2015

2-Dimension Analysis of Frontal Plane Projection Angle in Female Soccer Athletes

KyLee M. Tuchfarber
Otterbein University, kylee.tuchfarber@gmail.com

2-DIMENSION ANALYSIS OF FRONTAL PLANE PROJECTION ANGLE IN FEMALE SOCCER ATHLETES

KyLee M. Tuchfarber
Department of Health and Sport Sciences
Otterbein University
Westerville, OH 43081

31 March 2015

Submitted in partial fulfillment of the requirements for graduation with Distinction

Advisory Committee:

Shelley Payne, DHS, PT, ATC, AT
Distinction Advisor

Shelley Payne
Signature

Danielle Kilboy, M.S., ATC, AT
Second Reader

Danielle Kilboy
Signature

Shelley Payne, DHS, PT, ATC, AT
Distinction Representative

Shelley Payne
Signature

Acknowledgements

First, I would like to give a big thanks to Dr. Shelley Payne for all of her advising help throughout this entire research project. Also, for helping me narrow down my research project to a topic I was truly passionate about and for answering all of my questions.

Secondly, I would like to thank Danielle Kilboy for being my second reader and for supporting me throughout the process of my research project.

Next, I would like to thank Joe Wilkins for allowing me to use the video camera and for helping me transfer the videos on to the computer.

Lastly, I would not be where I am today without the help and support from all my friends and family. To all those that supported me through this process I am eternally grateful.

Abstract

Research has found a variety of mechanisms for ACL injuries. One mechanism that has been found is a decreased valgus control at the knee. One study found that that "the decreased active and passive controls of knee alignments may destabilize the knee and are purported to be measures related to increased risk of ACL injury in female athletes, as they mature" (Myer, Ford, Khoury, Succop, & Hewett, 2011, 248). The age of the subjects (12-16) is important because maturation may be a contributing cause of knee abduction moments (KAM). Three-dimensional analysis has been said to be the "gold standard" when analyzing biomechanics, however, researchers have commented on the "considerable financial, spatial, and temporal costs, which severely limit their application to the large scale screening, training, and evaluation programs necessary for successful prevention of non-contact ACL injuries" (Walker, Ford, Myer, Hewett, & Bogert, 2005, 355). Therefore, research has been completed on the accuracy and reliability of 2-dimensional analysis. A study found that when the joint centers can be easily identified, the use of 2-dimensional analysis to evaluate frontal plane knee motion is reliable (Mclean, Walker, Ford, Myer, Hewett, & Bogert, 2005). Mizner, ,Chmielewski, Toepke, and Toefte (2013) specified two reliable options when using 2-dimensional analysis including frontal plane projection angles (FPPA) and the knee:ankle separation ratio. The purpose of this research is to use 2-dimensional video analysis and frontal plane projection angles to evaluate landing biomechanics of pre-pubescent and post-pubescent female soccer athletes. The subjects will be a U-12 female soccer club team as well as the Otterbein University women soccer players. Also, the research will investigate the effectiveness of 2-dimensional analysis as an evaluation tool for ACL risk measurements.

Table of contents

List of Tables

v. List of Figures

Introduction

Anterior cruciate ligament injuries are very common, with reports of approximately 100,000 ACL injuries annually throughout the United States (Greenfield, Huston, & Wojtys, 2000). Females have been found to be 4-6 times more likely to injure their ACL compared to males (Hewett, Ford, & Myer, 2006). There are many factors that have been examined and analyzed as possible risk factors for ACL injuries. Pubertal changes have been linked to differences between males and females in jumping and landing tasks that have been associated with increased risk for ACL injuries (Hewett, Ford, & Myer, 2006). Comparisons have been investigated between male and female athletes, but few studies have compared risk factors between different age groups of the same sex.

Literature Review

Knee anatomy is crucial in considering the risk factors of ACL injuries in all ages. The knee consists of three joints; the tibio-femoral, the patello-femoral, and the tibiofibular. The knee joint consists of four main ligaments; the anterior cruciate ligament, the posterior cruciate ligament, the medial collateral ligament, and the lateral collateral ligament. The anterior cruciate ligament (ACL) prevents the tibia from sliding anterior on the femur, while the posterior cruciate ligament (PCL) prevents the tibia from sliding posterior on the femur in an open kinetic chain. The lateral collateral ligament (LCL) prevents varus movement and the medial collateral ligament (MCL) prevents valgus movement of the knee. Other structures important to the functioning of the knee are the menisci, which are also static stabilizers. There are two menisci, lateral and medial, that help with shock absorption, deepen the joint, and help with joint nutrition. The hamstrings and quadriceps also contribute to the biomechanics of the knee and are dynamic stabilizers. The hamstrings are responsible for knee flexion as well as helping to minimize anterior tibia translation during deceleration and the quadriceps are responsible for knee extension and help to decrease the ground reaction forces suffered at the knee during landing tasks.

Arthroscopic studies have found the anterior cruciate ligament to be made up of two bundles, including the anteromedial and posterolateral bundles (Steckel, Fu, Baums, & Klinger, 2009). Both bundles were found to have insertions associated with their names and had horizontal insertion sites (Steckel, Fu, Baums, & Klinger, 2009). During flexion and extension of the knee, the anteromedial bundle was found to be tight throughout the entire range of motion and the posterolateral bundle was found to be tight only with knee extension (Hanno, Fu, Baums, & Klinger, 2009). This arthroscopic study involved sixty knees on subjects without previous ACL injuries. ACL injuries occur when there is a disruption in the ligament due to various traumatic mechanisms, both contact and non-contact.

Given the high rate of ACL injuries, many authors have examined risk factors thought to be associated with risk for ACL injury. One risk factor known to have a negative impact is knee valgus, however, continued research continues to uncover all contributions of this specific factor (McLean, Huang, & van den Bogart, 2005). ACL injuries tend to have various contributing mechanisms including increased valgus load, knee abduction moments (KAM), cutting with deceleration, changing direction with deceleration, landing, and jumping, jumping or pivoting in a position of full extension, pivoting with a foot planted, knee hyperextension, and knee hyper flexion (McLean, Huang, & van den Bogart, 2005). Landing mechanisms also contribute to ACL injury mechanisms. One study examined the landing techniques and their effects on biomechanics of the lower extremities in twenty division I female college soccer athletes, ranging in age from 19 to 21 (Cortes, Morrison, Van Lunen, & Onate, 2012). An eight-camera high-speed motion capture system and force plates were used to measure the kinematics of the lower extremities. Kinematics is defined by The Free Dictionary as "the branch of mechanics that studies the motion of a body or a system of bodies without consideration given to its mass or the forces acting on it." The athletes were instructed to perform a side step as well as pivot using rear foot and forefoot techniques. The researchers found that a rear foot landing in side stepping/cutting demonstrated a greater valgus angle and a smaller knee flexion angle. In the pivot task, the rear foot landing technique also demonstrated a smaller knee flexion angle and the forefoot landing technique demonstrated a greater valgus angle. They also found that the athletes always have a valgus position regardless of the landing technique. Previous studies had shown that an increase in valgus angle is a predictor of an ACL injury, depicting the importance of this study (Cortes, Morrison, Van Lunen, & Onate, 2012). Therefore, "the decreased knee flexion angle combined with the knee adductor moment, during rear foot landing technique in the sidestep task, can potentially be creating higher stress and strain on the ACL" (Cortes, Morrison, Van Lunen, & Onate, 2012, 180).

Another important mechanism to consider is the knee valgus during sidestepping that was examined by McLean, Huang, & van den Bogart (2005). These researchers found the knee was in peak valgus during side stepping during the first 20% of stance phase (McLean, Huang, & van den Bogart, 2005). The association between knee valgus and an increase in initial hip flexion, hip internal rotation, and knee valgus positions was found to be significant. An important aspect of the study found that "peak knee valgus moment was associated with initial contact hip flexion and internal rotation position during side stepping" (McLean, Huang, & van den Bogart, 2005). This study brought to light the contributions of the muscular system to knee position rather than concluding that knee position is a static, bony alignment. It is therefore important to understand how hip neuromuscular control could be an important factor in ACL injuries. In relation to the hip neuromuscular control, a study was completed to evaluate the effects of injury prevention training on the lower extremity kinematics throughout a landing task (Pollard, Sigward, Ota, Langford, & Powers, 2006). The subjects of this study were made up of eighteen female soccer players ranging in ages from 14 to 17. Three-dimensional analysis was used to test the kinematics of the hip and knee at the start of the season as well as at the end. During these two test times, the kinematics were measured using the drop landing task and then throughout the season the athletes participated in practices, games, and injury prevention programs, specifically Prevent Injury and Enhance Performance (PEP) injury prevention. The results found that the kinematics changed at the hip with PEP injury prevention, but did not show change at the knee (Pollard, Sigward, Ota, Langford, & Powers, 2006). The changes at the hip that were observed included a decrease in hip internal rotation and an increase in hip abduction. These events occurred in the early deceleration phase of landing. Thus, the researchers concluded that this change in lower extremity kinematics might serve to protect the knee in game like situations. Therefore, hip neuromuscular control is an important aspect in ACL injury risk and should be trained in athletes (Pollard, Sigward, Ota, Langford, & Powers, 2006).

