration of a small volume should theoretically help to decrease residual error and increase the marker tracking accuracy. Reference markers with a diameter of 0.019 m were secured to anatomical landmarks with double sided adhesive tape and reflected infrared light back to the cameras. Any motion created by the subject within the calibration volume was relayed back to the six optical capture cameras via the reflective markers.

3.1.2.2 AMTI Force Plate

An AMTI force plate (AMTI, Watertown, MA Model #OR6-5-1 S/N 3115) was interfaced directly with the Eagle Digital optical capture system. Ground reaction force data during the landing and jumping tasks was recorded at 1200 Hz. The force plate was oriented according to the global reference system in that the positive X direction will point anteriorly away from the participants' right side, the positive Y direction will point laterally away from the participants' right side and the positive Z will point in the direction of the participants' head. (Figure 1)

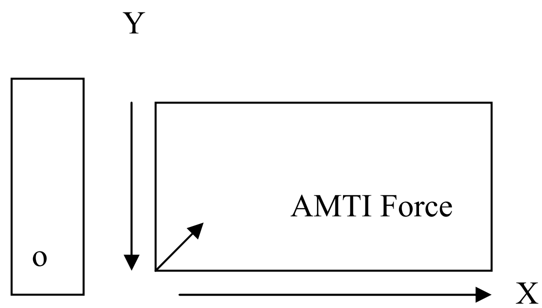


Figure 1. Orientation of force plate

3.1.3 Testing Procedures

3.1.3.1 Participant Preparation

Participants attended a sixty-ninety minute testing session in the exercise physiology laboratory in Trees Hall on the University of Pittsburgh's main campus. The testing session consisted of anthropometric measurements and motion analysis. Male subjects were asked to wear dark compression shorts, dark socks and sneakers. Female subjects were asked to wear dark compression shorts, a dark tank top, dark socks and sneakers. Prior to testing, participants provided an informed assent and parental written consent was obtained in accordance with the University of Pittsburgh Institutional Review Board policy. Participants, with the help of their parent completed a brief health history questionnaire (Appendix C) and a Tanner Staging self-assessment instrument. (Appendix A and B) An investigator then measured the participant's height and weight using a standard scale (Health O Meter, Inc., Bridgeview, IL) and tape measure.

Leg dominance was defined as the leg that the subject preferred to use to kick a soccer ball. (Fagenbaum & Darling, 2003; Ford et al., 2003; Hewett et al., 2005; Lephart et al., 2002)

3.1.1.1.1. Reflective Marker Placement

Fifteen reflective markers (B&L Engineering, Tustin, California) were adhered to the participant to enable the optical capture system to define each body segments position in 3-D space. Reflective markers were adhered unilaterally with double sided tape following the Cleveland Clinic marker set. Marker sites included: left and right anterior superior iliac spine, sacrum, lateral and medial epicondyles of the knee, lateral and medial malleoli, calcaneus and great toe. Additionally, a cluster of three marker sets were adhered to the mid-thigh and mid-calf. The cluster sets and medial epicondyle and malleolus markers were removed after the static trial was complete.

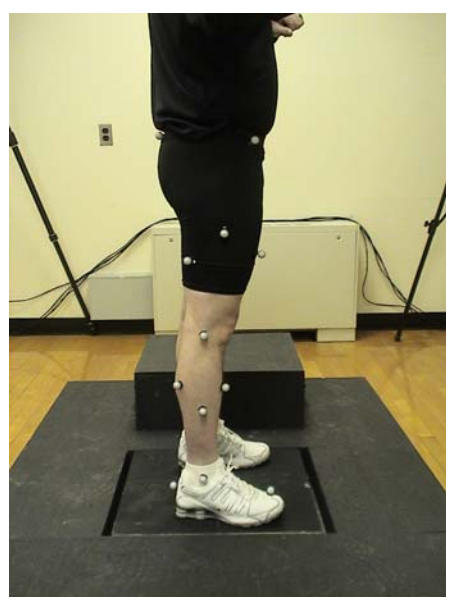


Figure 2. Reflective marker placement

3.1.1.1.2. Static Calibration Trial

Prior to data collection a static calibration trial was performed. Participants were asked to stand in anatomical position in the center of the capture volume. This allowed the investigator to determine the participant's joint angles in a static position was then used for marker placement errors if/when necessary.

3.1.1.1.3. Landing and Jumping Task

A landing and jumping task was assessed using the Digital system. Each participant was given a verbal description and visual demonstration of the landing and jumping techniques. The first task consisted of a landing from a box, placed 11 cm behind the force plate (Lephart et al., 2002). The box was 20 centimeters (cm) high for the 9-10 year old subjects and 15 cm high for the 6-7 year old subjects. The initial starting position for the landing task required the subject to balance on their dominant leg while placing their hands on their hips. They then were instructed to shift their weight forward, hop onto the force plate, and land on one leg. The second task consisted of a vertical jump. Participants were instructed to place their dominant foot onto the force plate while the non-dominant foot was placed on the runway. They were then instructed to squat down and perform a maximal vertical jump as if they were rebounding a basketball. A small ball was suspended from the ceiling above and in front of the subject to act as a target. Practice trials were given for each task until the subject felt comfortable with the skill. Five trials of each task were then collected. A trial was considered successful if the task was performed properly ending with the dominant legs foot landing completely on the force plate. A maximum of 15 trials total were allowed to ensure fatigue does not become a confounder.

3.2 DATA ANALYSIS

3.2.1 Data Reduction

3.2.1.1 Joint Kinematic and Kinetic Data

Ground reaction force data was calculated from raw analog force plate data after filtering with an optimal cut-off frequency (Jackson, 1979). For the landing and jumping tasks, kinematic data was analyzed for significance at both peak vertical reaction force and initial contact as defined by 5% of the subject's body weight on the force plate. Kinetic knee data was analyzed at peak vertical ground reaction force of the landing and jumping task. Kinematic data was filtered using a 4^{th} order Butterworth filter using an optimal cut-off frequency method (Jackson, 1979). Kinematic and kinetic data then underwent calculations within a custom designed MatLab program to determine knee kinematics of the dominant leg utilizing an inverse dynamics procedure as described by Vaughn et al. (Vaughn et al., 1992). The following is a concise summary of the underlying theories as described by Vaughn et al. (Vaughn et al., 1992) used to calculate the proposed variables.

Body Segment Parameters

- Vaughn et al. (Vaughn et al., 1992) developed linear regression equations for predicting segment masses based on studies of six cadavers by Chandler et al. (Chandler, Clauser, McConville, Reynolds, & Young, 1975).
- These linear regression equations will utilize values for body mass and anthropometric dimensions of the body segment of interest to predict the body segment mass.
- Linear regression equations will also be used to calculate segment moments of inertia by incorporating body mass and length of the specific segment around the flexion/extension, abduction/adduction and internal/external rotation orthogonal axes.

Linear Kinematics

- Vaughn et al. (Vaughn et al., 1992) utilized direct 3D measurements of 12 normal subjects and stereo X rays of one normal subject to derive prediction equations for calculating positions of joint centers.
- First markers will be placed on the body segment of interest in three different locations.
- An orthogonal uvw reference system will be created based upon these markers.
- The regression equations created by Vaughn (Vaughn et al., 1992) will then predict the 3D joint centers location based upon the 3-D positions of the external landmarks and anthropometric data.
- Segment orientation will be calculated relative to the global reference frame by an imbedded xyz reference system that is located at the segment's center of gravity.

