A Thesis

Entitled

The Effects of Knee Flexion and Extension Torque Production on Time to Stabilization in Healthy Women’s Soccer and Volleyball Players

By

Marie E. Siler ATC/L

Submitted as partial fulfillment of the requirements for
The Masters of Science in Exercise Sciences Concentration in Athletic Training

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College of Health Science and Human Service

College of Graduate Studies

The University of Toledo
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Objective: To determine the effects of knee flexion and extension torque productions in the concentric and eccentric manners on the amount of time needed to stabilize following a jump landing task. Design and Setting: Two stepwise regression analysis were performed for time to stabilization in the anterior/posterior (APTTS) and medial/lateral (MLTTS) directions. Also performed were 6 independent t-tests comparing soccer to volleyball athletes. Significance was set at p<0.05. All data was collected in a research laboratory. Subjects: Eleven healthy female athletes participated in this study. Six of these athletes were from the soccer team and five from the volleyball team at the
University of Toledo. **Measurements:** Subjects participated in two separate testing sessions. Session 1 was used to take a medical history to ensure that all subjects met the inclusion criteria as well as collection of TTS data. Five successful trials of a jump landing task were performed on the dominant extremity. The jump landing task consisted of a single leg landing from a jump height equivalent to 50% of the subject’s maximum jump height (50% $\text{Vert}_{\text{max}}$). Subjects stood 70 cm from the center of the forceplate (Bertec Corp; Columbus, OH) then jumped with two feet, reached up and touched the indicated marker, and landed on the dominant extremity on the forceplate. During session 2 subjects were asked to perform isokinetic testing on a Biodex System 2 (Biodex Medical Systems Inc., Shirley NY). Isokinetic testing was performed on the dominant extremity at 120 degrees per second in knee flexion and extension in the concentric and eccentric manners. **Results:** For APTTS and MLTTS there was no statistical significance with none of the predictors significantly predicting variance in TTS. All four knee torque production variables were not statistically significant difference between volleyball and soccer players. For eccentric knee flexion, there were notable differences with soccer players producing more normalized average peak torque production (0.68 ± 0.089 Nm/kg) compared to volleyball players (0.59 ± 0.06 Nm/kg) ($t= 1.904; p=.089$). APTTS ($t= -1.987; p=0.078$) and MLTTS ($t= -1.005; p=0.341$) were not statistically different when compared between soccer and volleyball. APTTS was observed to be longer in volleyball athletes (2.74±0.88 sec) when compared to the APTTS of soccer athletes (1.99±0.28 sec). **Conclusions:** Variances in torque productions did not
statistically predict variances in APTTS and MLTTS. Torque productions and
sport may not be significant contributors in time needed to stabilize. The
women’s soccer athletes used within this study participate in an ACL prevention
program. Due to this limitation we concluded that the decreased TTS in the
soccer athletes may be attributed to this program. Repetitive concentration on
proper landings may be the greatest factor in reducing
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Chapter 1
Introduction

Anterior cruciate ligament (ACL) injury is 4 to 6 times more likely to occur in female athletes when comparing them to male athletes that participate in the same landing and cutting movements that occur in sports.\(^1\) This increase in injury to the anterior cruciate ligament in the female sports population has inspired the increase in examination of the mechanisms associated with these occurrences.\(^1-3\) A rupture of the ACL is costly of both time and money. Surgery and rehabilitation could inhibit the athlete from participation for approximately 8-12 months.\(^2\)

The mechanism underlying an ACL injury consists of many factors. Numerous theories have been proposed in explaining these mechanism as well as the factors that increase the risk of ACL injury in females.\(^4\) These theories include both intrinsic and extrinsic factors.

The extrinsic factors include environmental and outside factors. Some examples of extrinsic factors are: weather, shoe to surface interaction, and bracing.\(^1\) The intrinsic factors include anatomical, hormonal, neuromuscular, and biomechanical differences.\(^1, 2\) Any single or combination of these factors can lead injury to the ACL.

In recent research, investigators have concentrated on the kinematic factors that attribute to ACL tears. Ford et al\(^2\) examined the landing patterns of
male and female basketball players during the landing phase of lay ups. His study concentrated on differences between genders as well as difference within subjects between their dominant and non-dominant extremities.\textsuperscript{2} This study found evidence that suggests that an increase in the knee valgus and a decrease in knee flexion during landing increase the risk of ACL injury.\textsuperscript{2}

Another key contributor to ACL tears is the imbalance between the strength of the quadriceps and hamstring muscle groups.\textsuperscript{4} Female athletes exhibit an increase in quadriceps strength after the onset of their menstrual cycle.\textsuperscript{4} With the shift in the quad-hamstring ratio, individuals are at an increased risk of ACL tears. The hamstrings are overpowered by the quads and lack the ability to slow the tibia down, thus increasing the amount of torque placed on the ACL.\textsuperscript{4}

In 2005 Cooper et al\textsuperscript{5} looked at balance and proprioceptive changes in subjects with ACL reconstructed knees. Post surgical repair subjects exhibited a significant decrease in proprioception as well as the ability for the subject to hold a static single leg stance, when compared with the uninjured limb.\textsuperscript{5}

Subjects with ACL reconstructed knees exhibit an increase in the amount of time needed to stabilize after landing from a jump.\textsuperscript{6,7} In 2006, Webster and Gribble\textsuperscript{6} compared female Division 1 collegiate athletes with prior ACL reconstruction to healthy athletes during a jump landing task. They reported a significant increase in APTTS as well as MLTTS when compared to a group of healthy subjects.\textsuperscript{6} This is consistent with the work of Colby et al\textsuperscript{7}, however they did not use elite level athletes.
From previous research conclusions have been made that kinematic differences at the knee exist during landing and these differences affect the ability to dynamically stabilize from a jump. With this conclusion the question of which factors are affecting the kinematic differences still remains. Our research will examine if strength defects are a key contributor to the alterations in dynamic stability within healthy subjects. This comparison may help clinicians understand contributions to ACL injury.

Due to the uncertainty of the relationship of strength and landing, we want to compare a group of athletes that would traditionally possess a high level of knee strength (soccer) to a group that has a high demand for jumping in their sport (volleyball). We hypothesize that the between group comparison for each measure of torque production and TTS will be significant.

**Statement of the Problem**

Research shows that there is a distinct relationship between the increase in ACL injury and the increase in knee valgus moments and extension of the knee during a jump landing.\(^1\)\(^-\)\(^3\),\(^8\) This relationship has been shown in numerous studies that have compared both male and female athletes. It has also been shown that subjects who exhibit these changes in kinematics need an increase in the amount of time needed to stabilize during the landing phase\(^1\),\(^3\),\(^8\),\(^9\), as well as the relationship between the amount of time needed to stabilize and ACL injury rates.\(^6\),\(^7\) However, no previous research investigated the effects of knee torque production and how it relates to the amount of time needed to stabilize when
landing from a jump. It is unknown if specific sport athletes demonstrate this relationship more effectively.