High knee loads have also been found to contribute to the risk of ACL injuries especially when there is an increase in knee abduction moments (KAM). Myer, Ford, Khoury, Succop, & Hewett (2011) found that many factors contribute to an increase in KAM including greater tibia length, decreased knee flexion during landing, increased knee abduction, and decreased hamstring strength. An important aspect of this research study was the age of the subjects, 12-16 years old. This age group is important because maturation may be a contributing cause to KAM. Specifically, Myer, Ford, Khoury, Succop, & Hewett found that in the frontal plane an increase in KAM and increased joint laxity is a puberty-divergence between female and male athletes. This study also found that "the decreased active and passive controls of knee alignments may destabilize the knee and are purported to be measures related to increased risk of ACL injury in female athletes, as they mature" (Myer, Ford, Khoury, Succop, & Hewett, 2011, 248). A study completed by Myer, Ford, & Hewett (2004) defined neuromuscular spurt as "increased power, strength, and coordination that occur with increasing chronologic age and maturation stage in adolescent boys" (353), but this has not been found in pubescent females. The researchers concluded that dynamic neuromuscular analysis training is important in improving neuromuscular imbalances, which is important for knee biomechanics and injury risk reduction (Myer, Ford, & Hewett, 2004). This change may increase ACL risks for females as they go through puberty.

Range of motion in joints other than the knee may also be important to consider examining ACL injury risk. A study was also done to examine landing biomechanics and the effect of ankle dorsiflexion range of motion (Blackburn, Fong, McGrath, Norcross, & Padua, 2011). A total of thirty five subjects were tested including 17 men and 18 women, ranging in age from 19 to 22. All subjects were tested using a manual goniometer to measure passive range of motion in an extended knee and flexed knee measurement. In order to test the landing biomechanics a 7 camera motion capture system was used to evaluate a drop test (Blackburn, Fong, McGrath, Norcross, & Padua, 2011). The results found that "greater passive ankle dorsiflexion was associated with greater knee flexion displacement and smaller ground reaction forces during landing" (Blackburn, Fong, McGrath, Norcross, & Padua, 2011, 5). The researchers found that the risk of ACL injury may be decreased with an increase in plantar flexor extensibility and dorsiflexion range of motion because of the reduced amount of load that would be placed on the ACL (Blackburn, Fong, McGrath, Norcross, & Padua, 2011). The findings of this study are consistent with that done by Kovac in that "heel to toe landings resulted in less sagittal plane displacement at the ankle, knee, and hip and greater vertical ground reaction forces" (Blackburn, Fong, McGrath, Norcross, & Padua, 2011, 7). Both studies found that knee valgus or knee displacement in the sagittal plane direction occurred during landing, which would place the ACL at risk.

An additional aspect to ACL injuries is the factor of returning to sport. In an article by Paterno et al (2010), it was found that in the short term, "estimates of the overall likelihood that an athlete will incur a subsequent ACL injury after return to sport participation after ACL reconstruction (ACLR) range between 1 in 4 (25%) to 1 in 17 (6%) athletes (2010). Not only is return to sport a risk factor for retear, but also Shelbourne et al (2010) in a study found that age also plays a factor in ACL retears. Shelbourne et al (2010) found that "younger patients were at higher risk, as 17% of patients under the age of 18 years sustained a second ACL injury, while only 4% over the age of 25 years sustained a second injury (Paterno et al, 2010, 1969). The purpose of this study was to investigate and define factors that were indicative of second ACL injuries and they hypothesized that "measured deficits in neuromuscular control at the hip and knee and in postural stability would predict second ACL injuries" (Paterno et al, 2010, 1969). The study used a "prospective, case-cohort design to identify the predictors of a second ACL injury and after primary ACLR and return to sport" (Paterno et al, 2010, 1969). In conclusion using multivariable logistic regression, the authors found that "the net hip rotation moment impulse, frontal plane knee range of motion during landing, asymmetries in sagittal plane knee moments at initial contact, and postural stability are collectively a strong predictor of a second ACLR with high sensitivity and high specificity" (Paterno et al, 2010, 1977). The previous study relates specifically to the physical barriers of returning to sport as well as the risks, but fails to investigate the psychosocial factors of ACL injuries and rehabilitation.

Wierike et al states that "one of the adverse consequences of injuries is that an athlete cannot train full-time in his or her sport. Even worse, it might be the reason why talented athletes stop performing their sport" (2013, 527). There are a variety of factors that may contribute to this psychosocial impact and these factors include "cognitive, affective, and behavioral factors" (Wierike et al, 2013, 527). According to Wierike et al, cognitive factors include "internal Health Locus of Control (HLOC) and self – efficacy" (2013, 535). Wierike defines the "HLOC as the degree to which individuals perceive their ability to control life events" (2013, 535). The systematic review concluded that for cognitive factors "a high internal HLOC and more self-efficacy pre-operatively can improve the outcome after an ACL injury followed by reconstruction" (Wierike et al, 2013, 535). Another factor investigated in this systematic review was "affective responses defined by the way athletes feel after an injury" (Wierike et al, 2013, 535). This review concluded that as an athlete continued through physical therapy they experienced "fewer negative emotions, more positive feelings about returning to sport, and less pain. However, individuals experienced a fear of re-injury that had a negative influence on the rehabilitation process" (Wierike et al, 2013, 535). The psychosocial behavioral factor was also investigated and Weirike et al found that "recovery was positively reinforced when someone pays attention to alternative goals and follows all the exercises and training sessions imposed by the trainer or physiotherapist" (2013, 536). In conclusion, all of these factors collectively contributed to outcome results that identified "fear of re-injury as the most common cause in athletes with an ACL injury and reconstructive surgery who failed to return to sports" (Weirike et al, 2013, 538). Due to the psychological and physical barriers that seem to prohibit athletes from successfully returning to sport at high rates, increasing efforts to screen athletes for injury risk and then implementing ACL prevention programs becomes increasingly important.

As the medical community begins to have greater understanding of some of the landing mechanics that may be associated with increased risk for ACL injury, it becomes important to understand how athletes might be best screened for these factors. Many tests examine the loading techniques and valgus angle of the knee using 3-dimensional analysis including Pollard, Sigward, Ota, Langford, & Powers (2006) and Myer, Ford, Khoury, Succop, & Hewett (2011). Three-dimensional analysis utilizes motion capture systems as well as force plates. Two-dimensional analysis uses digital video taken at different angles to assess knee valgus analyzing the video with computer software. According to Mizner, Chmielewski, Toepke, and Toefte (2013), there are two options to examine landing mechanics when using 2-dimensional analysis including frontal plane projection angles (FPPA) and the knee:ankle separation ratio. The knee:ankle separation ratio is found by measuring the distance between the knees and dividing that measurement by the distance between the ankles at landing (Mizner, Chmielewski, Toepke, and Toefte, 2013). The study concluded that both 2-dimensional and 3-dimensional analysis are reliable and are recommended to be used in further ACL risk measurements. For frontal plane projection angles and knee:ankle separation ratio the correlation coefficients were 0.918 and 0.939, respectively, depicting a strong correlation between 3-dimensional and 2-dimensional analysis (Mizner, Chmielewski, Toepke, and Toefte, 2013). The study also recorded strong correlations for the inter-rater and intra-rater reliability measurements for both FPPA and knee:ankle separation ratio (Mizner, Chmielewski, Toepke, and Toefte, 2013). Another study also found 2-dimensional analysis to be sufficient in measuring knee valgus in a side step test, using elite basketball players (Walker, Ford, Myer, Hewett, & Bogert, 2005). The researchers compared the data from a 3-dimensional analysis based on markers and 2-dimensional analysis based on frontal plane projections and digital video. Walker, Ford, Myer, Hewett, & Bogert (2005) acknowledged 3-dimensional analysis to be the "gold standard" when analyzing biomechanics, however, the researchers comment on the "considerable financial, spatial, and temporal costs, which severely limit their application to the large scale screening, training, and evaluation programs necessary for successful prevention of non-contact ACL injuries" (355). Therefore, the purpose of their study was to determine if 2-dimensional analysis was an alternative option in analyzing biomechanics. The study found that when the joint centers can be easily identified, the use of 2-dimensional analysis to evaluate frontal plane knee motion is reliable (Mclean, Walker, Ford, Myer, Hewett, & Bogert, 2005). The researchers also concluded that in side stepping and side jumping of elite basketball players, 2-dimensional analysis provides similar benefits as 3-dimensional analysis in injury prevention screenings (Mclean, Walker, Ford, Myer, Hewett, & Bogert, 2005). Lastly, the study concluded that "the 2D-Cam may be useful for evaluating the effectiveness of training programs aimed at reducing dynamic knee valgus motions" (Mclean, Walker, Ford, Myer, Hewett, & Bogert, 2005, 361). The study however did find that 2-dimensional analysis of precise knee valgus magnitudes during frontal plane, stance phase should not be utilized because the knee valgus was significantly greater in 2-dimensional analysis compared to 3-dimensional analysis (Mclean, Walker, Ford, Myer, Hewett, & Bogert, 2005).