Centers of Gravity

- Segment centers of gravity will be calculated using the location of the joint centers and body segment parameters.

- Segment centers of gravity velocity can now be calculated as the change in displacement of the segment over change in time.
- Acceleration of the segments centers of gravity is found by taking the change in segment velocity over the change in time.
- Velocity and acceleration data will be used later to examine joint forces and moments.

Angular Kinematics

- Anatomic joint angles are based on the work of Chao (Chao, 1980) and Grood and Suntay (Grood & Suntay, 1983).
- Anatomic joint angles are defined as how one segment is oriented to another according to the interaction of the reference frames in the proximal and distal segments. Anatomic joint angles are considered to be rotation of the distal segment relative to the proximal segment. Generally;
    - Flexion and extension, as well as dorsiflexion and plantarflexion occur in the mediolateral axis of the proximal segment.
    - Internal and external rotation occurs about the longitudinal axis of the distal segment.
    - Abduction and adduction occurs in a floating axis that is at right angles to the flexion/extension and internal/external rotation axes.
- Segment Euler angles will be calculated based the on the work of Synge and Griffith (Synge & Griffith, 1959) and Goldstein (Goldstein, 1965) .
- Euler angles are made up of the following three ordered rotations; flexion/extension about the Z axis (global reference), abduction/adduction about the line of nodes, and internal/external rotation about the z axis (segment axis).

- Angular velocity and angular acceleration of segments at each instant in time can be calculated utilizing Euler angles and their derivatives.

Dynamics of Joints

- Resultant joint forces and moments can be calculated from body segment parameters, linear kinematics, centers of gravity, angular kinematics and ground reaction forces.
- Calculations for the resultant joint forces and moments are based on Greenwood's (Greenwood, 1965) work.

  Joint Resultant Forces

  - Joint resultant forces will be calculated by first calculating the change in linear momentum.
  - The rate of change in linear momentum is equal to the product of the mass of the specified segment and the acceleration of the segments center of gravity.

  Joint Resultant Moments

  - Joint resultant moments will be calculated by examining the rate of change of angular momentum of a specified segment at its center of gravity.
  - The rate of change of angular momentum will include moments of inertia, angular velocity and acceleration.
- These calculations will be performed distally at the ankle joint and through Newtons's third law of motion (action reaction) can be applied sequentially up the kinetic chain.

Ground reaction force data will be identified to examine anatomical joint angles and resultant joint forces and moments at initial contact, peak vertical ground reaction force and maximum deceleration. All data will be averaged from the five test trials collected.

3.3 STATISTICAL ANALYSIS

Initially, a detailed descriptive data analysis was performed, including the computation of descriptive statistics appropriate to the level of measurement of each variable. Assessment and estimation of missing data, identification of outliers, identification of interrelationships between variables, and assessment for the violation of assumptions underlying identified statistical techniques was also performed. To determine if differences between genders existed, an analysis of variance (ANOVA) using SPSS 14.0 statistical software (SPSS Inc, Chicago, IL) analyzed significance for the following variables; knee flexion/extension and varus/valgus angles at initial and peak contact,, peak vertical ground reaction force, peak posterior ground reaction force and proximal anterior tibial shear force at peak vertical ground reaction force. A post-hoc power analysis will then be performed if there is no significance found to ensure that enough power was utilized. The alpha level will be set to 0.05.

4.0 RESULTS

The purpose of this study was to evaluate if biomechanical differences of the lower extremity exist between prepubescent children based on gender. The independent variable was gender and the dependent variables were knee joint kinematics and kinetics and vertical ground reaction forces. The specific dependent biomechanical variables included the following:

1) Knee flexion/extension and varus/valgus angle of the dominant limb at initial contact and peak vertical ground reaction force (degrees) of the dominant leg during a landing and jumping task.
2) Flexion/extension and varus/valgus moments at peak vertical ground reaction force of the dominant limb during a landing and jumping task.
3) Peak vertical ground reaction force (BW) and peak posterior ground reaction force (BW) during a landing and jumping task.
4) Peak anterior shear force at peak vertical ground reaction force during a landing and jumping task.

4.1 SUBJECT CHARACTERISTICS

Participants who volunteered for this study were healthy boys and girls between the ages of six through 10 with organized athletic experience. Subjects were recruited through informational flyers distributed to local youth coaches, community centers and newspapers. A total of twenty-seven participants were tested. Data on nineteen participants were analyzed. The data of six participant's data were un-useable due to a lack of quality captures within the allowable 15 trials. After running box and whisker plots for all subjects and variables, two participants were considered extreme outliers and were excluded from data analysis. All participants were soccer players from various teams and tested during their off season. Demographic descriptive data for all participants as well as individual gender are found in Table 1 below. There were no descriptive statistical differences found between the groups.

Table 1. Participant Demographic Data

	Overall mean±SD	**Males** mean±SD	**Females** mean±SD	**p-value***
	n=19	n=10	n=9	
Age (yrs)	7.63±1.56	7.60±1.89	7.66 ± 1.32	0.93
Height (cm)	130.43±11.36	128.19±12.28	132.92±11.13	0.39
Weight (Kg)	29.52±7.69	29.13±8.74	29.94± 7.35	0.83
BMI	17.07±2.41	17.33±2.47	16.77± 2.60	0.64

- alpha = .05

4.1.1 Specific Aim 1

Specific Aim 1: Determine the flexion/extension and varus/valgus angles of the knee at initial contact and peak vertical ground reaction force during a landing and jumping task.

The results for the investigation of the knee flexion/extension and varus/valgus angles at initial contact and peak vertical ground reaction force revealed no significant differences between groups with the exception of the knee flexion/extension angle at initial contact during the landing task. There were no significant differences found for any variable for the vertical jump task. A more detailed description can be found in Tables 2 and 3.

Table 2: Knee angles at initial contact and peak vgrf during a landing task.

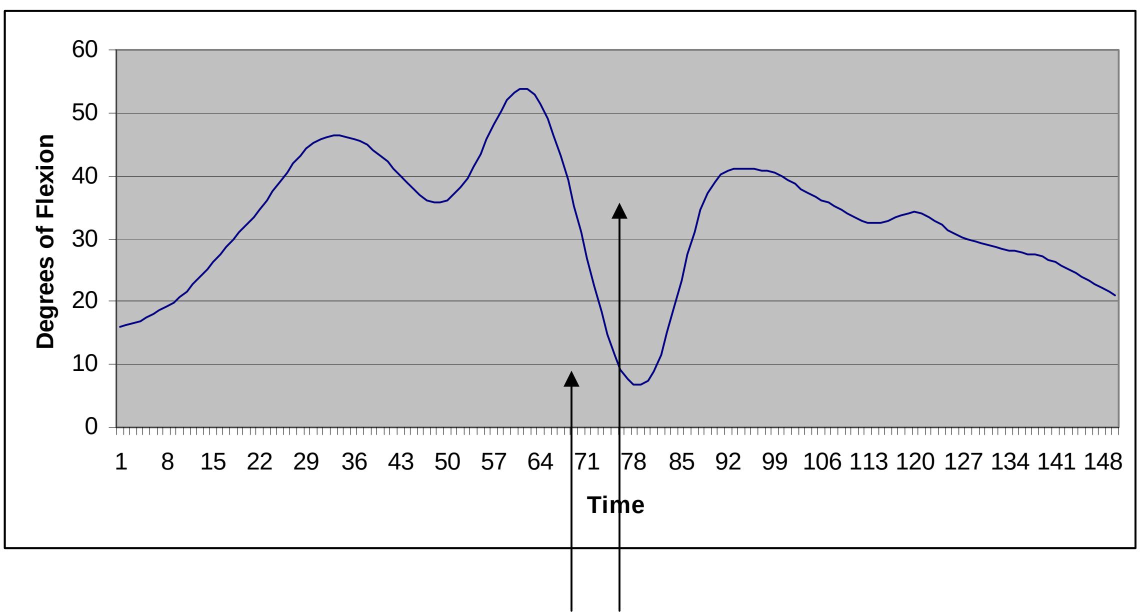
	Initial Contact		**Peak vgrf**	
	Flexion mean±SD	**Valgus** mean±SD	**Flexion** mean±SD	**Valgus** mean±SD
Girls	11.71 ±5.98	0.95 ± 10.23	21.54 ±5.54	0.31 ± 11.98
Boys	29.90 ± 20.37	-2.39 ±5.35	32.25±26.79	-2.55 ±5.01
p value	.020*	0.377	0.257	0.498