**Statement of Purpose**

The purpose of this study is to investigate the relationship of torque production during knee flexion and extension on the amount of time needed to stabilize after landing from a jump. The variables that we will be concentrating on are knee flexion and extension torque productions during a concentric and eccentric phase as well as APTTS and MLTTS. Then using this data we can make a comparison between healthy volleyball and soccer players. By comparing these factors in a regression analysis we will be able to determine if knee torque and sport are contributing factors to the changes in time to stabilization.

**Hypotheses**

H₁: For MLTTS; variances in sagittal plane knee torque will not significantly predict the changes in dynamic stability in the medial/lateral plane.

H₂: For APTTS; a combination of variances in eccentric and concentric knee flexion and extension torque production will significantly predict the variance in dynamic stability in the anterior/posterior plane.

H₃: The soccer players will have greater sagittal plane knee torque production measured eccentrically and concentrically compared to volleyball players.

H₄: The volleyball players will have a significantly faster APTTS and MLTTS
compared to soccer players.

H₅: For both APTTS and MLTTS, the presence of group will significantly contribute to the regression model to predict the variance in dynamic stability.

**Clinical Significance**

When looking at the medial/lateral time to stabilization we hypothesized that knee torque will not significantly predict changes in dynamic stability. However, we do hypothesize that in the anterior/posterior time to stabilization a combination of variances in both the eccentric and concentric knee flexion and extension torque production will significantly predict the variance in dynamic stability.

Also we have hypothesized that volleyball players will have a shorter TTS when compared with soccer players and when comparing volleyball and soccer players, the soccer athletes will have a greater torque production at the knee. However, the presence of group will not significantly contribute to the regression model to predict the variance in dynamic stability in both the anterior/posterior and medial/lateral directions.

It has been proven that a significant increase in the amount of time needed to stabilize increases the risk of ACL injury. If strength becomes a significant factor in the prediction of time to stabilization then by increasing the strength at the knee we could decrease the amount of time needed to
dynamically stabilize after a jump landing task. This may prove to be useful in prevention of ACL and other lower extremity injury.

**Operational Definitions**

**Proprioception:** the body’s ability to transmit position sense through afferent signaling.\(^{10}\)

**Neuromuscular Control:** the conscious or unconscious efferent response to an afferent signal concerning dynamic joint stability.\(^{10}\)

**Time to Stabilization:** the amount of time needed for the ground reaction forces exhibited after a landing to stabilize within a pre-determined range.\(^{11}\)

**Balance:** the body’s ability to maintain equilibrium by controlling the bodies center of gravity (COG) over its base of support.\(^{10}\)

**Isokinetic:** exercise or a program of exercises to increase muscular strength, power, and endurance based on lifting, pulling, or pushing variable weight or resistance at a constant speed.\(^{12}\)

**Limitations**

All subjects participating in this study are asked to give 100% of their effort. The lead investigator for this study is giving verbal cues and positive encouragement throughout the testing procedure. Despite the motivation, the amount of effort put forth by the subjects could be a limitation of this study.
Chapter 2
Literature Review

Anterior cruciate ligament (ACL) injury is 4 to 6 times more likely in females than males who participate in similar sports with the same extrinsic factors such as playing conditions and footwear.\textsuperscript{13-16} Mechanisms of injuries to the ACL are classified into two categories: contact and non-contact. Approximately 70% of ACL injuries are non-contact in nature.\textsuperscript{13-15,17} Potential risk factors for non-contact injuries may be attributed to four areas: environmental (extrinsic factors), anatomic (Q-angle, notch size, joint laxity), biomechanical (neuromuscular control, skill level), and hormonal (levels of estrogen, testosterone, progesterone, luteinizing hormone [LH], and follicle stimulating hormone [FSH]).\textsuperscript{16} While the exact mechanism(s) for ACL injuries remains unknown to investigators, it is probable that a combination of factors may contribute to the higher prevalence of ACL injuries in females in comparison to males.\textsuperscript{16-19} By understanding possible gender differences in these risk factors, steps may be taken clinically to help control the increased incidence of female ACL injuries.

This literature review will examine some of the known contributors to the increase in ACL prevalence in females when compared to males such as: joint laxity differences between genders, hormonal influences, kinematic landing
patterns, quadriceps to hamstring ratio importance, the relationship of injury to the amount of time needed to stabilize after landing, as well as an in depth look at the rationale and methods used in this study.

**ACL Laxity**

Excessive joint laxity is thought to predispose an individual to injury.\textsuperscript{20, 21} It is defined as the amount of non-pathological looseness in the joint, with the main contributors being the static stabilizers (i.e., the joint capsule, ligaments, and tendons). Anterior knee laxity and general joint laxity are common measures of joint laxity, and have been found to be greater in females compared to males.\textsuperscript{20, 21} When in excess, these measures of joint laxity have been associated with an increased risk of ACL injury, thus potentially contributing to the increased prevalence of ACL injury in females compared with males.

Greater anterior knee laxity has been associated with an increase in ACL injury rates.\textsuperscript{22-24} Scerpella et al\textsuperscript{22} and Woodford-Rogers et al\textsuperscript{24} retrospectively examined the association between non-contact ACL injury and knee laxity, and determined that ACL injured athletes had greater anterior knee laxity than the uninjured group. Scerpella et al\textsuperscript{22} also measured the uninjured side of ACL injured group to rule out possible bias from the actual injury or reconstruction. In agreement with these findings, Uhorchak et al\textsuperscript{23} prospectively examined numerous risk factors for their ability to predict ACL injury, and found that higher than normal KT-2000 athermometer values at 111N, 134N, 156N, and 178N were predictors of ACL injury risk.
**Hormonal Influences**

Sex differences in anterior knee laxity have also been investigated and consistently have been determined to be greater in females compared to males.\textsuperscript{23, 25-28} These studies looked at the amount of anterior knee laxity between genders, ages, and level of activity. Rozzi et al\textsuperscript{27} reported no significant findings in the amount of anterior knee laxity between sedentary individuals and the athletic population.

