THE EFFECTS OF PLAYING SURFACES ON LANDING MECHANICS DURING A JUMP REBOUND-LANDING TASK

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ABSTRACT

CONTEXT: Anterior cruciate ligament (ACL) injuries are common among physically active people. Most ACL injuries occur from a noncontact mechanism such as landing from a jump. It is well known that neuromuscular risk factors, such as poor landing mechanics can increase the risk for ACL injury. However, it is unknown how playing surfaces affect landing mechanics.

OBJECTIVE: Determine if landing on different athletic surfaces effects landing mechanics.

DESIGN: Repeated measures design

SETTING: Research Laboratory and Gymnasium

PARTICIPANTS: Thirty-two healthy, physically active individuals (14 males, 18 females; age=20±2 years; height= 172.1±9.7 cm and mass=71±14 kg) were recruited to participate in this study.

INTERVENTION: Independent variable was surface type, a wood basketball court and a volleyball sport court.

MAIN OUTCOME MEASURES: Landing mechanics, assessed by the LESS. A paired samples t-test was performed to compare the mean LESS scores on each surface within participants.

RESULTS: No significant differences (P=0.22) were identified between the LESS scores on the wood basketball court (6±1) and the volleyball sport court surfaces (6±2) within each participant.

CONCLUSIONS: The findings of this study demonstrated no differences in landing mechanics between a wood basketball court and a volleyball sport court surface as assessed by LESS scores.
Clinicians and researchers should also take into consideration that shoes were not standardized between participants, which could alter results due to differences in shoe-surface interaction. Therefore future research should examine other athletic playing surfaces, including outdoor surfaces such as grass and artificial turf as well as standardize shoes worn by participants.
Upon finishing my undergraduate education I had a fairly good idea what area research I wanted to focus on for my Master’s thesis. After having three ACL injuries of my own, I became interested in factors that cause ACL injuries. I began to do some preliminary research and discovered that there are more factors than I had even imagined that can contribute to this common, yet devastating injury. I was able to narrow my focus down to examining how different athletic surfaces can play a role in ACL injuries. I feel that this is an important topic to examine, as the number of ACL injuries seems to be on the rise.
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CHAPTER 1

INTRODUCTION

Anterior cruciate ligament (ACL) injury affects approximately 200,000 individuals each year\(^1\)-\(^4\), and of these, around 50,000 undergo reconstructive surgery to correct this injury.\(^5\) This injury along with the long-term effects, such as premature osteoarthritis, may be detrimental to the active lifestyle of an athlete or other physically active individuals.\(^3\),\(^6\)-\(^10\) Therefore, it is important to investigate the causes of ACL injury, in order to develop and implement prevention programs.\(^9\),\(^11\) ACL risk factors can be classified as modifiable and non-modifiable risk factors.\(^12\) Prevention programs will only be successful if they target factors of ACL injury that are deemed modifiable.\(^13\)-\(^16\) The main categories of modifiable risk factors of ACL injury that have been studied include environmental risk factors and neuromuscular risk factors.\(^12\)

**Development of Problem/Research Question**

Anterior cruciate ligament research has been quite extensive. Many studies have examined the mechanisms and possible causes of injury, including why injury rates are higher for females.\(^3\),\(^16\)-\(^33\) Numerous studies have also examined neuromuscular reasons (muscular strength, muscle activation patterns, muscle stiffness, physical fitness and muscle fatigue, landing mechanics, and forces upon landing) for ACL injury\(^13\),\(^15\),\(^17\)-\(^20,22,23,25,27\)-\(^32,34\)-\(^54\), while only a limited amount of research has been done on investigating environmental conditions (meteorologic conditions, playing surface, footwear, bracing, rules, referees, and coaching) and
how they may influence ACL injuries. Limited research examining landing mechanics in combination with environmental factors, such as different types of surfaces, exists. This is important to examine to establish if any differences between landing on surfaces exist in individuals with no knee injury history, in order to develop a basis for further studies in ACL deficient and ACL reconstructed individuals. This study will also create a starting point for more in-depth studies looking into different shoe types in combination with individuals with a knee injury history. Ultimately, the results of these studies may guide shoe selection and create recommendations for playing surfaces.