*alpha = .05

Table 3. Knee angles at initial contact and peak vgrf during vertical jump.

	Initial Contact		Peak vgrf	
	Flexion mean±SD	**Valgus** mean±SD	**Flexion** mean±SD	**Valgus** mean±SD
Girls	17.65 ± 8.65	2.04 ±12.06	36.20 ± 12.67	-0.28 ± 12.13
Boys	17.02 12.55	-4.24 ± 5.16	34.94 ± 14.60	-4.37 ± 5.62
p value	.902	0.150	0.844	0.351

*alpha = .05



IC Peak vgrf

Figure 3. Knee flexion/extension angle during a vertical jump

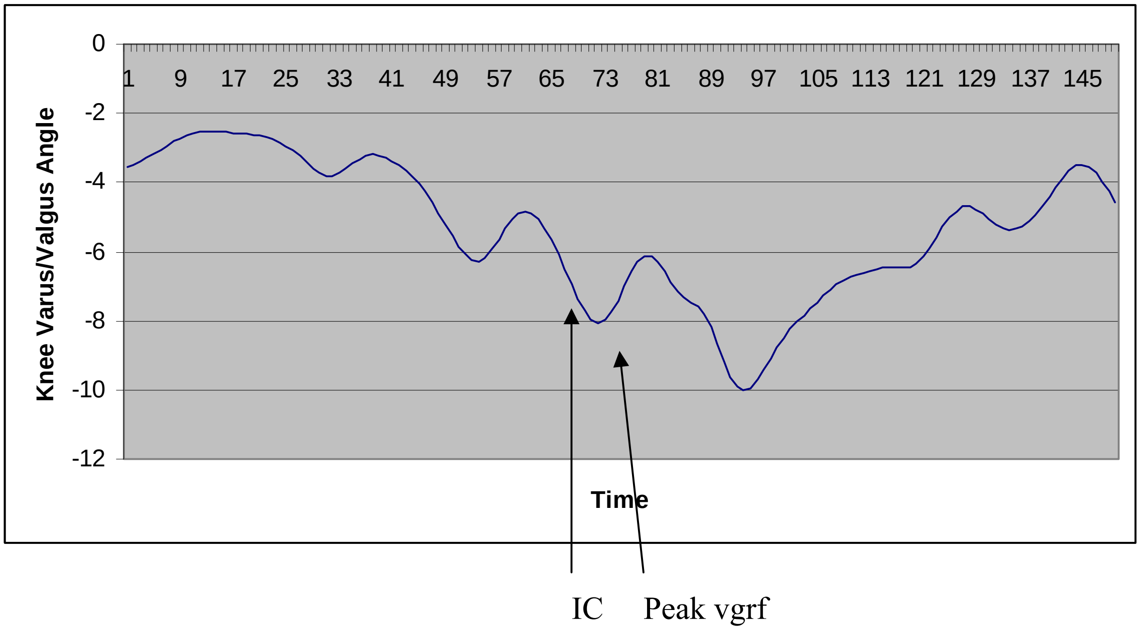


Figure 4. Knee varus/valgus angle during a vertical jump

4.1.2 Specific Aim 2

Specific Aim 2: Determine the flexion/extension and varus/valgus moments of the knee at peak vertical ground reaction force during a landing and jumping task.

Peak flexion/extension and varus/valgus moments were unable to be analyzed due to mechanical failure. While force plate data were collected, during data reduction it became evident that the force plate had encountered some type of failure with one of its load cells. Forces are correct; however, the center of pressure, which is essential in the calculation of joint moments, was not. A thorough calibration of the force plate was performed prior to beginning data collection, so the investigators can only assume that a load cell failed at some point during data collection.

4.1.3 Specific Aim 3

Specific Aim 3: Determine the peak vertical ground reaction force and peak posterior ground reaction force.

The results for aim 3, determining peak vertical and peak posterior vertical ground reaction forces during a landing and jumping task, showed no significant differences between genders. During the landing task, girls exhibited forces 4.2 times their body weight and 2.16 times their body weight for the landing and jumping tasks respectively. Boys exhibited similar but insignificant numbers as well, reporting 4.06 times their body weight and 1.98 times their body weight for the same landing and jumping task. Peak posterior forces were also found to be insignificant between genders, with girls landing and jumping at -2.21 and -0.65 times their body weight and boys landing and jumping at -2.30 and -0.88 times their body weight respectively. The results are shown in Table 4.

Table 4. Peak vertical and peak posterior vgrf during landing and jumping task.

	Landing Task (BW)		Vertical Jump (BW)	
	Peak vgrf mean±SD	**Peak Posterior grf** mean±SD	**Peak vgrf** mean±SD	**Peak Posterior vgrf** mean±SD
Girls	4.21 ± 0.34	-2.21±0.38	2.16±0.36	-0.65±0.15
Boys	4.06±0.44	-2.30±0.29	1.98±0.32	-0.88±0.17
p value	.683	.916	.482	.162