Gender differences in hormonal levels of estrogen, testosterone, progesterone, luteinizing hormone, and follicle stimulating hormone have also been researched when looking at ACL injury. Estrogen and progesterone have been suggested to have an influence on a variety of tissues in the body, including the growth and development of bone, muscle, and connective tissue.\textsuperscript{29-31}

Liu et al\textsuperscript{30} research also supports that progesterone and estrogen influence the physical properties of the ACL. They showed estradiol (the most potent form of estrogen) and progesterone receptors were located on human ACL fibroblasts, which are the cells responsible for the synthesis and maintenance of all connective tissue fibers.\textsuperscript{32} Collagen is the primary connective tissue in the ACL, and provides the tensile strength for the ligament.\textsuperscript{33} As a result, hormones are thought to play a role in the structure, composition, and physical properties of the ACL.\textsuperscript{30} Studies exposing ACL tissue to increased concentrations of estradiol resulted in decreased fibroblast proliferation and collagen formation.\textsuperscript{30, 34}
Conversely, increased levels of progesterone have been associated with increased fibroblast proliferation and collagen formation.\textsuperscript{30} In addition, Wreje et al.\textsuperscript{35} implicated that oral contraceptive use decreases type I and III collagen synthesis. Slauterbeck et al.\textsuperscript{36} tested the tensile strength of ACLs’ in rabbits with removed ovaries and compared those who were supplemented with excessive concentrations of estradiol to those who were not provided hormone supplementation. Their results revealed that rabbit ACLs’ that received estrogen replacement had lower failure loads when compared to the control group, further supporting potential impact of estrogen on the properties of the ACL.\textsuperscript{36}

Males produce testosterone more readily and in higher concentration than females, the role of testosterone in females has many functions, including potential effects on soft tissue structures similar to that of estrogen.\textsuperscript{37} Lovering and Romani\textsuperscript{37} studied the effect of testosterone on the female anterior cruciate ligament, and identified androgen receptors and specifically testosterone receptors on the ACL. They also associated higher concentrations of testosterone near ovulation with higher ACL stiffness (stiffness being defined as the change in force divided by displacement).\textsuperscript{37} This suggests that testosterone may also influence the remodeling and tensile strength of the ACL.

Given the effects of sex hormones on collagen structure and metabolism, this has led to the suggestion that variations in concentrations of sex hormones may also influence the measurement of knee laxity. Continued research is needed to determine how this relationship impacts the ACL injury rate.
Kinematic Patterns

Hewett et al\(^6\) in 2005 concentrated on the valgus loads during the jump landing tasks. Prospectively, there was a correlation between the subjects with the greatest amount of valgus moment and ACL injury in those female athletes.\(^9\)

The increase in research in lower extremity biomechanics and kinematics during sport specific activity has begun to examine the differences between male and female movement patterns that are related to sports. Specifically, at the knee researchers have suggested that females land with an increased valgus moment as well as a decrease in knee flexion. McLean et al\(^8\) found that in basketball players that performed a side stepping motion females have an increase in the knee valgus moment when compared to males that performed the same task. Subjects were asked to perform a sidestepping motion at an angle between 35 and 55 degrees while knee kinematics and torques were calculated. Both male and female subjects had notable increase in knee valgus moments during the side stepping motions\(^8\). After the peak valgus moment values were normalized the females had a statistically (p<.05) significant increase of the peak moments over the males.\(^8\) This data was consistent with data from other studies that compared males and females in the same sidestepping movements.

Ferber et al\(^38\) concentrated on the stance phase of running in healthy female athletes. Female athletes exhibited a statistically significant increase of knee valgus and a decrease in knee flexion after heel strike.\(^38\) The decrease knee flexion during landing as well as the increase in knee valgus moment has been linked to ACL injury.\(^38\) By examining at the landing kinematics of athletes
and the changes in their kinematics, it may be possible to create predictive models for ACL injury.

**Torque Production**

Dynamic stability maybe related to quadriceps and hamstring action and torques at the knee. Quadriceps muscle contraction creates anterior-directed shear forces on the tibia relative to the femur; which puts the ACL at risk for rupture.\(^4\) Several studies have suggested that the hamstring muscles assist the ACL by reducing the amount of anterior translation of the tibia by the quadriceps.\(^4\) Giove et al\(^{39}\) found that higher levels of sports participation were achieved by ACL-deficient patients whose hamstring strength was equal to or greater than their quadriceps strength. These findings have led to the implementation of ACL injury prevention programs based on improving dynamic control of the knee by emphasizing hamstring strengthening and proprioception.\(^4\)

Huston and Wojtys\(^{40}\) found that female athletes had weaker quadriceps and hamstring muscles than male athletes when normalized to body weight. Anderson et al\(^{41}\) found that the quadriceps to hamstring ratio was significantly lower for male athletes, indicating that the hamstring muscles in the female athletes were relatively weak when compared with the quadriceps muscles. Reduced hamstring to quadriceps ratios at or below 50% to 60% may indicate a predisposition for that athlete to ACL injury.\(^{41}\) Anderson et al\(^{41}\) concluded that female athletes tend to be “quadriceps dominant” in both strength and muscle firing patterns.
Isokinetic dynamometry has been used to compare torque productions at the knee in many studies. However, the argument can be made that an open kinetic chain torque assessment does not closely correlate with strength assessment or functionality. Jamshidi et al.\textsuperscript{42} looked at the relationship of a Biodex System 3 isokinetic test to the hop test. After running the test on subjects with unilateral ACL reconstruction, the statistical analysis showed that the functional hop test showed a strong correlation to the results of the Biodex testing.\textsuperscript{42} Jamshidi et al.\textsuperscript{42} concluded that there is a strong relationship between the open kinetic chain isokinetic tests to the functional hop tests. The results of the study also showed that the ACL reconstructed knee had a decrease in torque production at the knee in both flexion and extension as well as a decrease in the distance and height of the hop testing.\textsuperscript{42}

Beck and Wildermuth\textsuperscript{43} found that females are more vulnerable to noncontact ACL injuries when compared to males. Females tend to be more ligament dominant, relying on their ligaments for support.\textsuperscript{43} Males tend to be more muscle dominant, relying on their muscles as a major support for their joints.\textsuperscript{43} Beck and Wildermuth\textsuperscript{43} concluded that this difference was related to the lack of strength and eccentric control of the quadriceps muscle group. However, overtraining the quadriceps without equally developing the hamstring muscle group could potentially cause more harm to the female athlete’s knee.\textsuperscript{43} Many researchers have suggested that the hamstring acts as a support to the ACL.\textsuperscript{39-43} As the quadriceps muscle pulls the tibia into anterior translation the hamstring contract to limit the translation.\textsuperscript{43} With this being the theory then the quadriceps
to hamstring ratio should be as close to 1:1 as possible to limit the risk of ACL injury.

**Functional Testing of ACL Injury**

When looking at lower extremity dysfunctions after an ACL injury many clinicians use single leg hopping test for time or distance, vertical jump or shuttle runs. Each of these tests show alterations in torque production at the knee but don’t take into consideration the altered changes in proprioception and lower extremity stability. To measure lower leg stability many clinicians and researchers have begun to use the functional test of a single leg stance.