There are many areas of interest regarding risk of ACL injuries including hip neuromuscular control, knee abduction moment, and landing mechanisms. The gaps found in the literature pertain to the comparison of age in female athletes and finding accessible and reliable means to measure valgus moments at the knee. Specifically, there is a lack of research completed on youth athletes during prepubescence. This could be important in identifying ACL risks and for implementing prevention programs to address these risks. Additionally, further evidence is needed to continue to examine if there is a difference in risk factors between pre- and post-pubescent females in their landing mechanics. Investigating the difference in youth female soccer athletes around age 12 and college age athletes would add to the body of work pertaining to the prevention of ACL injuries as well give insight into maturation effect on landing mechanics. Use of 2-dimensional video analysis is a new area for screening at-risk populations. The purpose of this study will be to establish inter-rater reliability of 2-D measurements and to compare landing mechanics of prepubescent and post-pubescent female soccer players.

Methodology

Participants

This study was approved by the Otterbein University Institutional Review Board [Appendix A]. Potential subjects included the Otterbein University Women's soccer team and a youth female travel club team. The potential subjects were contacted by the student researcher through the coaches of each team. The parents of the youth team were also emailed information about the study along with the informed consent document. The email was forwarded to the team parents by the club coach. Prior to being tested the subjects, or parents of the subjects, signed an informed consent document that indicated the study was voluntary and the subject was able to drop out of the study at any time [Appendix B]. Prior to data collection, each participant also gave verbal consent to participate. There were no exclusion criteria.

Data Collection

Data was collected for the Otterbein team in August 2014 and for the club team in November 2014. After the subject had signed the informed consent and given verbal consent, black stickers were used to mark the center of their patella in order to improve accuracy when measuring variables. Next, the subjects were instructed to stand with feet shoulder width apart on a box (31cm) and then to drop off the box. Immediately after landing the subject was instructed to jump back up utilizing maximum force. This is known as the drop vertical jump (DVJ) and is used throughout the literature as an evaluation tool for landing mechanics. Soccer terminology was used in describing the jump immediately after landing from dropping off the box. Instruction was given as follows: act as if you were going up for a header or if you were

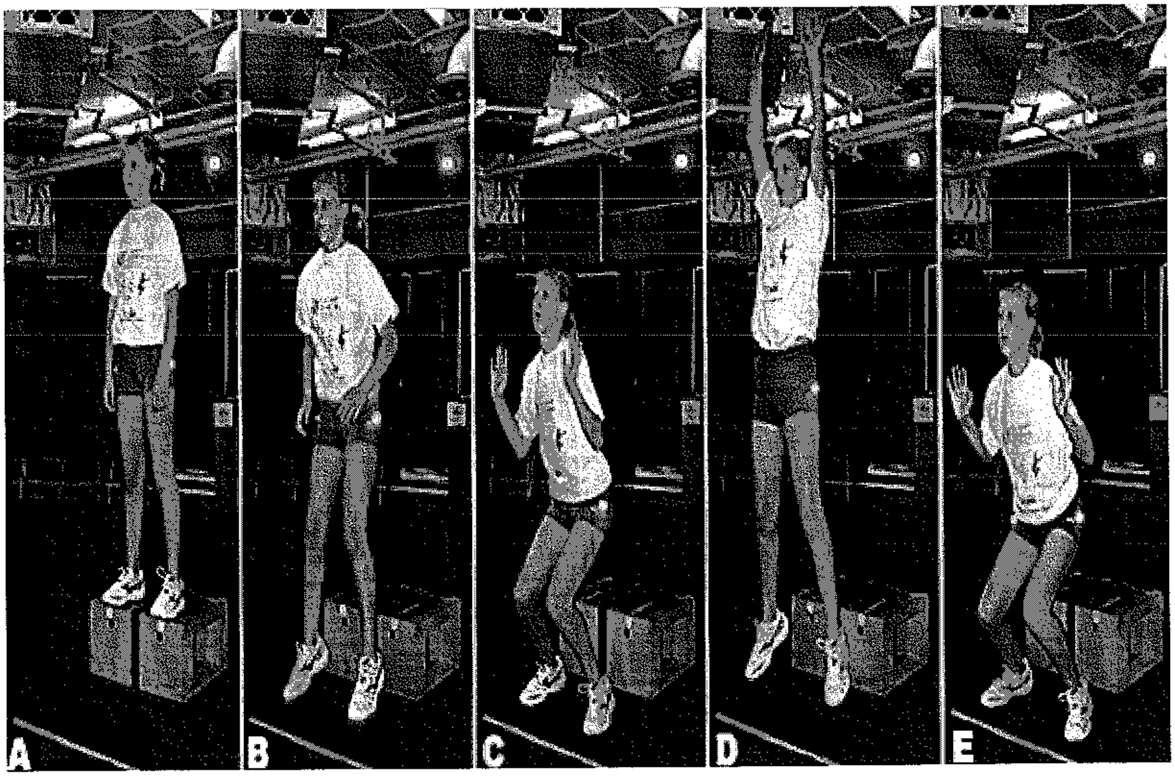


Figure 1. Drop Landing Test representation
http://www.craigliebenson.com/wp-content/uploads/2010/10/dropjump.jpg

jumping up to save a ball from going in the goal (Myer, Ford, Khoury, Succop, & Hewett, 2011). The distance from the HD video camera to the box was 15feet. Each subject completed three trial tests and then completed three trials that were video recorded. The data collection of each subject took approximately 5-7 minutes. All data was collected at two indoor facilities that consisted of safe landing areas, The Otterbein University Clements Recreation Center and Field Sports in Dublin, OH. Dartfish, a motion analysis software, was used to capture a .jpeg image of each athlete at maximum peak knee flexion from the video recordings. The captured .jpeg image was analyzed using a software called ImageJ that allowed measurement of tibial length, peak knee valgus, and the distance between the knees at landing in order to determine the frontal plane projection angle (FPPA). The ImageJ software is free and provided by the National Institute of Health. The distance between the knees and ankles at maximum landing to determine the knee:ankle separation ratio. The FPPA was measured by marking the angle of the Anterior Superior Iliac Crest, the center of the patella, and the center of the ankle between the tibia and talus bones and calculating the angle formed.

ImageJ was used by first selecting the desired subject picture from the specified folder. Next, the image was zoomed in twice in order to allow for better accuracy in measurement. The line length measurement tool was indicated by a straight line icon and the angle tool was indicated by an angle icon (Figure 2). To take the measurement for the knee:ankle separation ratio, the line tool was selected and then the researchers drew a line from the right to the left knee center (as determined by the markers placed) and then selected the "measure" option located under analyze tab (Figure 2).The same technique was repeated for the ankle center measurement. The measurements were copied into a spread sheet in ImageJ than copied into Microsoft Excel in a spreadsheet created specifically for this project. In a selected column the equation for the ratio was entered as follows: ratio=knee separation/ankle separation. The right and left frontal plane projection angle was measured by using the angle icon and drawing a line from the ASIS, the knee center, and the ankle center. These measurements were taken bilaterally (Figure 3). Figure 3 and Figure 4 give examples of the screen appearance for each measurement technique. After the angle was drawn, the measurement option was again selected and the data was added to the Microsoft Excel sheet in the same manner as the knee:ankle separation ratio data.

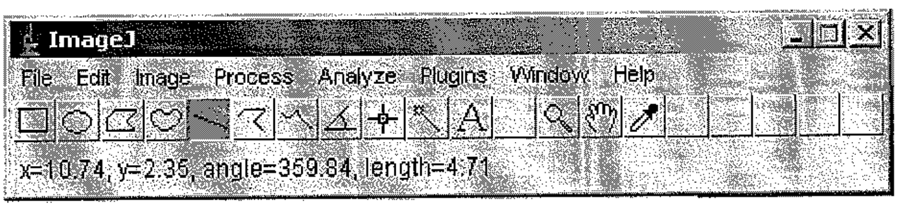


Figure 2 Representation of Image J software capabilities.