Dowling, et. al. examined landing mechanics and environmental factors in combination, but did so in a laboratory setting. The study examined movement strategies when participants performed a side-step cutting maneuver on two different surfaces, one with a high coefficient of friction (COF) of 0.87±0.19, and one with a low COF of 0.38±0.03. The COF is a measure of how much force is required to move an object across a surface. A high COF requires a greater force to move an object across a surface, whereas a low COF requires less force to move the same object across the same surface. Athletic surfaces have their own unique frictional properties, and when examined with the type of shoe worn, it can provide insight into shoe-surface interactions, and the possible etiology of an injury. Each participant in this study wore their own shoes. Results revealed the risk of an ACL injury was greater on a high COF surface. The authors suggest this is most likely due to the change seen in individual’s movement strategies between the two surfaces. However, Dowling, et. al. did not use commonly used surfaces such as wood court, grass, or turf fields, that are used for athletic competition, and as a result, the findings may not directly reflect movement strategies that may occur on sport surfaces.
Poor landing strategies seem to be related to the potential risk for ACL injury. Identifying individuals with poor landing strategies, and how landing strategies change on different surfaces is important to determine whether current athletic playing surfaces are a contributing factor for ACL injury. The purpose of this study is to examine the influence of landing strategies during a jump rebound-landing task (JRLT) and the interaction between common playing surfaces (wood, artificial turf, grass, multi-purpose court) within college-aged, physically active individuals. Both the initial landing and final landing during the JRLT will be assessed. The study will be performed in actual athletic locations (basketball court and volleyball court). The evaluation tool that will be used to assess landing strategies is the Landing Error Scoring System (LESS). Other variables that will be addressed are differences in landing mechanics between genders.

The LESS was designed as an alternate method to identify high-risk movement patterns upon landing from a jump. Although laboratory-based motion analysis systems are the gold standard for examining biomechanical risk factors, due to the cost and time constraints, these systems are not practical to use for large screenings with numerous individuals. The LESS was developed as a way to cut down on time and cost, but still provide an effective way to identify faulty landing patterns. The LESS involves videotaping individuals landing from frontal and sagittal views, and using a scoring system of 17 criteria to score the overall landing technique. The higher the LESS score, the more “faulty” the landing technique is, which indicates a higher predisposition to ACL injury. The LESS has been proven to be a valid and reliable tool for assessing “errors” in landing, as well as having an excellent (ICC=.835) interrater reliability between novice and expert examiners of overall LESS scores.
Hypotheses

1. LESS scores will be higher on artificial turf and multi-purpose court than on grass and wood court landing surfaces.

2. Males will demonstrate decreased LESS scores compared with females.

3. Similar landing mechanics and LESS scores will be observed between the initial and final jumps of the JRLT.

Operational Definitions

Landing Error Scoring System (LESS): A quantitative way of assessing landing technique “errors” by observing items of human movement. Participants are videotaped from frontal and sagittal views during a JRLT from a height of 30 centimeters (~1 foot). Landing technique is scored according to 17 different criteria. Higher scores indicate a poor jump-landing technique as compared to low scores which indicate an excellent jump-landing technique.

Jump rebound-landing task: A task that is used and examined to find individuals at-risk for injury due to high-risk movement patterns exhibited during the task. A horizontal jump down from a box onto an “X” placed (50% of their height away in distance). After landing on the “X”, a maximal vertical jump takes place.

Healthy individuals: No history of cardiovascular disease, pulmonary disease, neurological disorders, or systemic conditions. No history of ACL injury or surgery, no ligamentous instability, no other lower extremity surgery in the past 2 years, or lower extremity injury within the last 6 months.

Physically active: Exercise at least 3 times each week for 30 minutes for the last 3 months.
Assumptions

The following assumptions will be made for this study:

1. Participants will accurately report their health history & physical activity level.
2. Participants perform enough trials of the JRLT to feel comfortable with it.
3. Novice LESS rater is reliable.

Delimitations

The following are delimitations of this study:

1. Participants are physically active college-aged students.
2. Participants are being recruited from only one university.
3. One clinician must interpret LESS scores accurately.
4. Age and overall use of the athletic surface used for landing may influence landing mechanics.