Colby et al\(^7\) looked at the single limb stance in individuals with ACL impairment. In this study 25 healthy subjects, 13 ACL deficit subjects, and 12 subjects with 1 prior reconstructed ACL were used.\(^7\) The purpose of this study was to determine the reliability of the single limb stance and center of pressure measurements on the force plate.\(^7\)

Subjects were instructed to perform a single leg step down as well as a single limb hop onto a force plate. The ground reaction forces and moment data from the trials were recorded. Using these ground reaction forces and moment data the center of pressure data was calculated, focusing on at the anterior-posterior and medical lateral displacement. Subjects repeated the protocol for 3 sessions.\(^7\) After all data was collected an interclass correlation was developed to determine the most effective way to measure stabilization time.\(^7\)
Colby et al\textsuperscript{7} determined that the stabilization times for the hop test were statistically significant when comparing the ACL reconstructed and deficient knees. When looking at the data it could not predict which of the ACL impairments the subjects had. In conclusion, Colby et al\textsuperscript{7} showed the reliability of using a force plate in determining time to stabilization. This method has become a useful tool in research that is looking for a correlation between time to stabilization and injury rate within the athletic population.\textsuperscript{7}

Many researchers have used time to stabilization measures in subjects with functionally unstable ankles. Ross et al\textsuperscript{11} looked at time to stabilization in individuals with chronic ankle instability. The conclusions of this study were that individuals with a functional unstable ankle took longer to stabilize after a jump landing task. With these measures clinicians began to look further into proprioception and injury prevention by working to decrease time to stabilization.\textsuperscript{11}

Webster and Gribble\textsuperscript{6} compared the difference in APTTS and MLTTS between ACL reconstructed knees to knees of subjects without any lower extremity pathology. They built on the earlier work of Colby et al\textsuperscript{7} by utilizing all division I collegiate athletes. Their conclusions showed that the individuals with reconstruction had a significant increase in time needed to stabilize in both the anterior/posterior and medial lateral directions.\textsuperscript{6} Research has shown that division 1 female athletes with ACL reconstruction have a decrease in overall stabilization or an increase in the amount of time needed to stabilize.\textsuperscript{6} Therefore can time to stabilization be linked to strength deficits or kinematical variations? If
time to stabilization can be linked to strength deficits, then clinicians can begin to use measures of torque production as a predictive measure of potential ACL injury.

**Summary**

This study will help to provide a more in depth look into the relationship between torque productions in knee flexion and extension and time to stabilize during a jump landing task. The jump landing task was selected as the task due to the close correlation to sport specific activity. By conducting this study we hope to provide information that may lead to prevention of injuries to the knee, specifically the ACL. If decreased torque production is a strong predictor of an increase in time needed to stabilize, then we can conclude that by increasing the torque production in the knee flexors and extensors we may be able to minimize the amount of time needed to stabilize when landing form a jump, thus reducing the risk of injury.

Research has shown that ACL injury has a vast array of potential factors that are attributed to it. However, there are proven relationships between variations in kinematic movements and patterns and injury rates\(^8, 9, \& 38\), as well as time to stabilization and injury rates.\(^6, 7\) Using these relationships and methods, this study will concentrate on determining the relationship between torque production and time to stabilization. The diagram below graphically will explain the relationships that are proven and the relationship that will be looked into further by this study. The dotted line shows the relationship that will be
under investigation in this study. The solid lines have been proven by previous research outlines in this literature review.

Many sports teams use an injury prevention program to help minimize risk of ACL or related knee injuries. The clinical significance of this study may help contribute to the development of such programs that will be helpful in prevention of ACL injury as well as identify individuals that may be at high risk. Once the relationship has been determined between torque production and time to stabilization and at-risk individuals identified; the sports medicine team can concentrate on increasing the strength in the muscle groups with the potential deficiency, and in the long term hopefully prevent injury.
Chapter 3
Experimental Design and Methods

Subjects

Eleven female, collegiate athletes were recruited from the University of Toledo’s athletic department. All subjects volunteered for this study and read and signed an approved informed consent form. This study was approved by the University of Toledo’s IRB. The subjects were members of the women’s soccer (6) and volleyball (5) teams. All subjects are healthy with no lower extremity pathologies or surgeries.

Instrumentation

A Bertec 4060NC forceplate (Bertec, Inc., Columbus, OH) integrated with MotionMonitor software (Innovative Sports Technologies Inc., Chicago, IL) was used for collection of ground reaction forces during the jump-landing task, sampled at 200Hz. A Vertec vertical jump tester (Sports Imports, Columbus, OH) was used to measure the standing and maximum jump heights. For the task, 50% maximum jump height was calculated and the target was displayed by the Vertec.

Motion Monitor software was used to export the data into a spreadsheet (Microsoft Excel; Microsoft, Corp, Redmond WA). A custom program written in
LabView (National Instruments, Inc.; Austin, TX) software was used to calculate the TTS variables.

A Biodex System 2 (Biodex Medical Systems Inc., Shirley NY) and the accompanying software were used to determine torque production at the knee in both the concentric and eccentric manner at 120 degrees per second.

SPSS v 15.0 (SPSS, Inc. Chicago, IL) was used for all statistical comparison. For statistical analysis 2 different statistical analyze were performed.

**Statistical Model for Regression Analysis:**

**Predictor Variables**

1. Group (soccer, volleyball)
2. Eccentric knee flexion, average peak torque production
3. Concentric knee flexion, average peak torque production
4. Eccentric knee extension, average peak torque production
5. Concentric knee extension, average peak torque production

**Dependent Variables**

1. TTS in the anterior/posterior direction (APTTS)
2. TTS in the medial/lateral direction (MLTTS)
**Statistical Model for Independent T-Tests:**

**Independent Variables**

1. Group (soccer, volleyball)

**Dependent Variables**

1. Eccentric knee flexion, average peak torque production
2. Concentric knee flexion, average peak torque production
3. Eccentric knee extension, average peak torque production
4. Concentric knee extension, average peak torque production
5. TTS in the anterior/posterior direction (APTTS)
6. TTS in the medial/lateral direction (MLTTS)

**Procedures**

Prior to being selected for this study, all subjects were asked questions regarding their injury status and history of lower extremity pathologies. Inclusion criteria were set that all subjects will be Division 1 female athletes participating in volleyball or soccer. All subjects had no prior history of lower extremity injuries or balance disorders. Once subjects were selected and fit within the inclusion criteria they signed up for two forty-five minute testing sessions. To complete this study subjects must attend both sessions. All subjects read and signed a university approved informed consent form.

The first session started with recording the subjects age, height, weight, and sex. Next, standing reach height was recorded by having subjects stand
next to the Vertec vertical jump tester (Sports Imports, Columbus, OH). The subject reached up and touched the highest point possible while keeping the feet flat on the ground. Next the subjects were asked to perform 3 maximal jump height trials. Each subject jumped off both feet and reached as high as possible. After the three trials the highest jump height was recorded. Maximum jump height (Vert$_{\text{max}}$) was calculated as the highest jumping height minus the standing jump height. The target for the test trials was calculated as 50% of their maximal vertical jumping height and called 50%Vert$_{\text{max}}$.