*alpha = .05

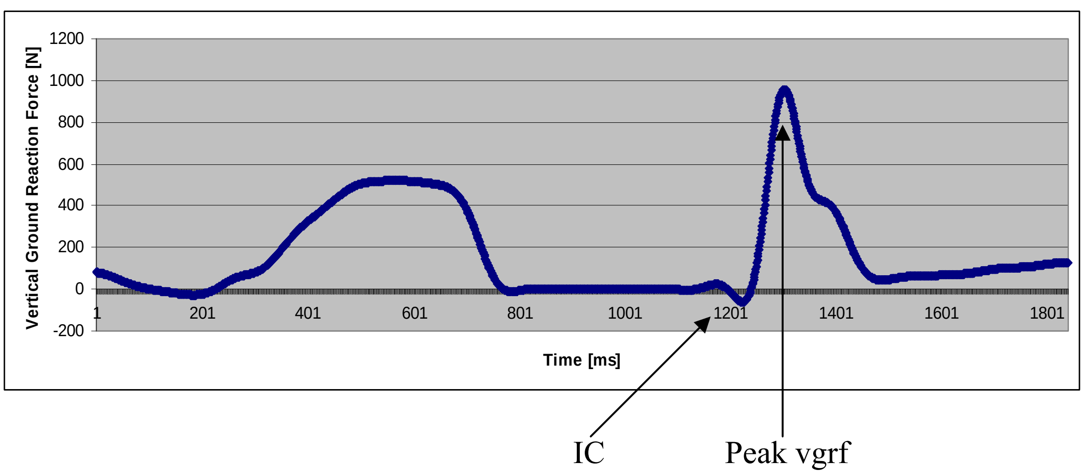
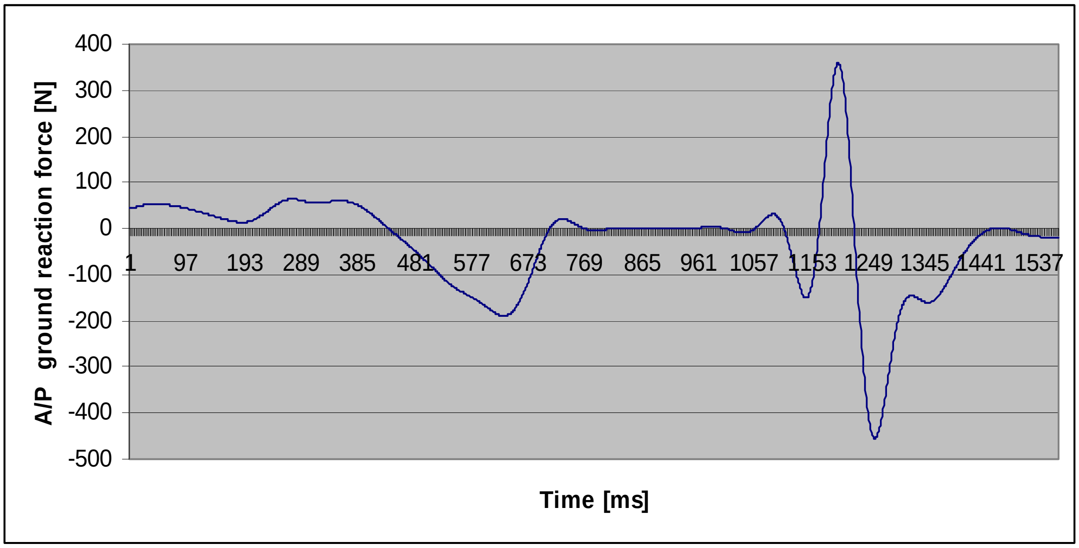


Figure 5. Peak vertical ground reaction force during a vertical jump



Peak Posterior vgrf

Figure 6. Peak posterior ground reaction force during a vertical jump

4.1.4 Specific Aim 4

Specific Aim 4: Determine proximal anterior tibial shear force at peak vertical ground reaction force.

The results of aim 4, investigating the anterior shear force, were found to be insignificant for both groups for both the landing task and vertical jump. For the landing task, results were -0.96 and -0.65 percent body weight for girls and boys respectively. Additionally, results for the vertical jump were 0.75 percent body weight for the girls and 0.78 percent body weight for the boys. The results for proximal anterior shear force are shown in Table 5.

Table 5. Anterior shear force during a landing task and vertical jump.

	Anterior Shear Force [percent BW]	
	Landing Task mean±SD	**Vertical Jump** mean±SD
Girls	-0.96 ± 0.74	0.75 ± 0.53
Boys	-0.65 ± 1.31	0.78 ±0.94
p value	0.649	0.645

5.0 DISCUSSION

5.1 INTRODUCTION

Female participation in organized athletics has steadily risen since the inception of Title IX in 1972 (Lopiano, 2000). This increase in athletic participation has been evident in collegiate (NCAA, 2001), and high school (NFSHSA, 2005) populations, which stems from an increase in participation by very young athletes who are working their way up through the age ranks. Along with increased participation or exposure to athletic activity comes an increase in potential injury. This is apparent by a reported annual 2.6 million emergency room visits from individuals between the ages of five through twenty-four which are directly due to athletic participation (Burt & Overpeck, 2001). One of the most distressing injuries is a non-contact ACL tear, occurring four to six times more frequently in females than their male counterparts (Agel et al., 2005; Arendt, 1999; Ferretti et al., 1992; Gwinn et al., 2000; Lindenfeld et al. 1994; Myklebust et al., 1998). The disproportionate injury rate has been clearly established for the high school and collegiate population however little data exist for a pre-pubescent population. Furthermore, the scant data that have been reported for the pre-pubescent population suggest that boys actually suffer a higher ACL injury rate only to be significantly surpassed by females after the ages of 11-12 (Shea et al., 2004). Interestingly, the aforementioned surge in ACL injuries at the ages of 11-12 coincides with the average age in which children enter puberty (Malina et al., 2004). Additionally, the purported biomechanical differences which are believed to contribute to the increased ACL injury risk for females also begin to develop at differing rates between genders during puberty (Griffin et al., 2000). The purpose of this study was to determine if biomechanical differences existed between prepubescent boys and girls, particularly differences in knee flexion and varus/valgus angle, knee flexion/extension and varus/valgus moments, vertical ground reaction forces and proximal anterior tibial shear force of the dominant leg during a landing and jumping task.

The overall results of this study revealed that prepubescent girls and boys do not have significant biomechanical differences at the knee during a landing and jumping task.

5.2 KNEE ANGLES

Knee Flexion/Extension Angle

The results of this study revealed a statistically significant difference between genders for the knee flexion angle at initial contact during a landing task whereas the boys landed with over twice as much flexion as the girls. All other variables analyzed revealed no statistically significant differences. Previous research investigating knee angles between prepubescent girls and boys is near nonexistent. Most of the research to date has either investigated gender differences in a postpubescent age group or between pre- and postpubescent females only.

Swartz et al. (Swartz et al. 2005) performed similar research to this study where they investigated knee angles during a vertical jump between gender and pubertal status. Swartz et al. found the knee flexion angle to be 10 degrees at initial contact during the vertical jump for both prepubertal girls and boys. Furthermore he found the flexion angle at peak vertical ground reaction force to be at 31 degrees and 28 degrees for girls and boys respectively. These angles are smaller than the flexion angles found in this study in which the vertical jump knee flexion angle for boys and girls was 17 degrees at initial contact and 36 and 35 degrees for girls and boys respectively at peak vertical ground reaction force. It is of interest to note that while knee flexion angles within this study are lower for both variables between the sexes, neither study found significance between the sexes for the aforementioned variables during the vertical jump. The overall lower angles during the vertical jump for this study's cohort could be attributed to multiple factors, including skill level or jumping height. While this study used a standardized height (15 or 20 centimeters) for the box from which the participants jumped, the Swartz study used a variable jumping height based on fifty percent of the participants premeasured maximum vertical jump height. Furthermore, the average age for our group was seven years whereas the average age in the Swartz study was 9 years. While Swartz's younger group was considered prepubertal they were two years older and two years ahead of ours in development; hence, closer to the average age of eleven coinciding with pubertal onset and maturation when females tend to exhibit stiffer or more extended landing strategies. This may explain why the prepubertal group Swartz tested yielded lower knee flexion angles than ours. Furthermore, the Swartz study utilized a slightly different marker set compared to this study. While the overall consensus is that marker sets are personal preference and all equally effective, it is possible that slight discrepancies may occur which could influence the final angle data.