http://www.wlcastleman.com/equip/reviews/85mm/mtf/method/imageJ.jpg

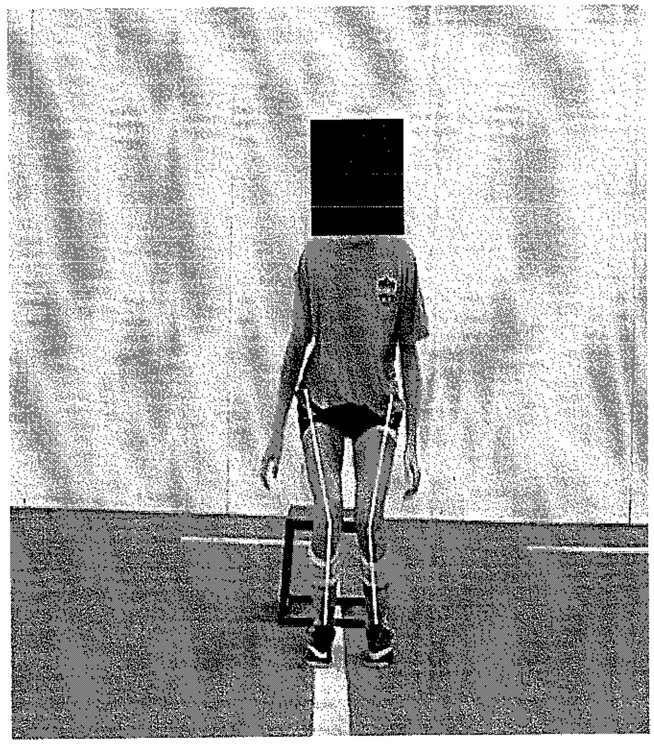


Figure 3 Measurements of knee:ankle separation ratio using ImageJ software (left)

Figure 4 Measurements of Right and Left Frontal Plane Projection Angles using ImageJ software (right)

Data Analysis

Statistical Package for the Social Sciences (version 17.0, SPSS Inc., Chicago, IL) was used for all data analysis. Descriptive statistics were used to describe group characteristics. To determine inter-rater reliability, each researcher recorded measurements for knee:ankle separation ratio, right front plane projection angle, and left frontal plane projection angle. The student's measurements and the primary researcher's measurements were analyzed using a simple correlation to determine an interrater correlation coefficient. To determine intra-rater reliability each investigator repeated the measurement of the same variables (K: A separation and FPPA) one week later. Using the repeat measurements, a simple correlation was used to determine the intrarater correlation coefficient.

In order to examine if there was a difference between the pre- and post-pubescent females, the FPPA and the knee:ankle separation ratio between each group was analyzed using an independent t-test. An alpha level of $p \leq 0.05$ was established for all statistical analysis. The research design of this project was an exploratory design because the research investigated a topic that has been investigated minimally and may provide insight into further experiment designs for future research.

Results

The subjects consisted of 24 college level female soccer players with a mean age of 19.58 years old. The second group consisted of 7 youth female soccer players with a mean age of 12.29 years old, see Table 1. The purpose of this research was to investigate the inter-rater and intra-rater reliability of two-dimensional analysis in measuring frontal plane projection angles and knee:ankle separation ratio in pre-pubescent and post-pubescent female soccer players. This study also compared the same variables between subject groups. Figures 5, 6 and 7 are representative Box and Whisker Plots of the collected mean data for each group.

	Mean Age	Mean RFPPA	Mean LFPPA	Mean K:A Separation
Group 1(Post-Pubescent)	19.58	167.90 ± 9.081	167.97 ± 8.11	0.91 ± 0.15
Group 2(Pre-Pubescent)	12.29	163.20 ± 12.21	165.81 ± 10.45	0.078 ± 0.12

Table 1. Mean age, RFPPA, LFPPA, K:A separation ratio for both groups.

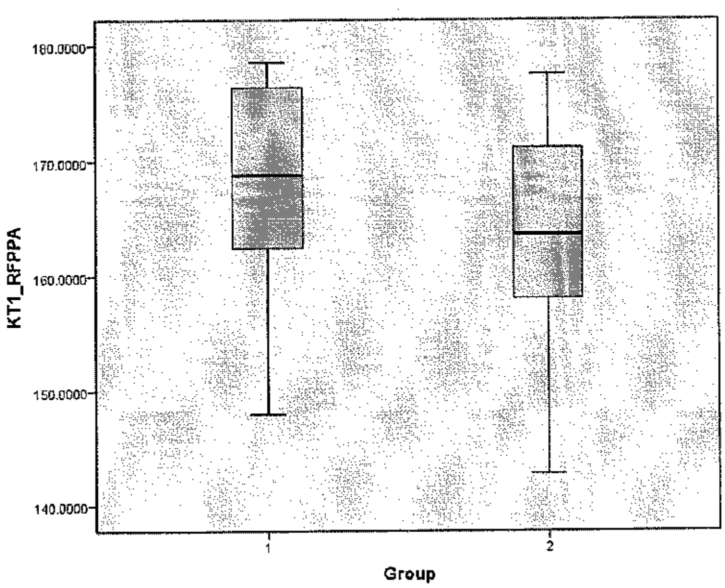


Figure 5. Box and Whisker Plot of RFPPA for groups 1 and 2.

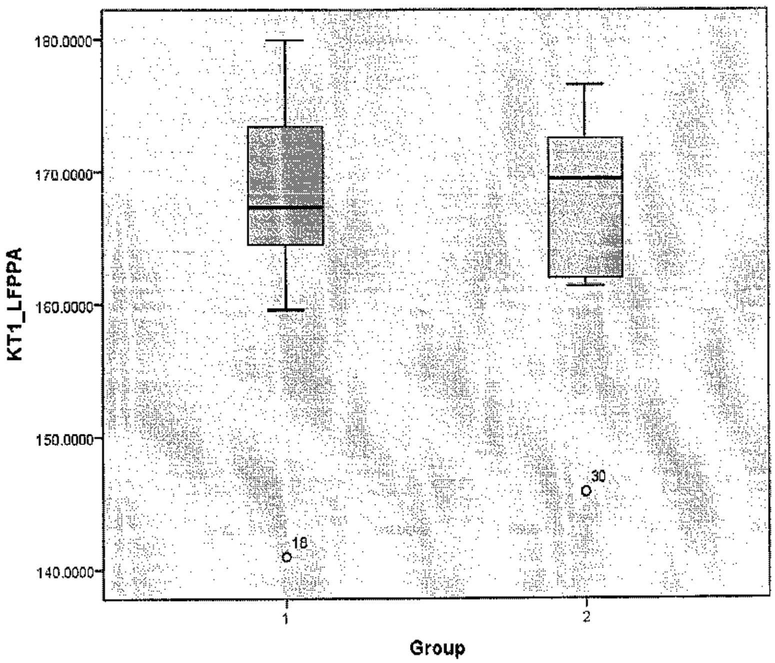


Figure 6. Box and Whisker Plot of LFPPA for groups 1 and 2.

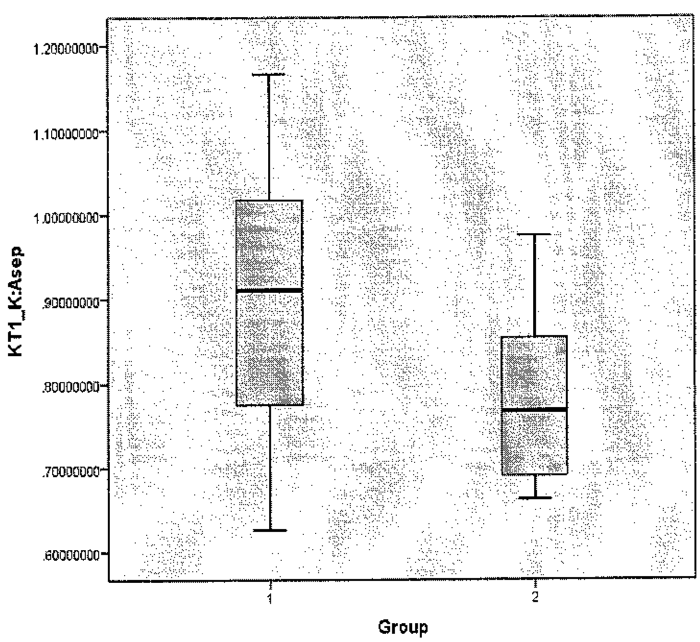


Figure 7. Box and Whisker Plot of K:A separation ratio for groups 1 and 2.

An error bar chart shows each group as a bar with whiskers representing the lowest and highest measurement for each group. If the two bars from each group do not overlap there is a significant difference between the groups. The means for each group's measurements of each variable are found in Table 2. The large standard deviations are a result of the data having a large range. This may to lead to less reliable results. A small standard deviation represents a smaller range of results meaning that the results may be more reliable.

	Mean	
	Group 1	Group 2
Knee: Ankle Separation	0.91 $\pm$ 0.15	0.078 $\pm$ 0.12
Right Frontal Plane Projection Angle	167.90 $\pm$ 9.080	163.20 $\pm$ 12.21
Left Frontal Plane Projection Angle	167.97 $\pm$ 8.11	165.81 $\pm$ 10.45

Table 2. Means for each group's measurements. Group one represents the post-pubescent and group two represents pre-pubescent female soccer athletes.

The box and whisker plots are used to summarize the data for each measurement taken for each group. According to Flowingdata.com, the middle line represents the mean of the data, while the upper and lower whisker represents the highest and lowest measurement taken, not including outliers. The upper and lower quartiles represent the top 50^{th} percentile and the bottom 50^{th} percentile of the data, respectively. The points away from the main box are outlier measurements.