For the testing of time to stabilization the dominant limb was assessed in a single leg landing task. The dominant limb was determined as the limb preferred while kicking a ball. When performing the jump-landing task, each subject was asked to complete five successful trials on the dominant limb. The jump landing task began 70 cm away from the forceplate. Each subject was instructed to jump from both limbs, hit their 50% Vert$_{\text{max}}$ and land on the designated testing limb. Once they stabilized they were instructed to place both hands on their hips as quickly as possible and hold that position while continuing to remain forward. If the subject is forced to place their other limb down, hop, or loses balance in any manner the trial was discarded and repeated.

Each subject was allowed as many practice trials of the jump landing task as needed to ensure familiarity with the testing procedure as well as the task. After the practice trials a five minute rest period was given. Subjects then perform the five test trials with one minute rest between each trial.
During the second testing session subjects were instructed to wear athletic apparel and athletic shoes. Subjects were instructed on proper technique and methods of the isokinetic testing. Each subject performed a series of tests on the knee of the dominant limb in both the concentric and eccentric manners. Average peak torque production for knee flexion and extension was assessed eccentrically and concentrically. Subjects were positioned in the isokinetic unit according to manufacturer guidelines.

Subjects were allowed as many trials needed for them to become comfortable with the task. Once the subjects were comfortable with the task a 5 minute rest period was given. Each test consisted of 5 repetitions of concentric and eccentric flexion and extension. The orders of eccentric and concentric assessments were randomized. Between each assessment subjects were given 2 minutes of rest.

**Data Processing**

Time to stabilization was calculated using the method reported by Ross et al.\(^2,3\) First we determined the range of variation of a given ground reaction force component. This range of values came from the smallest absolute range value of a ground reaction force measured in the last seconds of the single leg stance portion of the jump landing task.\(^3\) Using a third order polynomial to fit the data, the TTS is the point at which this polynomial transects the range of variation line.\(^3\) The process allows the calculation of TTS in the AP (anterior/posterior)
and ML (medial/lateral) directions. The mean TTS of the 5 jump trials was used for statistical analysis for both of these variables.

To calculate the average peak torque production on the Biodex System 2 we used the accompanying software. After all tests have been completed we looked at the graphs and determine the peak torque productions of each contraction. From the peak torque values of each repetition, the average peak torque was calculated and utilized in the statistical analysis.

**Statistical Analysis**

For each dependant variable (APTTS and MLTTS), a separate step-wise regression analysis was performed. The regression analyses determined which combinations of Group and the isokinetic variables are significant predictors of the TTS measures.

Additionally, to isolate Group differences, six separate independent samples t-test were performed to compare the volleyball and soccer players on the variables of APTTS, MLTTS, and the four isokinetic variables.

SPSS 15.0 (SPSS Inc, Chicago, IL) was used to perform all statistical analysis. Significance was set a priori at p <0.05.

**Potential Health Risks**

Throughout the course of this study were potential health risks that could occur. These risks were low in incidence as well as severity. The potential risks that could have occurred were muscular soreness, injury during the jump landing
task due to loss of balance, and fatigue. To reduce the occurrence of these risks each subject was given proper verbal and visual cues as well as ample practice time to become familiar with the tasks. Subjects were monitored throughout the testing session for fatigue and was allowed adequate amount of rest time between conditions. At any point the subjects feel pain, discomfort, or unsure about the task at hand the test was stopped.
Chapter 4
Results

Torque Production

All four knee torque production variables were not statistically significant difference between volleyball and soccer players (Table 1). For eccentric knee flexion, there were notable differences with soccer players producing more normalized average peak torque production (0.68 ± 0.089 Nm/kg) compared to volleyball players (0.59 ± 0.06 Nm/kg) (t= 1.904; p=.089).

Time to Stabilization

APTTS (t= -1.987; p= 0.078) and MLTTS (t= -1.005; p=0.341) were not statistically different when compared between soccer and volleyball (Table 2). APTTS was observed to be longer in volleyball athletes (2.74±0.88 sec) when compared to the APTTS of soccer athletes (1.99±0.28 sec). For MLTTS volleyball athletes had a longer amount of time needed to stabilize (1.29±0.12 sec) than soccer athletes (1.24±0.064 sec).
Regression Analysis for APTTS

The variance in different knee torque values as well as the difference in sport predicted between 30.5% and 37.0% of the variance in APTTS, but none of these predictive models were statistically significant (Table 3).

Regression Analysis for MLTTS

The variance in different knee torque values as well as the difference in sport predicted between 21.2% and 40.1% of the variance in APTTS, but none of these predictive models were statistically significant (Table 4)
### Table 1. Knee Torque Production by Sport, Means and Standard Deviations

<table>
<thead>
<tr>
<th></th>
<th>Ecc Knee Flex</th>
<th>Ecc Knee Ext</th>
<th>Con Knee Flex</th>
<th>Con Knee Ext</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soccer</td>
<td>0.68 ± 0.89 Nm/kg</td>
<td>0.92 ± 0.17 Nm/kg</td>
<td>0.67 ± 0.08 Nm/kg</td>
<td>0.98 ± 0.19 Nm/kg</td>
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<tr>
<td>Volleyball</td>
<td>0.59 ± 0.06 Nm/kg</td>
<td>0.97 ± 0.08 Nm/kg</td>
<td>0.61 ± 0.04 Nm/kg</td>
<td>0.94 ± 0.11 Nm/kg</td>
</tr>
<tr>
<td>p value</td>
<td>0.089</td>
<td>0.517</td>
<td>0.147</td>
<td>0.673</td>
</tr>
<tr>
<td>t value</td>
<td>1.904</td>
<td>-0.675</td>
<td>1.588</td>
<td>0.659</td>
</tr>
</tbody>
</table>

### Table 2: APTTS and MLTTS Means and Standard Deviations by Sport

<table>
<thead>
<tr>
<th></th>
<th>APTTS</th>
<th>MLTTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soccer</td>
<td>1.99 ± 0.28 sec</td>
<td>1.23 ± 0.06 sec</td>
</tr>
<tr>
<td>Volleyball</td>
<td>2.74 ± 0.88 sec</td>
<td>1.29 ± 0.12 sec</td>
</tr>
<tr>
<td>p value</td>
<td>0.078</td>
<td>0.341</td>
</tr>
<tr>
<td>t value</td>
<td>-1.987</td>
<td>-1.005</td>
</tr>
</tbody>
</table>
Table 3. APTTS Regression Model

<table>
<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>R²</th>
<th>F</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.609</td>
<td>0.379</td>
<td>0.588</td>
<td>0.713</td>
</tr>
<tr>
<td>2</td>
<td>0.606</td>
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<td>0.534</td>
</tr>
<tr>
<td>3</td>
<td>0.589</td>
<td>0.346</td>
<td>1.236</td>
<td>0.366</td>
</tr>
<tr>
<td>4</td>
<td>0.570</td>
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<td>5</td>
<td>0.552</td>
<td>0.305</td>
<td>3.948</td>
<td>0.078</td>
</tr>
</tbody>
</table>