Limitations

The following are limitations to this study:

1. Clinician interpretation of LESS scores.
2. Participants will wear their own athletic shoes during the trials, shoe type will not be standardized between participants.
3. Participants will only perform the JRLT from only one height (30 cm).
4. Grass and turf fields are subject to environmental conditions (precipitation).
Conclusions

Although ACL injuries have undergone extensive research, evidence is limited on examining how environmental factors such as surface type influence landing mechanics. Therefore, the goal of this study is to examine the effects of the external environment (landing surfaces) on landing mechanics. Landing mechanics that have previously been associated with ACL injury will be examined to investigate whether landing on different surfaces changes landing mechanics, and potentially predisposes individuals to ACL injury. A secondary purpose is to investigate any differences between male and female participants. This study will provide a general basis for future studies involving more in-depth searches into environmental risk factors of ACL injury. The results of this study could also potentially be used for ACL prevention programs.
CHAPTER 2

LITERATURE REVIEW

This review of literature will discuss the search strategy used, background on the anterior cruciate ligament (ACL) and injuries to this ligament, including incidence, mechanisms of injury, and a discussion on gender differences. Risk factors (unmodifiable & modifiable) will be discussed, specifically focusing on neuromuscular responses to landing and environmental risk factors, as well as ACL intervention programs.

Search Strategies

The CINAHL, MEDLINE, PubMed, and SportsDiscus databases were searched for the following keywords, either separate or in combination: anterior cruciate ligament, anterior cruciate ligament injury, surface, surface interaction, terrain, artificial turf, shoes, footwear, gender differences, history of injury, landing mechanics, landing strategies, joint stiffness, EMG, muscle activation, postural control, fatigue, coefficient of friction, landing error scoring system (LESS), and jump-rebound landing task.

Background

Anterior cruciate ligament injuries are very common in athletics.\(^1\)\(^-\)\(^3\) Approximately 250,000 ACL ruptures occur each year within athletes.\(^1\)\(^,\)\(^4\)\(^6\) In Norway alone, the total number of first time ACL reconstructive surgeries was 2,793 in just 18 months collected at 57 hospitals.\(^8\) Within select NCAA schools, approximately 5,000 ACL injuries were reported over a 16 year
What is more alarming is that these 5,000 injuries represent only about 15% of the total population of NCAA schools and sports. The majority of ACL injuries that occur are non-contact in nature.\textsuperscript{1,3,11,13,14,17-19,35,37,46,64} In fact, it has been found that approximately 70-78% of all ACL injuries are of a non-contact origin.\textsuperscript{6,11,13,65-69}

Specific non-contact ACL injury mechanisms include, foot contact upon landing\textsuperscript{10,15,20,34,36,70}, a deceleration before a change in direction (cutting), landing from a jump\textsuperscript{18,21,71}, and an unanticipated change in direction of play.\textsuperscript{1,3,6,9,11,19,21,37,46,64,67,69,71-74} These types of injuries are more likely to take place during game situations rather than during a sports practice, despite the fact that practice exposures are much higher than game exposures.\textsuperscript{2,11,72}

Movement patterns associated with these mechanisms include knee valgus, tibial rotation, and a small degree of knee flexion.\textsuperscript{6,22,68} A combined state of loading\textsuperscript{71} and excessive tibial rotation seems to demonstrate a greater risk for injuring the ACL.\textsuperscript{6}

Compared with their male counterparts, females have a greater risk of sustaining an ACL injury.\textsuperscript{3,4,10,11,16-33,68,69,71,74-77} Approximately a two to eight times greater risk in females has been reported.\textsuperscript{4,6,11,13,17-19,32,35,47,68,69} Faulty lower extremity biomechanics and lack of dynamic neuromuscular control currently seem to be the most likely modifiable risk factor as to why females are more susceptible for these injuries.\textsuperscript{10,66,71,75,76} It is possible that males and females are susceptible to ACL injuries through different mechanisms.\textsuperscript{22,78} Examining the National Collegiate Athletic Association (NCAA) and their injury statistics, females participating in NCAA basketball and soccer displayed a greater number of ACL injuries when compared with other sports.\textsuperscript{23} Between NCAA female soccer players and basketball players, the soccer athletes were at a higher risk of ACL injury.\textsuperscript{23}
Interestingly enough, although most studies on ACL injuries focus on females, males actually have a higher absolute number, or prevalence of ACL injuries. Prevalence, however, should not be confused with incidence rates. Incidence refers to the number of injuries compared with the number of exposures (hours of participation in sport practices or games). Females have a much greater incidence rate of ACL injury, but males have a higher total prevalence. There are also more males than females that participate in sports.