All correlations (both intrarater and interrater) were found to be significant at a 0.01 level (2-tailed). The correlation of right frontal plane projection angles was calculated as 0.925 also showing a significant correlation. (Figure 8). The correlation for left frontal plane projection angles was 0.945, also significant (Figure 9). Lastly, the correlation for knee: ankle separation ratio was 0.983 representing a significant correlation (Figure 10). The closer the correlation to one the stronger the correlation.

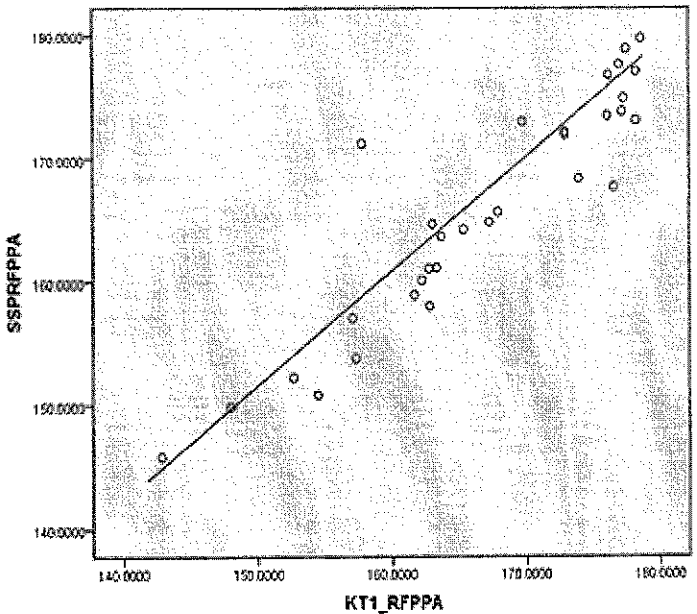


Figure 8. Representation of Strong Correlation for Inter-Rater Reliability in RFPPA.

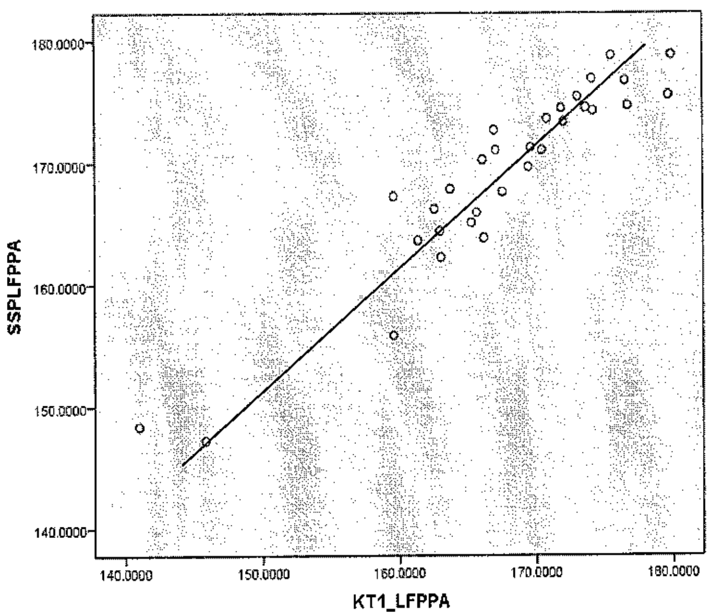


Figure 9. Representation of Strong Correlation for Inter-Rater Reliability in LFPPA.

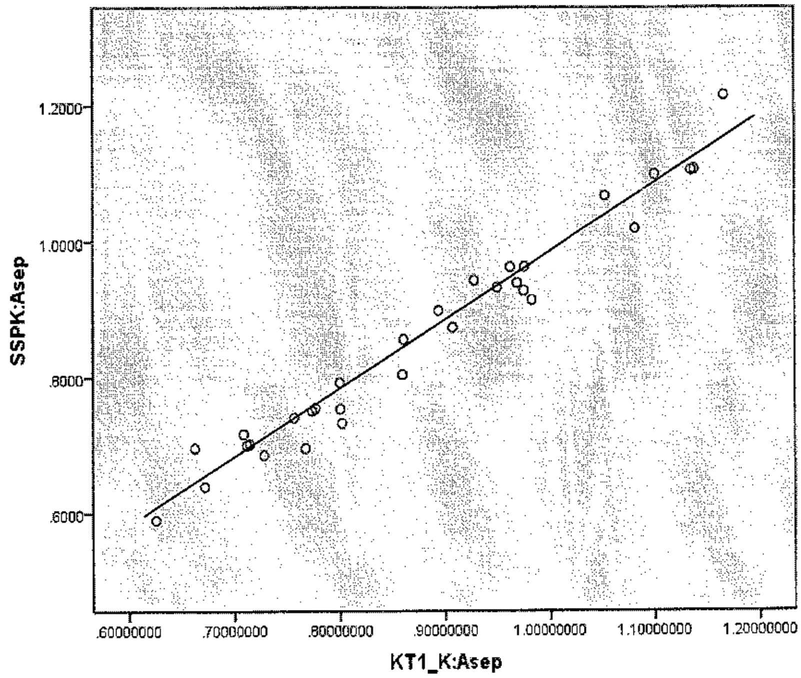


Figure 10. Representation of Strong Correlation for Inter-Rater Reliability in K:A separation ratio.

Along with inter-rater reliability, intra-rater reliability was also investigated. The analysis and reporting of intra-rater reliability was similar to inter-rater reliability. The significance of the correlation was also analyzed at a 0.01 level (2-tailed). The correlation was also found to be strong for right frontal plane projection angles with a correlation coefficient of 0.959 (Figure 11). The correlation coefficient for left frontal plane projection angle was found to be significantly lower than the other measured variables at 0.875, but was still found to be significant (Figure 12). The intra-rater reliability for the student researcher knee: ankle separation ratio was 0.966, representing a significant strong correlation (Figure 13).

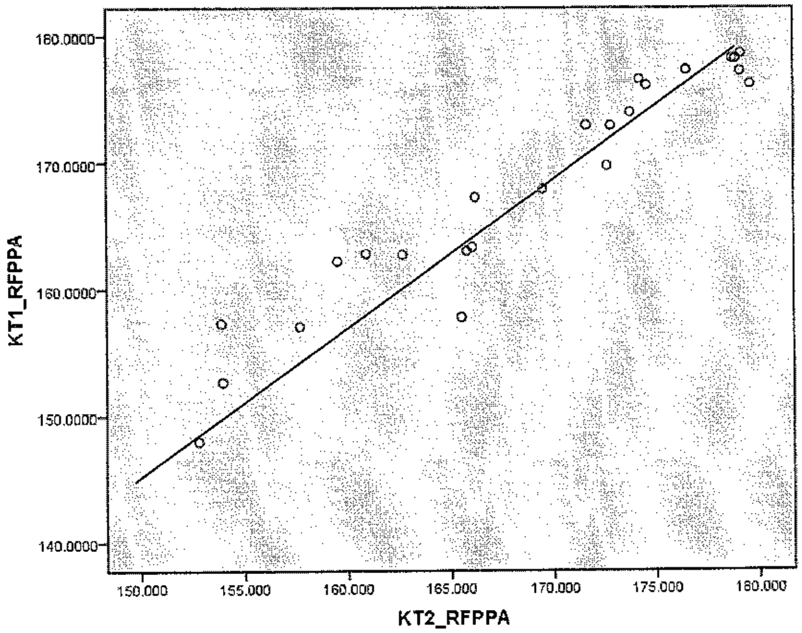


Figure 11. Representation of Strong Correlation for Intra-Rater Reliability in RFPPA.

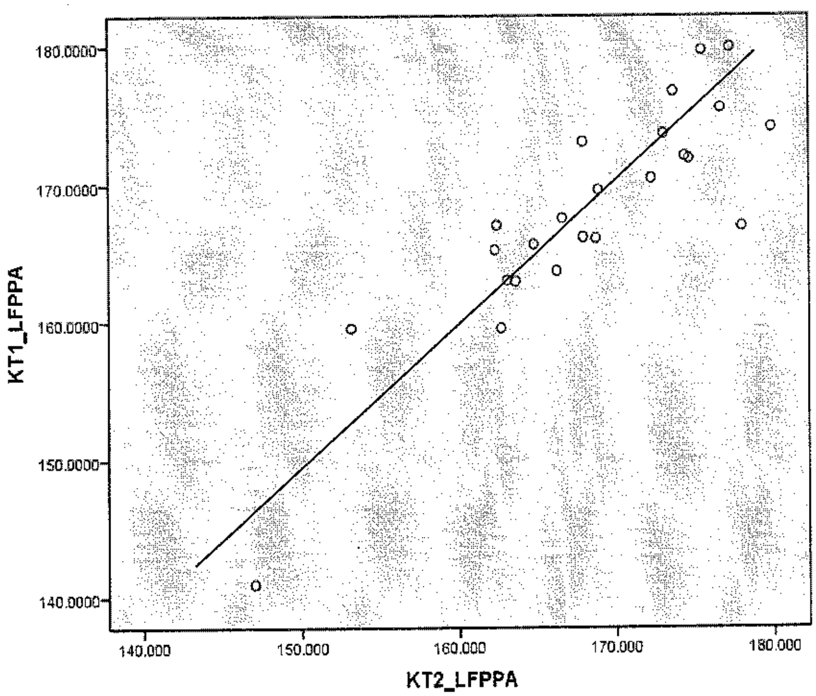


Figure 12. Representation of Strong Correlation for Intra-Rater Reliability in LFPPA.