**Model 1 Predictors:** Concentric knee extension, eccentric knee extension, sport, concentric knee flexion, eccentric knee flexion

**Model 2 Predictors:** Eccentric knee extension, sport, concentric knee flexion, eccentric knee flexion

**Model 3 Predictors:** Eccentric knee extension, sport, concentric knee flexion

**Model 4 Predictors:** Sport, eccentric knee extension

**Model 4 Predictors:** Sport
Table 4. MLTTS Regression Model

<table>
<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>R²</th>
<th>F</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.665</td>
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<tr>
<td>2</td>
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</tr>
<tr>
<td>4</td>
<td>0.630</td>
<td>0.397</td>
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<td>1.133</td>
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<tr>
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<td>0.461</td>
<td>0.212</td>
<td>2.427</td>
<td>0.154</td>
</tr>
</tbody>
</table>

**Model 1 Predictors:** Concentric knee extension, eccentric knee extension, sport, concentric knee flexion, eccentric knee flexion

**Model 2 Predictors:** Eccentric knee flexion, eccentric knee extension, sport, concentric knee flexion

**Model 3 Predictors:** Eccentric knee flexion, eccentric knee extension, sport

**Model 4 Predictors:** Eccentric knee extension, sport

**Model 5 Predictors:** Eccentric knee extension
Chapter 5
Discussion

The purpose of this study was to investigate the effects of torque production during knee flexion and extension on the amount of time needed to stabilize after landing from a jump between female soccer and volleyball players. We hypothesized that the torque production values could be used to predict the amount of time needed to stabilize after a jump landing task between volleyball and soccer athletes. This line of inquiry was intended to examine a group of healthy female athletes for the purpose of gaining insight on potential factors in identifying risk factors of an ACL injury.

The independent t-test comparisons revealed that there was not a statistically significant difference between soccer and volleyball players in MLTTS, APTTS or torque productions in the concentric and eccentric manners in knee flexion and extension. This result is contradictory to our hypothesis that volleyball players would have better dynamic stabilization when compared to soccer players. It also contradicts the hypothesis that soccer players would have greater knee torque productions when compared to volleyball players. The lack of statistical significance may be attributed to a low sample size. We only tested five volleyball players and six soccer players; a result of limited subjects that met our inclusion criteria. In spite of the absence of statistical significance, we feel
that there are some interesting differences in the means that may have clinical importance; especially as more subjects are added to the samples during this ongoing project.

We hypothesized that soccer players could produce higher torques because of the demands of kicking in their sport. Statistical significance was not discovered, however there was a notable difference in eccentric knee flexion torque production. Soccer players had a torque production of 0.68±0.09Nm/kg while volleyball players exhibited a lower torque production of 0.59±0.06 Nm/kg, a difference that approached statistical significance (p=0.089). This difference suggests that soccer players may possess a greater amount of hamstring eccentric torque production compared to volleyball players. We offer two rationales that may help to explain this difference.

First, the soccer players have been participating as a team in an ACL injury prevention program that, among other tasks, emphasizes eccentric hamstring work. Specific exercises are incorporated during the program that require the athletes to utilize this type of muscle contraction to slow down knee extension; the purpose related to reducing translation of the femur on the tibia to improve dynamic stability of the knee. We feel additional subjects added to the pool may help to realize this difference statistically.

A second rationale for the increased eccentric knee flexion torque in soccer player may be explained by the demands of the sport of soccer. When a soccer athlete is asked to kick a soccer ball, the quadriceps are contracting concentrically to produce knee extension to generate force against the ball.
Simultaneously, it is necessary for the hamstring muscle group to contract eccentrically to control the anterior translation of the tibia on the femur while contributing to the skill of the kick through deceleration. The kicking task performed by soccer players may have afforded these athletes a higher measurable eccentric knee flexion torque.

We also hypothesized that volleyball players would have better dynamic stability because of the demands of landing from a jump in their sport. This hypothesis was shown to be incorrect. Our data showed that soccer athletes had a time to stabilization of 1.99±0.28 sec and volleyball athletes had a time needed to stabilize at 2.74±0.88 sec, but this relationship was only approaching statistical significance (p=0.078). The contradictory finding that soccer players had better dynamic stabilization compared to volleyball players could be related to three different rationales.

First, we feel this observed difference could be highly influenced by the fact that the soccer team is participating in the ACL injury prevention program that was mentioned previously. Within this program athletes are required to practice jumping in a controlled environment. The repetition and concentrating on the increased knee flexion when landing as well as the practice in controlling the landing and holding it may have increased the soccer players’ ability to stabilize during the jump landing task.

Second, our study included volleyball players that were offensive and defensive players, and this may have contributed to the higher variability in our sample mean. In the sport of volleyball, some players, such as the libero and
defensive specialists, only play in the back row and typically do not perform a
jump landing task during practice and competition. Also, attacking players may
utilize different landing techniques depending on if they are outside hitters or
middle blockers. These potential variances in landing styles may have lead to
more variability within this group of athletes, evidenced by a higher standard
deviation in the mean scores for volleyball players (2.74±0.88 sec) compared to
soccer players (1.99±0.28 sec).

A third rationale is that in the sport of volleyball, athletes may not be
required to “stick” and hold the landing position, as is the requirement for the
assessment of TTS. Instead, the jumping or attacking players will jump, land,
and immediately transition off of the net into either a defensive position or for a
follow up attacking preparation as the play continues. For soccer athletes, the
primary need for jumping is to head the ball. Typically, during this jump landing
task, the soccer athlete will land from the jump and then look around for
development of the play before making an immediate transition movement.
Therefore, it is possible that soccer athletes are more accustomed to maintaining
a stable position after landing from a jump and subsequently had shorter TTS
times compared to volleyball players.

An alternative to our hypotheses could have been that knee torque and
landing could have been related with the same subjects excelling in both. Voigt
and Vetter examined the importance of strength in volleyball athletes, relating
knee torque production to vertical jump height. Using only offensive position
volleyball players, they determined that an increase in knee torque production
was a significant contributor to their maximum vertical jumping height. However, these authors did not quantify the landing phase of this task.

Our results, which did examine the amount of stability during the landing phase of this task, suggest that there may not be consistency between knee torque production and improved landing ability during a jumping task. We report observable differences that suggest that soccer players have better dynamic stability in the anterior/posterior plane, and have higher eccentric knee flexion average peak torque compared to volleyball players. We feel that these two factors may provide some important insight into a factor (hamstring eccentric torque) that influences dynamic stabilization. We will discuss more of this impact in the Clinical Significance section.