Hass et al. (Hass et al., 2005) investigated a drop jump between pre- and postpubescent female athletes. Their findings revealed that postpubescent females landed in a knee flexion angle decreased by four percent than the prepubescent group for the same landing task. The Hass study found prepubescent girls landing at initial contact with nineteen degrees of flexion whereas the postpubescent girls were landing in 15 degrees of flexion. The findings of my study found prepubescent girls to land at initial contact with eleven degrees of knee flexion and 21 degrees of knee flexion at peak vertical ground reaction force which is in direct contrast to Hass' findings for initial contact. Unfortunately the Hass study investigated knee flexion angles at touchdown and not peak vertical ground reaction force so that data are unavailable for comparison. The drop jump height used in Hass' study were fashioned similar to Swartz's' in that the box height used was set relative to a maximum vertical jump height. While the exact height of the jumping platform for Hass' subjects was not reported, differences found between this study and Hass' study may be attributed to the selection of jumping height. It may be hypothesized that a higher take-off height may lead to an increase in the flexion angle as to absorb higher forces that would be incurred during landing. This may explain why the flexion angles in Hass' study were close to double those found in this study.

Knee Varus/Valgus Angle

The results of this study found no significant differences between genders in the varus/valgus angle at the knee for either the jumping or landing task. For the jumping task at initial contact girls had two degrees of knee valgus compared to -4 degrees of valgus (i.e. 4 degrees of varus) by the boys. Furthermore, at peak vertical ground reaction force, the girls moved into a more varus position at -0.28 degrees while the boys stayed relatively the same as initial contact with -4.37 degrees of valgus. In a similar study discussed earlier by Swartz et al., (Swartz et al. 2005) pre- and postpubescent girls and boys were analyzed during a vertical jump. Swartz found no significant differences between genders; however, he did find a significant difference between maturation groups. The knee valgus angle reported for the prepubescent group from the Swartz study is much higher than the angles we found. Swartz found prepubescent females to land at initial contact with eleven degrees of valgus moving into 9 degrees at peak vertical ground reaction force, while the prepubescent boys landed with 12 degrees of valgus at initial contact and 10 degrees at peak vertical ground reaction force. Furthermore he found the postpubescent group to land with nine and 6 degrees of valgus at initial contact for females and males respectively followed by 7 degrees of valgus for the females and 3 degrees of valgus for the males at peak vertical ground reaction force.

Hewett et al. (Hewett et al., 2004) investigated the valgus angle during a drop jump between pre-, mid- and postpubertal boys and girls. Hewett found angles more similar to ours for the landing task at initial contact with his prepubescent girls landing at two degrees of valgus whereas this study found girls to land at initial contact with 0.95 degrees of valgus. However, at the point of peak vertical ground reaction force, this study found girls to have 0.31 degrees of valgus while Hewett's study found 14 degrees of valgus. The prepubescent boys in this study elicited numbers in contrast to Hewett's research, reporting -2.39 degrees of valgus (i.e.2.39 degrees of varus) at initial contact and -2.55 degrees at peak vertical ground reaction force, whereas Hewett reported valgus angles at approximately two degrees for initial contact and peak vertical ground reaction force.

It is unclear as to the etiology of mixed results of the valgus angle found not only when comparing the research in this study but when comparing all of the previously mentioned work. Numerous factors could be attributed to this finding including the age, skill level, task being assessed, jumping height and biomechanical technique, such as marker sets used and joint center definitions.

5.3 GROUND REACTION FORCES

Ground reaction forces are important variables to investigate in that they may assist clinicians in understanding an athlete's landing mechanics. It has been hypothesized that individuals landing with a less flexed, stiffer knee will incur a much higher peak vertical ground reaction force when landing in comparison to others landing in a more flexed position (Hewett et al., 1996). Higher vertical ground reaction forces are thought to occur in response to the body's inability to absorb the landing forces at the knee due to the less flexed position. Peak posterior ground reaction force is a measure of the dissipation of force. This measure is another important variable in that it represents the force as it is dissipated from the landing at the forefoot to the hind foot. A stiffer, less flexed landing may lead to a higher posterior ground reaction force as the individual may be landing in a pes planus or flat footed position.

The results of this study revealed no statistically significant difference between the girls and boys in respect to peak vertical ground reaction force or peak posterior ground reaction force.

Peak Vertical Ground Reaction Force

The results of the landing task elicited peak vertical ground reaction forces of 4.21 and 4.06 times their body weight for girls and boys respectively. Additionally, the vertical jump yielded lower results measuring 2.16 and 1.98 body weight for girls and boys respectively. The results of this study are similar to those found by Quatman et al. (Quatman et al. 2006) who measured peak vertical ground reaction force in female and male pre- and postpubescent athletes during a vertical jump. The results of the Quatman study found no significance between genders for the pubertal stage, however they did find significance when analyzing gender by the maturation status. Quatman found prepubescent girls to land with 2.2 times their body weight and boys to land at 2.1 times their body weight, a result very similar to this study. However, when Quatman compared the landing forces by gender between maturation status, they found that after puberty the boys were actually decreasing their landing forces whereas the females did not. These findings are further supported by work done by Hass et al. (Hass et al., 2003) who investigated forces while landing from a vertical jump after a stride jump. Hass found no significance between pre- and postpubertal females for peak vertical ground reaction force although his force findings were slightly higher than ours at 2.6 times the body weight for both maturation levels. In contrast, Sigg et al., (Sigg et al., 2001) investigated landing from a vertical jump between genders in elementary aged children. His findings were significant; however the forces were still similar to ours at 2.34 BW and 2.45 BW for girls and boys respectively. Not only were these findings significant between genders, but it was also found that boys were landing with higher forces than the girls. This is in contrast to the aforementioned findings. While the assessment task was the same, a vertical jump, this study utilized a cohort of students that all attend the same elementary school. It may be possible that these students are all being taught physical education or coached in sports by the same individuals which may be a confounder to this study. Finally, Swartz and colleagues (Swartz et al., 2005) included a mixed gender and maturation status in their study of forces during a vertical jump. While Swartz reported their results as a measure of Newton/Joules as opposed to body weight it is of interest to note that they as well found no significance between the genders for peak vertical ground reaction force but did find significance between maturational status with the prepubescent group landing with less vertical ground reaction that the postpubescent group. Without knowing the body weight of each of Swartz's subjects, it is impossible for us to compare our data to theirs.

Peak Posterior Ground Reaction Force

Peak posterior ground reaction force between genders was also not found to be significant for either the landing or jumping task in this study. Hass et al., (Hass et al., 2003) found no significance in their study between pre- and postpubescent females reporting -0.94 and -0.82 peak posterior ground reaction forces, respectively. For comparison purposes, the current study found peak posterior ground reaction force at -0.65 for the prepubescent girls. Unfortunately, the Hass study did not include males in their research for further comparison with our group.

Peak posterior ground reaction forces were not investigated in any of the landing studies cited in this work. However, for this study it is of interest to note that the peak vertical and peak posterior vertical ground reaction forces for landing were much lower for the vertical jump than the landing task. Recall, that the girls landed from a vertical jump with -0.65 BW and the landing task with -2.21BW while the boys landed with -0.88 BW and -2.30 BW from the vertical jump and landing task, respectively. As mentioned earlier, forces have been shown to be higher for landings where there is a lower knee flexion angle. While significance was not analyzed, it is noteworthy that the landing task elicited higher forces but a lower knee flexion angle when compared to the forces and flexion angle found in the vertical jump.