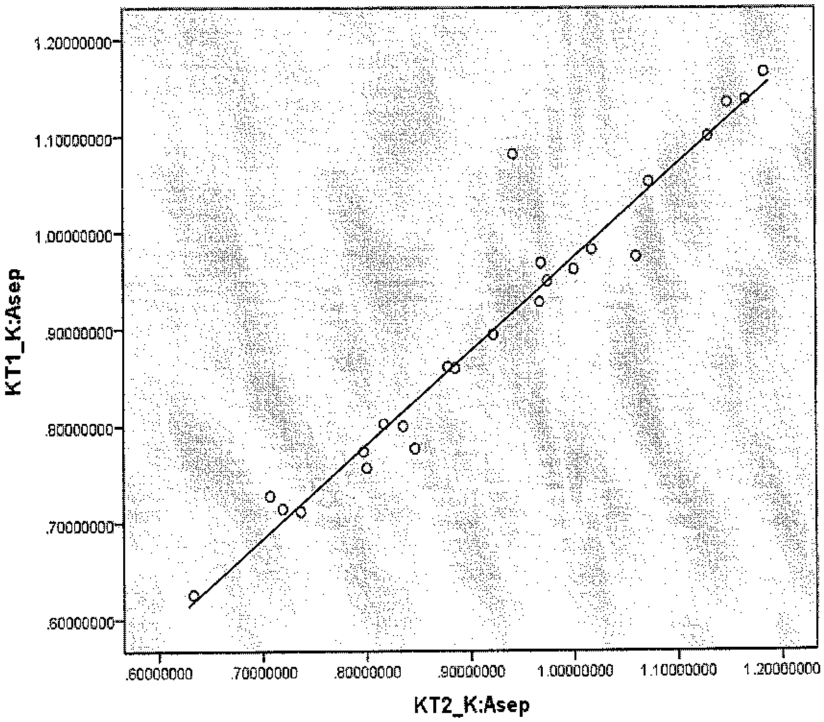
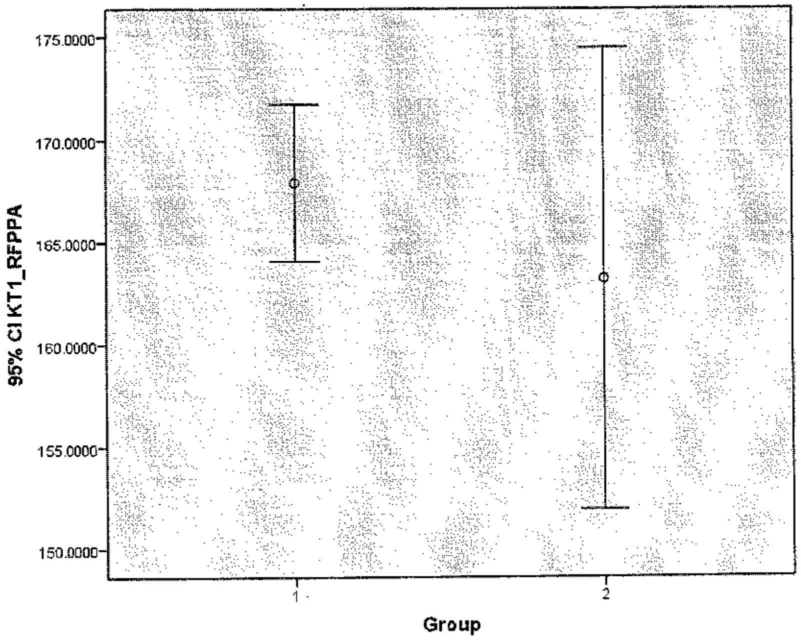


Figure 13. Representation of Strong Correlation for Intra-Rater Reliability in K:A separation ratio.

Independent t-tests were used to determine any significant difference between groups on any variable. The significance level for the knee: ankle separation ratio was p=0.067. The youth athletes (group2) had lower knee:ankle separation ratios. Therefore, the difference between the two groups was not significant. The significance level for right frontal plane projection angles was p=0.273 and the significance level for left frontal plane projections angles was p=0.566. Therefore, the differences in frontal plane projection angles were also not significant between groups. Error bar charts were completed to exemplify the insignificance of each variable (Figure 14, 15,



16).

Figure 14. Error Bar Chart of RFPPA with overlap of bars indicating no significant difference between the two groups.

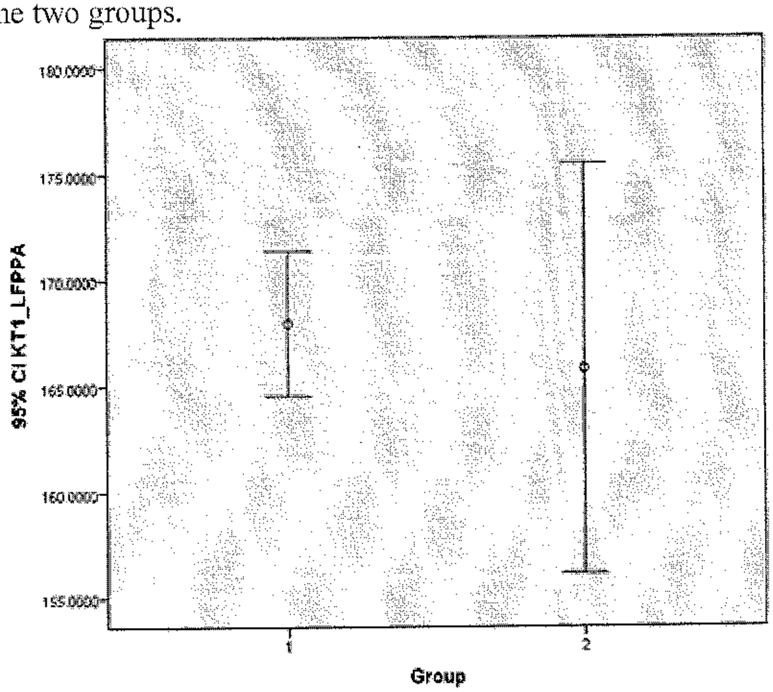


Figure 15. Error Bar Chart of LFPPA with overlap of bars indicating no significant difference between the two groups.

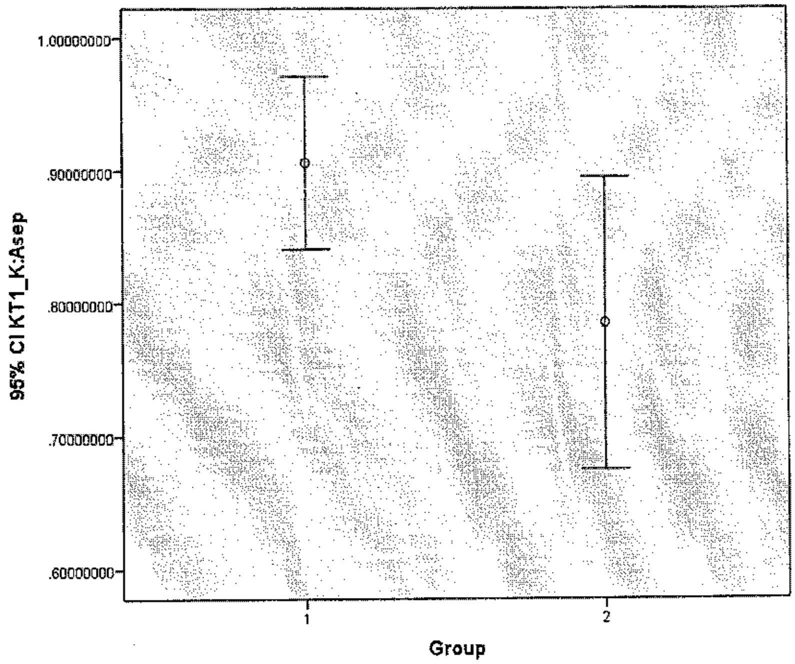


Figure 16. Error Bar Chart of K:A separation ratio with overlap of bars indicating no significant difference between the two groups.