The t-test analyses have lead us to these conclusions that hamstring eccentric strength may be related to time to stabilization scores; and with more subjects statistical significance may become associated with these differences. It was our secondary purpose to relate torque production in the knee and the presence of soccer or volleyball as a sport to variances in Time to Stabilization using a regression analysis approach. It was hypothesized that for MLTTS, variances in sagittal plane knee torque would not significantly predict the changes in dynamic stability in the medial/lateral plane. The data supported this hypothesis, with torque productions and sport only predicting approximately 21-40% of the variance in MLTTS, and none of the predictive models demonstrating statistical significance.
For APTTS, we hypothesized that a combination of variances in eccentric and concentric knee flexion and extension torque production would significantly predict the variance in dynamic stability in the anterior/posterior plane. Our hypothesis wasn’t realized, with variances in concentric and eccentric knee extension and flexion, as well as sport only predicting 31-37% of the amount variance in the time needed to create stabilization in the anterior posterior direction, with statistical significance.

It is clear from these analyses that open chain knee torque production cannot provide a strong predictive model for dynamic stabilization. We feel this is also a product of low sample size. Regression analysis is incumbent upon the amount of variances in sample means versus the scale of the model variables. With our low sample size and inherently small scales of the torque and TTS variables, it is not surprising that the regression models were particularly strong. We feel it will be interesting to reexamine these relationships as more subjects are added to the samples during this ongoing project.

**ACL Injury Factor**

This study was meant to help answer the question of whether torque production is a strong predictor of variances in time to stabilization, which in the future may help to understand ACL injury risk factors. Ford et al. examined kinematic changes in male and female basketball players during the landing phase of a jumping task. They reported that a decreased knee flexion angle and an increase in knee valgus during the landing phase increased the individuals’
risk of ACL injury.\textsuperscript{2} These changes in kinematic landing techniques have shown to increase the amount of time needed to stabilize.\textsuperscript{8,9} This increase in time needed to stabilize could be related to a vast array of different variables. The specific relationship we were interested in was if knee torque production could significantly predict landing stabilization as measured with TTS.

Previous research has demonstrated that deficits in knee strength may lead to increased ACL injury rates. Ahmad et al\textsuperscript{4} stated that the shifts in the quad to hamstring ratio could predispose individuals to ACL injury. Concentrating on the point within their menstrual cycle Ahmad et al\textsuperscript{4} concluded that the increase in ACL injury rate after onset of their menses was do to the increased strength of the quadriceps. Another rationale was discussed by Beck and Wildermuth\textsuperscript{43}. They reported that females tend to be more ligament dominant as opposed to males who were more reliant on muscle contraction for stability. This increased reliance on the ligaments to provide the stability to the knee could be one reason for in increase in ACL injury in females over males,\textsuperscript{43} Anderson et al\textsuperscript{41} state that the rationale for females to be ligament dominant is due to the lack of strength of the quadriceps and hamstring muscle groups, increasing a female’s chances of sustaining an ACL injury.

Webster and Gribble\textsuperscript{6} compared APTTS and MLTTS in healthy versus ACL reconstructed knees in division I female athletes after the same jump landing task utilized in our current study. These authors reported significantly longer APTTS and MLTTS in the ACL reconstructed knees. This finding is
consistent with Colby et al\textsuperscript{7}, who used recreationally active subjects, but still found deficits in dynamic stability in those with ACL reconstructed knees.

These two studies did not utilize TTS measures to predict ACL injury, but rather demonstrated that this variable could expose a deficit related to this pathology. Our results indicate that the variances eccentric knee extension torque productions contribute to the variances in APTTS. Anderson et al\textsuperscript{41} theorized that the increased injury rate was due to lack of strength. Our study provides some evidence that a diminished eccentric torque production of the hamstrings and an increase in APTTS may be observed simultaneously. This relationship may help clinicians and researchers understand the linkage between strength and functional deficits and potential risk factors for ACL injury. It will be important to use this data and track the number of injuries that occur in these samples to determine if a strength or dynamic stability deficit as well as the amount of predictive relationship between the two can serve as a predictive factor for injury occurrence.

**Clinical Significance**

The data and the results of this study are only a small portion of a larger picture when it comes to ACL injury. The data from this study will be used in an on-going and long term study looking at ACL injury and other possible risk factors or predictive measures. The implications of this study are the beginnings of helping researchers investigate the importance of torque production at the knee during landing.
The results from our research could suggest that the injury prevention programs that concentrate on repetitive landings with proper technique and hamstring eccentric contraction are successful. Athletes that practice landings in a controlled setting are more apt to use those proper techniques in a game; thus decreasing the risk of non-contact ACL injury. One such injury prevention program is the Santa Monica Performance Enhancement Program (PEP), which is currently implemented into the strength and conditioning program of the varsity soccer team at the University of Toledo. Within this program, athletes concentrate on proper mechanics in a stable and controlled environment. The purpose of this project is to help an athlete adapt to mechanics that will lessen the risk of injury. During PEP, athletes are asked to cut, jump and land, as well as strengthen all accessory musculature that supports proper lower extremity mechanics. Therefore, one possible rationale for the shorter TTS in the soccer athletes when compared to the volleyball athletes is due to their participation in an ACL prevention program. While this factor is clearly a potential limitation to this study, it also provides some positive feedback that the PEP program may be a successful and useful utilization of time and effort by the players, coaches and athletic trainer.

**Limitations**

We only examined the dominant limb in this study, defined as the leg the athlete would prefer to kick a ball with. Future research may need to include bilateral limb comparisons. Due to low sample size of our study, subsequently
we have a lower level of statistical power. The sample size is a product of the need to test a specific population, division I varsity female soccer and volleyball players. Studies conducted in the future should have an increased sample size and an inclusion of other sports. This current study is part of an ongoing line of investigation in the laboratory of the faculty advisor. It is the plan of the advisor that this data will be combined with ongoing yearly testing of incoming freshman female athletes at the University of Toledo, which will grow the data set.

The jump landing task used in the study could be changed to use a task that is closer to the jumping patterns involved within sports. Many times in the game situation, specifically volleyball, athletes jump and land on 2 feet. While the TTS method has demonstrated deficits in stability among subjects with lower extremity pathology, a task that is closer related to the demands of the sport may provide additional useful information in this line of inquiry.

With the inclusion of volleyball in the study, a suggestion could be made to compare the specific player positions that are being tested. Volleyball athletes that play on the defensive end of the game are rarely asked to jump. The inclusion of such an array of different positions may have increased the variability in our sample. Future investigation may need to sub-divide this group of subjects if the sample becomes large enough to do so.

Both groups of athletes used in this study were accustomed to jumping and landing as a large part of their sport. It could be possible that the lack of significance between APTTS and MLTTS is due to the learned techniques of
landing acquired in the sport. Further research may need to include athletes from non-jumping sports.