5.4 PROXIMAL ANTERIOR TIBIAL SHEAR FORCE

Proximal anterior tibia shear force (PATSF) is a measure of the shear force the tibia is enacting on the femur in an anterior direction. Like other ground reaction forces, this is typically expressed as a measure relative to body weight. The PATSF is of interest as the anterior shear force direction will stress the ACL and ultimately may contribute to an ACL rupture. The results of the anterior shear force analysis yielded no significance between genders for either the landing or jumping task. The results of this study found a PATSF of -0.96 BW and -0.65 BW for girls and boys respectively during the landing task. Moreover we found results of 0.75 BW and 0.78 BW for girls and boys respectively when analyzing the vertical jump. Previous research has suggested that a lower flexion angle will produce a higher PATSF (Boden et al., 2000, Markolf et al., 1995,) however that is not the finding with this study. Proximal anterior shear forces were much higher for the vertical jump landing while the knee flexion angle was also found to be higher for this task. Chappel et al. (Chappel et al., 2002) conducted a study investigating the PATSF between male and female adult recreational athletes during a stop jump task. Chappel's study found no significant differences between genders, furthermore, exact data were not reported, however, data was displayed in a figure that displayed results between 0.01BW and 0.30BW for both genders.

At the time of this writing, no current published research could be found investigating the PATSF between genders in prepubescent children. As a result of the lack of published data it is hard to speculate to the findings of our prepubescent group. Due to the lack of published findings yet potential importance of the variable, further analysis of this variable for prepubescent children is warranted.

5.5 AGE COMPARISONS WITHIN THE SUBJECTS

While the variables were not broken into gender and age groups for statistical comparison, the data is presented below in table format for the readers knowledge. The females landed in both the landing task and vertical jump with similar flexion angles, however the valgus angles are quite different. Angles and ground reaction forces for both boy groups are similar as well. The number of subjects is too small to make inferences however it is of interest that the older girls are displaying angles that are not similar to reported postpubescent findings.

Table 6. Knee Angle Variables for landing grouped by gender and age

	Flexion Angle @ IC	Valgus Angle @IC	Flexion Angle @ Peak	Valgus Angle @Peak
	mean ± SD	mean ± SD	mean ± SD	mean ± SD
6/7 Girls	11.07±6.23	-4.22±6.90	20.69±5.86	-5.79±9.48
9/10 Girls	12.97±6.49	11.31±7.66	23.26±5.51	12.52±3.76
6/7 Boys	32.79±18.48	-2.34±3.81	35.72±26.7	-3.29±5.47
9/10 Boys	25.57±25.1	-2.47±6.56	27.04±29.9	-1.43±4.75

Table 7. Ground reaction force variables for landing grouped by gender and age

	pvgrf (BW)	ppgrf (BW)	PATSF (BW)
	mean ± SD	mean ± SD	mean ± SD
6/7 Girls	4.16±0.37	-2.22±0.45	-1.29±0.71
9/10 Girls	4.29±0.31	-2.18±0.23	-0.30±0.01
6/7 Boys	3.97±0.55	-2.27±0.36	-0.53±1.71
9/10 Boys	4.2±0.14	-2.33±0.21	-0.83±0.83

Table 8. Knee Angle Variables for vertical jump grouped by gender and age.

	Flexion Angle @IC	Valgus Angle @IC	Flexion Angle @ Peak	Valgus Angle @Peak
	mean ± SD	mean ± SD	mean ± SD	mean ± SD
6/7 Girls	15.56±8.25	3.29±10.67	32.06±13.74	5.14±11.51
9/10 Girls	21.83±9.49	12.74±6.31	44.47±3.96	9.43±6.77
6/7 Boys	18.06±15.69	-5.66±5.9	36.66±14.26	-6.12±6.06
9/10 Boys	15.49±7.57	-2.13±3.46	32.36±16.92	-1.76±4.31

Table 9. Ground reaction force variables for vertical jump grouped by gender and age

	pvgrf (BW)	ppvgrf (BW)	PATSF (BW)
	mean ± SD	mean ± SD	mean ± SD
6/7 Girls	2.17±0.44	-0.65±0.17	0.87±0.38
9/10 Girls	2.13±0.17	-0.65±0.14	0.50±0.79
6/7 Boys	1.88±0.17	-0.79±0.12	0.45±1.05
9/10 Boys	2.12±0.45	-1.02±0.14	1.29±0.47

5.6 PREVENTION PROGRAMS

In an effort to reduce the incidence of non-contact ACL injuries in females, there has been an influx of injury prevention programs (Hewett et al., 1999, Myklebust et al., 2003, Mandelbaum et al., 2005). Injury prevention programs often employ various methods of training to target neuromuscular or biomechanical factors that are thought to contribute to the higher noncontact ACL injury risk for females. These methods may include but are not limited to strength training, flexibility training, balance, proprioception and plyometrics.

Typically, prevention program outcome studies either follow a cohort through single or multiple sports seasons and assess the incidence of injury as it relates to the amount of athletic exposures the subjects incurred, or the study compares the biomechanical and neuromuscular characteristics thought to contribute to ACL injuries pre- and post- prevention program implementation.

Hewett et al. (Hewett et al., 1999) conducted a prospective cohort study involving thirty female and 13 male soccer, volleyball and basketball high school teams. This intervention program consisted of athletes participating in eighteen preseason sessions or a non-active control group. At the conclusion of the study, Hewett et al. assessed the ACL injury incidence and found that noncontact ACL injury risk was significantly reduced by seventy-two percent in the female athletes who used the intervention training.

In a similar study, Myklebust et al. (Myklebust et al., 2003) investigated the outcomes of implementing a prevention training program throughout the season with three different levels of Norwegian handball teams over the course of 3 seasons. At the conclusion of Myklebust's study, the researchers reported an overall trend of decreased ACL injuries for all three teams over the 3 seasons with a significant decrease within the elite division group.

Finally, Mandelbaum et al. (Mandelbaum et al. 2005) implemented a prevention training program over the course of two years enrolling over nineteen hundred soccer players between the ages of 14 and 18. This prospective study followed two cohorts, either intervention or control, throughout two seasons. At the conclusion of injury incidence data collection, the prevention program cohort had incurred six ACL ruptures while the control group incurred 67.

While participation in an injury prevention program is no guarantee that the athlete will not incur an ACL injury, preliminary data from the aforementioned studies lends credibility to their effectiveness in decreasing the likelihood of an ACL injury. The most effective programs seem to involve a combination of methods incorporating strength, plyometrics and balancing tasks. It is important to note that it has yet to be established if the desirable outcomes of the prevention programs can be attained through pre- mid- or post season participation as well as the duration of program participation needed. What is known, through biomechanical analysis, is that the prevention programs have shown neuromuscular modifications to physical and performance characteristics that have been elicited to contribute to the higher incidence of noncontact ACL injuries. The results of this study showed that the biomechanical differences observed in a postpubescent population are not present in a prepubescent population. It may be possible that by implementing a prevention program at an earlier age, athletes may be able to avoid some of the biomechanical and neuromuscular risk factors that are purported to predispose them to a higher risk of non-contact ACL injury.