DISCUSSION

The purpose of this study was to investigate the use of 2-dimensional analysis to compare the landing biomechanics of pre-pubescent and post-pubescent female soccer players. The study also investigated the inter-rater and the intra-rater reliability of the screening tool. Our hypothesis was that the post-pubescent athletes would have a greater valgus angle due to bony growth that occurs during and after puberty that was not associated with neuromuscular spurt. Our hypothesis of post-pubescent female soccer athletes having a greater knee valgus than pre-pubescent female soccer athlete due to neuromuscular spurt was not supported. We did not find a significant difference between groups for knee: ankle separation ratio, right frontal plane projection angle, or left frontal plane projection angle. However, knee: ankle separation ratio was approaching significance, but not in the direction we had hypothesized. The knee:ankle separation ratio approached significance for Group 2, the pre-pubescent group. We had expected the post-pubescent group to have greater neuromuscular control due to a neuromuscular spurt during puberty. However, there was a significant correlation for both inter-rater and intra-rater reliability, exemplifying this tool as an effective screening tool that a variety of experience levels could utilize. The means had a large standard deviation due to a wide range of values, leading to a less reliable data.

We found that 2-dimensional analysis is an effective tool in screenings with a significant correlation coefficient for both inter-rater and intra-rater reliability. This finding agreed with a study completed by Mizner, Chmielewski, Toepke, and Toefte that found that 2-dimensional analysis was a reliable tool along with 3-dimensional analysis in screening for ACL risk factors. Another study found that when the joint centers can be easily identified, the use of 2-dimensional analysis to evaluate frontal plane knee motion is reliable (Mclean, Walker, Ford, Myer, Hewett, & Bogert, 2005). These previous finding also support our results. We found that when the bony landmarks were clearly identified, the tool was more reliable and found that when the landmarks were blocked from clear view, intra-rater reliability decreased in correlation such as in the left frontal plane projection angle measurements.

Neuromuscular spurt was reported to not be found in pubescent female athletes (Myer et al, 2004) and therefore agreeing with our findings that neuromuscular spurt may not be a factor with female athletes. Our findings are in conflict with the neuromuscular spurt data because, Myer, Ford, & Hewett (2004) defined neuromuscular spurt as "increased power, strength, and coordination that occur with increasing chronologic age and maturation stage in adolescent boys" (353), which was not found in our subject pool.

Errors that could have occurred in this study are due to the limited amount of subjects. Another error that may have affected the results is that in many of the images the left arm blocked the ASIS. This caused us to have to estimate the location and therefore causing a discrepancy in measurements. The estimation of the location, especially for the left frontal plane projection angle measurements, may have led to the lower correlation coefficient. Consideration of these errors is relevant to several areas of improvement that could be applied to this study. Firstly, a larger number of athletes for both groups, especially the pre-pubescent female athletes should be used in order to have a better representation of each population. Another form of improvement could be that college level athletes and travel club team athletes are too advanced. Also, is the age of 13 too old for the pre-pubescent female athletes? Another way to improve this study is to implicate exclusion criteria such as a history of ACL injuries. Lastly, a large limitation of this study was that there were no normative values to compare our results.

The significance of this research is the application of using 2-dimensional analysis for screening of frontal plane projection angles and knee: ankle separation ratios. The attributes of this type of screening tool is that there is a high inter-rater and intra-rater reliability. Therefore, any experience level would be able to utilize this screening tool and the measurements they obtain. Also, this screening tool was identified as appropriate for large scale screening (Mclean et al, 2005). With the utilization of a more accessible screening tool, many costs associated with ACL injuries could be alleviated. According to Sugimoto et al, there are "50,000 ACL reconstruction surgeries performed annually in the United States...with a sum financial cost of $3 billion annually" (2012, 714). Therefore, the low financial cost of a 2-dimensional analysis would greatly assist in decreasing the annual cost for ACL surgeries if successful. Along with the financial cost ACL injuries also cause "premature osteoarthritis and reduced quality of life due to limited knee function" (Sugimoto et al, 2012, 715). These costs are only a few reasons why this screening tool could be beneficial. Other areas that would benefit from use of this screening tool include insight on incidence of ACL re-tear as well as athletes not returning to sport. As previously mentioned, "estimates of the overall likelihood that an athlete will incur a subsequent ACL injury after return to sport participation after ACL reconstruction (ACLR) range between 1 in 4 (25%) to 1 in 17 (6%) athletes (Paterno et al, 2010, 1969). Also, all of these Weirike et al identified four factors that collectively contributed to outcome results that identified "fear of reinjury as the most common cause in athletes with an ACL injury and reconstructive surgery who failed to return to sports" (2013, 538). Therefore, this 2-dimensional analysis screening tool could assist in identifying individuals with increased risk factors for return to sport and second ACL tears. This would assist the physical therapist in creating a rehabilitation program that would focus on these increased risk factors. Along with this identification, several studies have found that compliance to neuromuscular training is key to a successful rehabilitation as well as a multi-component rehabilitation programs (Michaelidis & Koumantakis, 2014). Michaelidis et al identified three programs that were soccer specific that were most successful in reducing risk of re-injury. These prevention programs are PEP, the HPT, and the Walden (Michaelidis et al, 2014). According to Michaelidis et al, “a successful training program for ACL injury prevention should start in the preseason for at least 6 weeks and continue in-season with less frequency, should include strength training, plyometrics along with balance, proprioception, and education feedback on correct technique” (2014, 208). Sugimoto et al identified “that higher compliance rates were associated with lower rates of ACL injury incidence in physically active young females” (2012, 722). Sugimoto et al also identified “that the moderate NMT compliance clinical trials had a 3.1 times (low-compliance 4.9 times) greater risk of experiencing ACL injuries than high compliance clinical trials” (2014, 560). The significance of these finding shows that not only can 2-dimensional analysis screening be beneficial to ACL injury rehabilitation, but also to ACL injury prevention programs.

Possible future research could be completed on younger less advanced female soccer players. For instance, high school athletes for the post-pubescent group and club teams prior to travel team participation for the pre-pubescent athletes. Future research could also focus on the possibility of following athletes throughout their soccer career to measure when the valgus angle adapts. Also, future research should focus on determining normative values across ages and populations to improve screening methods. Methods that are currently being study include the Star Excursion Balance Test (SEBT). A literature and systematic review completed by Gibble et al identified the SEBT as “a reliable measure and has validity as a dynamic test to predict risk of lower extremity injury, to identify dynamic balance deficits in patients with a variety of lower extremity conditions, and to be responsive to training programs in both healthy participants and participants with lower extremity injuries” (2012, 356). Therefore, further research should focus on the potential of utilizing in collaboration 2-dimensional analysis and the Star Excursion Balance Test.

References

Barber-Westin, S., Noyes, F., & Galloway, M. (2006). Jump-land characteristics and muscle strength development in young athletes: A gender comparison of 1140 athletes 9 to 17 years of age. *American Journal Of Sports Medicine*, *34*(3), 375-384.

Biencourt, N., Ocarino, J., Fonseca, S., Mendonça, L., & Hewett, T. (2012). Foot and hip contributions to high frontal plane knee projection angle in athletes: A classification and regression tree approach. *Journal Of Orthopaedic And Sports Physical Therapy*, *42*(12), 996-1004.

Blackburn, J., Fong, C. McGrath, M., Norcross, M. F. & Padua, D. A. (2011). Ankle-Dorsiflexion Range of Motion and Landing Biomechanics. *Journal of Athletic Training*, 46(1), 5-10.

Cortes, N., Morrison, S., Van Lunn, B. L., & Onate, J. A. (2012). Landing technique affects knee loading and position during athletic tasks. *Journal Of Science & Medicine In Sport*, 15(2), 175-181.

Fox, A., Bonacci, J., McLean, S., Spittle, M., & Saunders, N. (2014). What is Normal? Female Lower Limb Kinematic Profiles During Athletic Tasks Used to Examine Anterior Cruciate Ligament Injury Risk: A Systematic Review. *Sports Medicine*, *44*(6), 815-832.

Greenfield, M. V. H., Huston, L.J., & Wojtys, E.M. (2000). Anterior Cruciate Ligament Injuries in Female Athlete: Potential Risk Factors. *Clinical Orthopaedics & Related Research,*372, 50-63.

Gribble, P. A., Hertel, J., & Plisky, P. (2012). Using the Star Excursion Balance Test to Assess Dynamic Postural-Control Deficits and Outcomes in Lower Extremity Injury: A Literature and Systematic Review. *Journal Of Athletic Training (Allen Press),* 47(3), 339-357.

Hewett, T. E., Ford, K. R., & Myer, G. D. (2006). Anterior Cruciate Ligament Injuries in Female Athletes Part 2, A Meta-analysis of Neuromuscular Interventions Aimed at Injury Prevention. *American Journal of Sports Medicine*, 34(3), 490-498.

Laible, C., & Sherman, O. H. (2014). Risk Factors and Prevention Strategies of Non-Contact Anterior Cruciate Ligament Injuries. *Bulletin Of The Hospital For Joint Diseases*,*72*(1), 70-75.

McLean, S. G., Huang, X., & van den Bogert, A. J. (2005). Association between lower extremity posture at contact and peak knee valgus moment during sidestepping: Implications for ACL injury. *Clinical Biomechanics*, 20(8), 863-870.