During the isokinetics testing all athletes were asked to provide their maximal effort. Efforts were made by the investigator to provide consistent motivation during the testing procedures, but it cannot be guaranteed that all subjects made a maximum effort.

Lastly the women’s soccer athletes that were used in this study participate in an ACL prevention program as a part of their practice. This could have an adverse effect on the results of our study. The volleyball athletes do not participate in the equivalent program for injury preventions. The purpose of this study was not to compare the effects of a prevention program, it was to compared the effects of torque production on TTS. However, as the sample sizes grow with additional athletes tested in the coming years, this will need to serve as a factor for comparison.

**Future Research**

Future research in the area of determining if torque production is a significant predictor of TTS should begin with the inclusion of more subjects as well as the inclusion of both genders. Research shows that males are less likely to sustain ACL injury and subsequently the inclusion of males could prove to be a critical comparison.

Once the relationship has been established between torque production and TTS and risk of ACL injury, researchers and clinicians should develop
intervention programs for those individuals who may be determined to have a deficit in this relationship. With the development and implementation of such a program researchers may be able to improve the current injury prevention programs. In its current state, our data would appear to suggest that the strongest relationship of factors to dynamic stabilization during landing may be eccentric knee flexion and may be the initial areas for intervention if deficits are realized in an athlete.

Conclusions

This study attempted to determine if torque productions at the knee would prove to be a strong predictor of time to stabilization in volleyball and soccer athletes. The evidence suggests that there is not a strong or statistically significant predictor of time to stabilization within this study. However, learned landings and repetitive concentration of theses landings help to increase a person’s ability to dynamically stabilize. Potentially, the concentration on eccentric knee flexion control and torque production could improve this relationship. This research is another step in understanding possible predictive measure in ACL injury. Our research is limited due to the low number of subjects tested as well as the results from this study can only be used when looking at volleyball and soccer athletes. Additional research should be conducted to include hip and ankle torque production involvement in addition to knee torque production. This research and future research examining the mechanisms of ACL injury could impact the athletic training community by improving prevention
of such a devastating and costly injury. With the increasing knowledge about
ACL injury gained by researchers, clinicians may be able to develop better
interventions for the prevention of ACL injury.
References


Appendix A: Human Subjects Consent Form
INFORMED CONSENT FORM FOR HUMAN RESEARCH STUDY
University of Toledo

Title of Project: Jump-Landing Assessment of University of Toledo Athletes

Person in Charge: Phillip Gribble
Department of Kinesiology
HHS 2505-H
Mailstop #119
Toledo, OH 43606
(w) (419) 530-2691
phillip.gribble@utoledo.edu

1. This section provides an explanation of the study in which you will be participating:

   A. The study in which I am participating is part of research intended to assess performance of the lower extremity during jump-landing tasks. I will be asked to complete one session during the pre-season.

   B. I will be asked to complete two separate bouts of multiple trials of jumping and landing each using a different landing leg. I will be asked to complete a series of maximum and sub-maximal jumps consisting of jumping off 2 feet and landing on one foot.

   C. My participation will include one sessions for a total of approximately 45 minutes.

   D. I may experience slight soreness or tiredness following the jump-landing protocol or strength assessments. Additionally, there is a slight chance of falling during the jump-landing testing. However, I am free to terminate the testing session at any time.

   E. The testing session will consist of the following protocols.

   1) **Maximum Jump Height** – At the beginning of the testing session, the investigator will measure my maximum jump height by asking me to jump off 2 feet, reach as high as possible with one hand to touch a point on a height measurement device, and land on a designated test leg. At the time of the testing session, I will be told if I will perform the first set of jumps using my right or left leg first. I will be asked to perform 3 trials of this task. The highest level that I can reach and land successfully without touching down with the opposite leg will be called my maximum jump height. After completing my maximum
jump trials, I will be given a 10-minute break during which I will sit down and rest quietly.

2) Sub-Maximal Jump Analysis – Based on my maximum jump height, the height measurement device will be adjusted to a height equal to 50% of my maximum jump height. I will perform trials during which I will jump off both feet, reach and touch the designated 50% height level and land on the designated test leg. I will be given time to practice the task jumping off the designated surface as many times as I want until I feel comfortable landing safely. I will be given as much rest time between practice trials as I need. When I feel comfortable, I will complete 10 test jumps. I will be given as much time as I want in between test-jumps. When I have completed all five jumps using the first designated testing leg, I will be given a 10-minute break period during which I will sit and rest quietly. After the rest break, I will repeat the same procedures as before this time using the other leg as the landing leg. I will be given time to practice the task landing on the second designated testing leg as many times as I want until I feel comfortable landing safely. I will be given as much rest time between practice trials as I need. When I feel comfortable, I will complete 10 test jumps using the second designated testing leg. I will be given as much time as I want in between test-jumps.

2. This section describes your rights as a research participant:

A. I understand that I may ask the investigator any questions about the research procedures, and these questions will be answered.

B. My participation in this research is confidential. Only the person in charge will have access to my identity and information that can be associated with my identity. In the event of publication of this research, no personally identifying information will be disclosed. To make sure my participation is confidential, only a code number will appear on the data collection sheet. Only the researchers can match my name with my code number.

C. My participation is voluntary. I am free to stop participating in the research at any time, or to decline to answer any specific questions without penalty.

D. I may contact the Office for Research, 2300 University Hall, University of Toledo, Toledo, OH 43606, (419) 530-2844, for additional information concerning my right as a research participant.
3. This section indicates that you are giving your informed consent to participate in the research:

Participant:

I agree to participate in the scientific investigation described above, as an authorized part of the education and research program of the University of Toledo.

I understand the information given to me, and I have received answers to any questions I may have had about the research procedure. I understand and agree to the conditions of this study as described.

To the best of my knowledge and belief, I have no physical or mental illness or difficulties that would increase the risk to me of participation in this study.

I understand that my participation in this study does not entitle me to any compensation, financial or otherwise.

I understand that my participation in this research is voluntary, and that I may withdraw from this study at any time by notifying the person in charge.

I am 18 years of age or older.

I understand that medical care is available in the event of injury resulting from research but that neither financial compensation nor free medical treatment is provided. I also understand that I am not waiving any rights that I may have against the University for injury resulting from negligence of the University or investigators.

I understand that I will receive a signed copy of this consent form.

_____________________________________________ ____________
Signature        Date

Researcher:

I certify that the informed consent procedure has been followed, and that I have answered any questions from the participant above as fully as possible.

_____________________________________________ ____________
Signature        Date
Appendix B: Subject Information Sheet
Subject Information Sheet

Name:______________________________________________________

Subject #:___________________________________________________

Sport:______________________________________________________

Age:_______________________________________________________

Date of Birth:________________________________________________

Leg Dominance:_____________________________________________

Height:_____________________________________________________

Weight:_____________________________________________________