5.7 LIMITATIONS TO THE STUDY

The participants in this study were between the ages of six and 10 and were recruited through various community athletic groups, newspapers and flyers. No participants were excluded based upon skill. Additionally, participants were not broken into groups dependent upon the amount of time they had been participating in athletic activity. It is possible that skill level among the participants could have varied considerably due to either time spent in organized athletics or their individual motor development and athletic skill.

There are two popular methods to determine the dominant leg; using the "jumping leg" (Chapel et al., 2002) or utilizing the leg in which a person prefers to use when kicking a soccer ball (Fagenbaum & Darling, 2003; Ford et al., 2003; Hewett et al., 2005; Lephart et al., 2002) This study chose to use the soccer ball method for 2 basic reasons. The group with whom we were working had experience with soccer and was easily able to answer the question, and moreover, we were able to visually verify their answer by rolling a soccer ball toward them and further assess leg dominance by their reaction.

Reflective marker placement could significantly affect the kinematic calculation data. In an effort to increase reliability and decrease variability the same investigator placed the markers on all participants. Anatomical bony landmarks were used as reference points for all marker placements except for the cluster of three markers on the mid-shank and mid-calf which are meant to be placed haphazardly but still forming a triangle. In an effort to preserve modesty and the comfort level of the participants, it was essential to place some markers on the participants clothing. It is possible that during the individual trials the markers may shift with the movement of the clothing. To reduce clothing movement, participants were given the smallest size possible so that the compression shorts and shirt adhered to the skin tightly to minimize marker movement. Lastly, in some rare instances markers will be absent during a few frames of data capture. A minimum of 2 cameras must be able to view the marker for it to register digitally within the software system. When a marker was not visible by two cameras it was possible through the motion analysis software to create a “virtual marker” using mathematical interpolation. In these rare instances a “virtual marker” was used to fill gaps that may be present during data reduction if the marker was missing for ten frames (i.e. 0.08 seconds or less).

5.8 CLINICAL SIGNIFICANCE

The results of this study revealed that there were no significant statistical differences between groups in knee mechanics during a landing and jumping task other than knee flexion/extension angle at initial contact during a landing task. This finding is in agreement with similar studies done with this age range however, the findings are dissimilar to those studies with a post- or mid-pubescent age range. When analyzing similar variables in an older population, there have been findings of statistically significant differences between the sexes for these same tasks and variables. In an effort to change the way females land and place them in a more flexed and varus position, injury prevention programs have been created and have typically been implemented at a later, more post-pubescent age. Preliminary data suggest that the aforementioned prevention programs may be effective in decreasing non-contact ACL injuries by decreasing the biomechanical differences at the knee between genders. It has further been hypothesized that these biomechanical differences may be a result of puberty and the anatomical and physiological changes that occur during that time. To that end, it may be possible that by implementing the injury prevention programs at an earlier, pre-pubescent age, and following those programs throughout puberty, girls may be able to modify the biomechanical differences that they typically exhibit during athletic maneuvers that require landing and jumping.

5.9 CONCLUSIONS

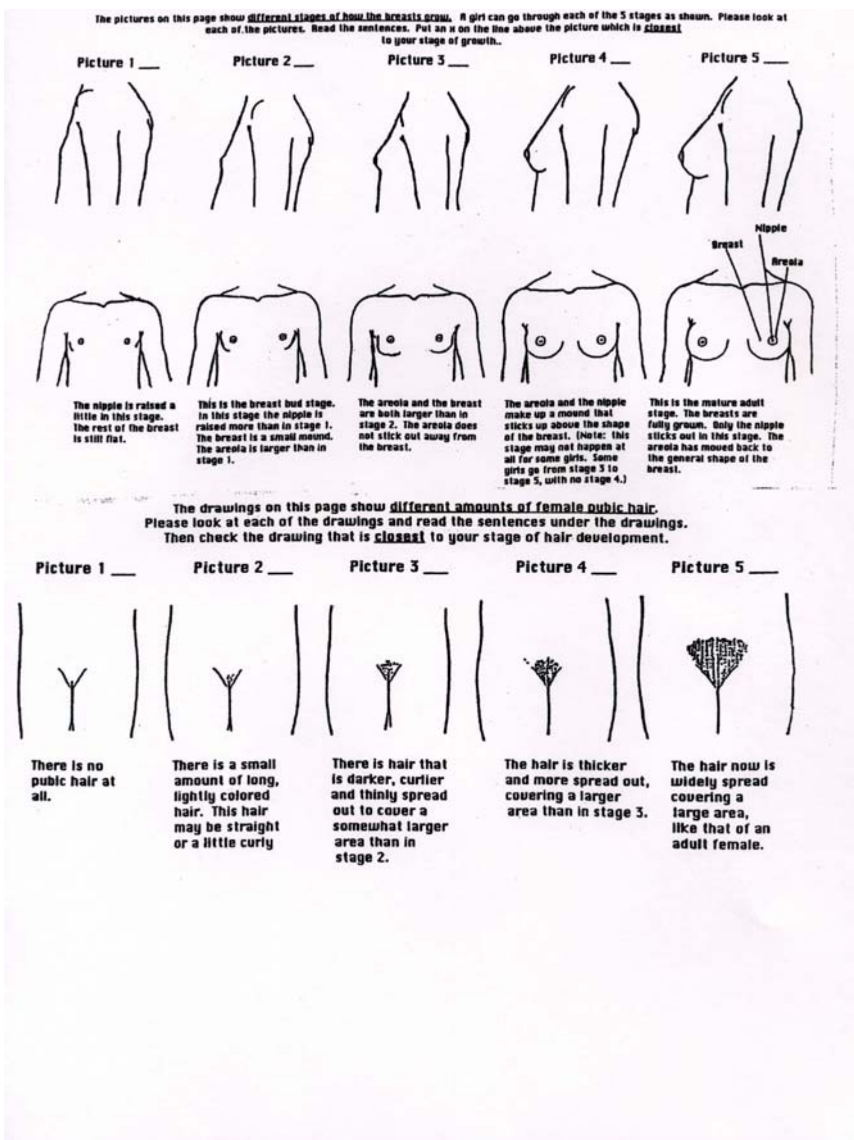
The purpose of this study was to investigate if there was a significant biomechanical difference in the lower extremity between genders during a landing and jumping task. The variables assessed included flexion/extension and varus/valgus angles of the knee, peak vertical and peak posterior ground reaction forces and peak anterior shear force. The results of this study indicate that the only statistically significant finding was the flexion angle at the knee at initial contact during a landing task. Previous research investigating these variables within the same age range have found mixed results.

5.10 FUTURE RESEARCH

Future analysis of this data may include analyzing differences in gender further broken down by the total amount of time spent in organized athletics. This may elicit a relationship between athletic volume and landing or jumping skills. Another variable worthy of exploration includes the gender differences pertaining to time to peak angles and vertical ground reaction force. In addition to the variables explored in this study, future research could include an assessment of moments during the tasks and if a significant difference exists between genders. Furthermore, it may be of interest to examine the tasks with three separate cohorts of each gender; pre-, mid- and post- pubertal. Ideally, it would be of interest to design a study where a young prepubescent group is baseline tested for the variables investigated in this study and then followed through until late adolescence with periodic retesting. This would allow the researcher to then retrospecitvely identify common variables or risk factors that were present in those participants who do or do not tear their ACL. Finally, the addition of electromyography to the aforementioned cohorts could allow the researcher to determine if neuromuscular differences, such as muscle firing patterns and timing are present. All of the previously mentioned research suggestions could help to further understand the lower extremity neuromuscular and biomechanical differences between genders and may aid clinicians in identifying athletes who may be at risk for a non-contact ACL injury allowing the implementation of an injury prevention program at an earlier age.