McLean, S.G., Waler, K. K., Ford, K.R., Myer, G. D., Hewett, T.E., & van den Boget, A.J. (2005). Evaluation of a two dimensional analysis method as a screening and evaluation tool for anterior cruciate ligament injury. *British Journal of Sports Medicine,* 39(6), 355-362.

Michaelidis, M., & Koumantakis, G. A. (2014). Effects of knee injury primary prevention programs on anterior cruciate ligament injury rates in female athletes in different sports: A systematic review. *Physical Therapy In Sport*, 15(3), 200-210.

Myer, G. D., Ford, K. R., & Hewett, T. E. (2004). Rationale and Clinical Techniques for Anterior Cruciate Ligament Injury Prevention Among Female Athletes. *Journal of Athletic Training,* 39(4), 352.

Myer, G., Ford, K., Khoury, J., Succop, P., & Hewett, T. (2011). Biomechanics laboratory-based prediction algorithm to identify female athletes with high knee loads that increase risk of ACL injury. *British Journal Of Sports Medicine*, 45(4), 245-252.

Nilstad, A., Andersen, T., Kristianslund, E., Bahr, R., Myklebust, G., Steffen, K., & Krosshaug, T. (2014). Physiotherapists can identify female football players with high knee valgus angles during vertical drop jumps using real- Time observational screening. *Journal Of Orthopaedic And Sports Physical Therapy*, *44*(5), 358-365. doi:10.2519/jospt.2014.4969

Noyes, F., Barber-Westin, S., Fleckenstein, C., Walsh, C., & West, J. (2005). The drop-jump screening test: Difference in lower limb control by gender and effect of neuromuscular training in female athletes. *American Journal Of Sports Medicine 33*(2), 197-207.

Paterno, M. V., Schmitt, L. C., Ford, K. R., Rauh, M. J., Myer, G. D., Bin, H., & Hewett, T. E. (2010). Biomechanical Measures During Landing and Postural Stability Predict Second Anterior Cruciate Ligament Injury After Anterior Cruciate Ligament Reconstruction and Return to Sport. *American Journal Of Sports Medicine*, *38*(10), 1968-1978.

Pollard, C. D., Sigward, S. M., Ota, S., Langford, K., & Powers, C. M. (2006). The Influence of IArtn Season Injury Prevention Training on Lower-Extremity Kinematics during Landing in Female Soccer Players. *Clinical Journal Of Sport Medicine*, 16(3), 223-227.

Steckel, H., Fu, F. H., Baums, M. H., & Klinger, H. M. (2009). Arthroscopic evaluation of the ACL double bundle structure. *Knee Surgery, Sports Traumatology Arthroscopy,* 17(7), 782-785.

Sugimoto, D., Myer, G., Barber Foss, K., & Hewett, T. (2014). Dosage Effects of Neuromuscular Training Intervention to Reduce Anterior Cruciate Ligament Injuries in Female Athletes: Meta and Sub-Group Analyses. *Sports Medicine*, *44*(4), 551-562.

Sugimoto, D., Myer, G. D., Bush, H. M., Klugman, M. F., Mckeon, J. M., & Hewett, T. E. (2012).\ Compliance With Neuromuscular Training and Anterior Cruciate Ligament Injury Risk Reduction in Female Athletes: A Meta-Analysis. *Journal Of Athletic Training (Allen Press)*, *47*(6), 714-723.

Wierike, S. M., Sluis, A., Akker-Scheek, I., Elferink-Gemser, M. T., & Visscher, C. (2013). Psychosocial factors influencing the recovery of athletes with anterior cruciate ligament injury: A systematic review. *Scandinavian Journal Of Medicine & Science In Sports*, *23*(5), 527-540.

Appendix A

INSTITUTIONAL REVIEW BOARD
RESEARCH INVOLVING HUMAN SUBJECTS
OTTERBEIN UNIVERSITY

X Original Review
_____ Continuing Review
_____ Five-Year Review
_____ Amendment

ACTION OF THE INSTITUTIONAL REVIEW BOARD

With regard to the employment of human subjects in the proposed research:

HS # 14/15-01
Payne & Tuchfarber: 2-Dimension Analysis of Frontal Plane Projection in Female Soccer ...

THE INSTITUTIONAL REVIEW BOARD HAS TAKEN THE FOLLOWING ACTION:

_____ Approved
✓ Approved with Stipulations*
_____ Deferred
_____ Disapproved
_____ Waiver of Written Consent Granted

*Stipulations stated by the IRB have been met by the investigator and, therefore, the protocol is APPROVED.

It is the responsibility of the principal investigator to retain a copy of each signed consent form for at least four (4) years beyond the termination of the subject's participation in the proposed activity. Should the principal investigator leave the college, signed consent forms are to be transferred to the Institutional Review Board for the required retention period. This application has been approved for the period of one year. You are reminded that you must promptly report any problems to the IRB, and that no procedural changes may be made without prior review and approval. You are also reminded that the identity of the research participants must be kept confidential.

Date: 28 August 2014

Signed: ______________________
Chairperson

OC HS Form AF

Appendix B

OTTERBEIN UNIVERSITY **Protocol No.___________**

INFORMED CONSENT
Parental

I, ____________________________, hereby agree (to allow my child) to take part in a research study titled, "2-Dimensional Analysis of Frontal Plane Projection Angle in Female Soccer Athletes" which is being conducted by Kylee Tuchfarber through Otterbein University for her senior distinction research project. The researcher is working closely with Dr. Shelley Payne to analyze the knee biomechanics in female soccer athletes.

We are interested in looking at your biomechanics when you jump. It is estimated that each session will take no more than 15 minutes of your time. The information gained will be helpful in determining factors that may be associated with knee pain in athletes. It is unlikely that you would experience any discomfort with this testing.

The researcher, Kylee Tuchfarber, will answer any questions about the research now, or during the course of the project at kylee.tuchfarber@otterbein.edu. Should you have additional questions you may contact Dr. Shelley Payne at spayne@otterbein.edu.

Your participation is solicited although strictly voluntary. You will be videotaped for later analysis and you will not be given individual feedback. In order to provide confidentiality, the video obtained will be transferred to a folder on KyLee's password protected computer. The video will be deleted from the camera after it is transferred. The video file will be used to capture one still (jpeg) image of the lower extremities in order to analyze knee biomechanics. The jpeg image will not include your face. After the jpeg image is captured, the original video file will be deleted from KyLee's computer. The jpeg image will be labeled with a subject number only and will remain in a password protected folder on KyLee's computer only. We assure you that your name will not be associated in any way with the research findings. The information will be identified only by a code number.

I hereby acknowledge that I have been provided with sufficient information and understand the study procedures described above as well as my rights as a subject. I am aware that I can withdraw at any time without fear of penalty. I also recognize that all of my questions have been answered to my satisfaction, and I agree to (allow my child to) take part in this study. I have been given a copy of this form to keep.

____

Name of Parent Signature Date

Child's Date of Birth (used to categorize by age): ____________________

OTTERBEIN UNIVERSITY **Protocol No.____________**

INFORMED CONSENT

Otterbein Soccer Players

I, ______________________________, hereby agree to take part in a research study titled, "2-Dimensional Analysis of Frontal Plane Projection Angle in Female Soccer Athletes" which is being conducted by Kylee Tuchfarber through Otterbein University for her senior distinction research project. The researcher is working closely with Dr. Shelley Payne to analyze the knee biomechanics in female soccer athletes.

We are interested in looking at your biomechanics when you jump. It is estimated that each session will take no more than 15 minutes of your time. The information gained will be helpful in determining factors that may be associated with knee pain in athletes. It is unlikely that you would experience any discomfort with this testing.

The researcher, Kylee Tuchfarber, will answer any questions about the research now, or during the course of the project at kylee.tuchfarber@otterbein.edu. Should you have additional questions you may contact Dr. Shelley Payne at spayne@otterbein.edu.

Your participation is solicited although strictly voluntary. You will be videotaped for later analysis and you will not be given individual feedback. In order to provide confidentiality, the video obtained will be transferred to a folder on KyLee's password protected computer. The video will be deleted from the camera after it is transferred. The video file will be used to capture one still (jpeg) image of the lower extremities in order to analyze knee biomechanics. The jpeg image will not include your face. After the jpeg image is captured, the original video file will be deleted from KyLee's computer. The jpeg image will be labeled with a subject number only and will remain in a password protected folder on KyLee's computer only. We assure you that your name will not be associated in any way with the research findings. The information will be identified only by a code number.

I hereby acknowledge that I have been provided with sufficient information and understand the study procedures described above as well as my rights as a subject. I am aware that I can withdraw at any time without fear of penalty. I also recognize that all of my questions have been answered to my satisfaction, and I agree to take part in this study. I have been given a copy of this form to keep.

____

Name of Participant Signature Date

With my signature I affirm that I am at least 18 years of age.

Date of Birth: ______________