APPENDIX A

TANNER SELF-ASSESSMENT STAGING INSTRUMENT – GIRLS



The pictures on this page show <u>different stages of how the breasts grow.</u> A girl can go through each of the 5 stages as shown. Please look at each of the pictures. Read the sentences. Put an x on the line above the picture which is <u>closest</u> to your stage of growth..

Picture 1 ___ Picture 2 ___ Picture 3 ___ Picture 4 ___ Picture 5 ___

The nipple is raised a little in this stage. The rest of the breast is still flat.

This is the breast bud stage. In this stage the nipple is raised more than in stage 1. The breast is a small mound. The areola is larger than in stage 1.

The areola and the breast are both larger than in stage 2. The areola does not stick out away from the breast.

The areola and the nipple make up a mound that sticks up above the shape of the breast. (Note: this stage may not happen at all for some girls. Some girls go from stage 3 to stage 5, with no stage 4.)

This is the mature adult stage. The breasts are fully grown. Only the nipple sticks out in this stage. The areola has moved back to the general shape of the breast.

The drawings on this page show <u>different amounts of female pubic hair.</u> Please look at each of the drawings and read the sentences under the drawings. Then check the drawing that is <u>closest</u> to your stage of hair development.

Picture 1 ___ Picture 2 ___ Picture 3 ___ Picture 4 ___ Picture 5 ___

There is no pubic hair at all.

There is a small amount of long, lightly colored hair. This hair may be straight or a little curly

There is hair that is darker, curlier and thinly spread out to cover a somewhat larger area than in stage 2.

The hair is thicker and more spread out, covering a larger area than in stage 3.

The hair now is widely spread covering a large area, like that of an adult female.

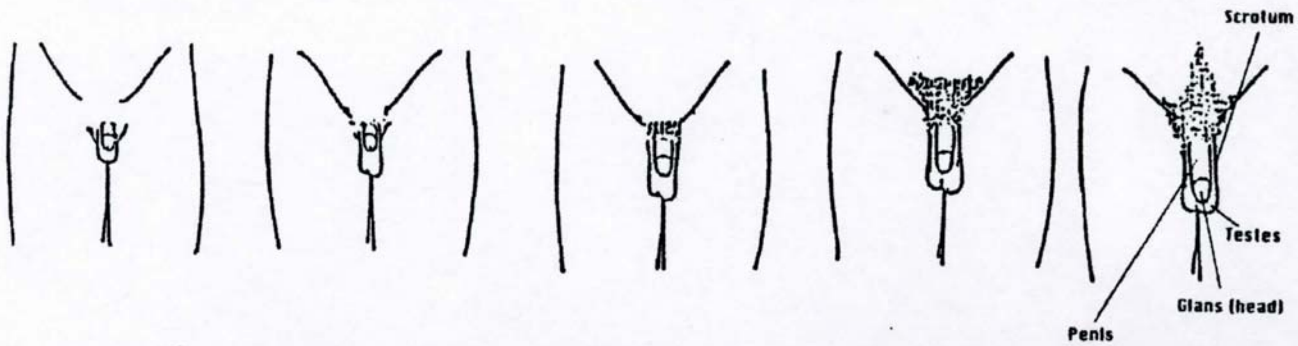
APPENDIX B

TANNER SELF-ASSESSMENT STAGING INSTRUMENT – BOYS

The pictures on this page show <u>different stages of growth of the testes, sctrotum, and penis.</u> A boy goes through each of the 5 stages as shown. Please look at each of the pictures. Read the sentences. Put an x on the line above the picture which is <u>closest</u> to your stage of growth.

<u>Do not look at pubic hair growth!</u>

Picture 1 ___ Picture 2 ___ Picture 3 ___ Picture 4 ___ Picture 5 ___



Picture 1	Picture 2	Picture 3	Picture 4	Picture 5
The testes, scrotum, and penis are about the same size and shape as they were when you were a child.	The testes and scrotum are bigger. The skin of the scrotum has changed. The scrotum (the sack holding the the testes) has gotten lower. The penis has gotten only a little bigger.	The penis has grown in length. The testes and scrotum have grown and dropped lower than in picture 2.	The penis has gotten even bigger. It is wider. The glans (the head of the penis) is bigger. The scrotum is darker than before. It is bigger because the testes are bigger.	The penis, scrotum, and testes are the size and shape of that of an adult man.

APPENDIX C

HEALTH HISTORY AND PHYSICAL ACTIVITY QUESTIONNAIRE

Health History Questionnaire

Please answer the following questions regarding your child to the best of your ability.

1. Age (as of today): _______ years old Date of Birth: ____/____/____

2. Gender: _____ Female _____ Male

3.
4. Has your child ever been told to not participate in any type of physical activity?
_____ Yes _____No

5. Has your child ever seriously hurt their lower extremity before? _____ Yes _____No
    a. Please indicate which body part and side:
    Hips: ___________ Right _____ Left _____ Both

    Knees: __________ Right _____ Left _____ Both

    Ankles: _________ Right _____ Left _____ Both

    Toes/Feet: _______ Right _____ Left _____ Both

    b. When did your child hurt the body part indicated in part 'a'? _____-
    ____

    c. How did your child hurt the body part indicated in part 'a'? (please be specific)
    ____

    d. Please check the doctor's diagnosis of the injury (if known):
    _____ muscle/tendon strain, which structure/s (if known): __________________

    _____ dislocated/fractured bone, which structure/s (if known):

_____ ligament sprain, which structure/s (if known):

_____ unsure

_____ other: ____

e. Did your child have surgery as a result of this injury? _____ Yes _____ No

If yes, Date of Surgery: ____/____/____

Name of Procedure, (if known): ____________________________________

6. Has your child ever been diagnosed with a neuromuscular disorder or disease? _______

If Yes, please explain ____

____

7. Please indicate how often your child participates in organized SOCCER activity?
8.

_____ 1-2 times per week _____ 1-2 hours per session

_____ 3-4 times per week _____ 2-3 hours per session

_____ 5-7 times per week _____ 3-4 hours per session

When did they first enter organized soccer? __________________________

6. Please indicate how often your child participates in organized BASKETBALL activity?

_____ 1-2 times per week _____ 1-2 hours per session

_____ 3-4 times per week _____ 2-3 hours per session

_____ 5-7 times per week _____ 3-4 hours per session

When did they first enter organized basketball? _________________________

7. Please indicate how often your child participates in organized VOLLEYBALL activity?

_____ 1-2 times per week _____ 1-2 hours per session

_____ 3-4 times per week _____ 2-3 hours per session

_____ 5-7 times per week _____ 3-4 hours per session

When did they first enter organized volleyball? _________________________

8 Please indicate how often your child participates in any other ORGANIZED physical

activity?

_____ 1-2 times per week _____ 1-2 hours per session

_____ 3-4 times per week _____ 2-3 hours per session

_____ 5-7 times per week _____ 3-4 hours per session

What type of activity is this? ______________________________________

When did they first enter this activity? _______________________________

THANK YOU!

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