One problem with ACL injuries is that other injuries often occur in combination with them. These types of injuries commonly include meniscal injury and bone bruising, which may have permanent effects on the knee joint, specifically the articular cartilage of the tibia and femur. Fifteen years following an ACL injury, not dependent on the course of treatment taken, 50% of patients will exhibit radiographic osteoarthritis. Another study suggests that 7-20 years following an ACL injury, regardless of treatment, 50-90% of patients will show signs of osteoarthritic changes of the knee joint. This is a concern because these long-term complications may functionally limit individuals from sport participation in the future. Following an ACL injury, instability and laxity are present within the knee joint, and often times individuals will report a “giving way” of their knee as a result.

Anterior cruciate ligament injuries often require ACL reconstructive surgery (especially for most active individuals) to replace the injured ligament and regain dynamic knee stability. Salmon et al. examined males and females over a five year period following ACL reconstructive surgery. The findings of this study revealed that 12% of the study population had a repeat ACL rupture, either ipsilateral or contralateral or both. The repeat ipsilateral ACL ruptures were the greatest within a year from the initial surgery. Individuals sustaining an injury to the ACL have at least double the risk of re-injury to the ligament when compared with
uninjured, healthy individuals. Injuries to the ACL not only have long-term health complications, but are also a financial burden, and cause an athlete or physically active individual to lose time from participating in sport or other activities. The inability to participate in activities that have previously been part of a daily routine and lifestyle can also extremely impact the psychological well-being of an individual.

**Risk Factors**

Anterior cruciate ligament injury risk factors have previously been classified as intrinsic and extrinsic. Anterior cruciate ligament injuries have recently begun to be classified into modifiable risk factors and non-modifiable risk factors, in order to identify the factors that can be changed or prevented versus the ones that cannot.

Non-modifiable risk factors are factors that are most likely not amenable to interventions, or not easily changed. These types of factors include demographics of the individual (age, injury history, familial history, genetics, gender, height, and race), anatomical factors (Q-angle, navicular drop, notch size, ACL geometry and properties, tibial slope angle, etc.), hormonal influences (menstrual cycle and hormone concentrations), and environmental considerations (playing situation, opponent behavior, unanticipated events during play). The anatomical factors in theory could potentially be modified, but to change them may not always be a feasible option, therefore they are classified as non-modifiable.

Modifiable risk factors are factors that are amenable to intervention. These factors include anatomical (foot pronation, body composition and body mass index), hormonal, environmental (footwear, playing surface, referees, coaching, bracing), and neuromuscular factors (muscle strength, muscle activation patterns, muscle stiffness, muscle fatigue and physical fitness, and skill level). Some main categories of risk factors, such as
environmental, anatomical, and hormonal risk factors have risk factors that fall under both the modifiable and non-modifiable sections. This review will focus on the modifiable risk factors, specifically the neuromuscular and environmental factors of ACL injury.

**Neuromuscular Responses & Landing**

Landing is important to examine because it is a common maneuver in athletic activity, and also a common mechanism for an ACL injury. Mal-alignment of the lower extremity may occur during landing, which could potentially be due to an inefficiency of neuromuscular control. The type of landing technique that an individual exhibits as well as how they absorb the force upon landing may be associated with the potential for experiencing an ACL injury.

**Ground Reaction Force (GRF)**

Upon landing from a jump, the action of the downward acceleration of the body mass introduces GRFs to the knee joint. These forces have been associated with anterior tibial acceleration and shear force, which put excess load on the ACL, and can predispose this ligament for injury. Factors that impact the amount of GRF that the body sustains are, the motion of the body’s center of mass, internal forces such as muscle contractions, pre-activation of the lower extremity muscles (feed-forward mechanisms), the body geometry (or joint angles), the contact area between the foot and the landing surface, as well as the material properties of the landing surface. Several of these factors are related to neuromuscular control, which demonstrates the importance of adequate neuromuscular control to limit GRFs and possible injury. Any type of neuromuscular deficiency may result in altered muscle pre-activation patterns and joint angles, which may ultimately lead to an increased GRF.
Neuromuscular Control

Neuromuscular control involves the interaction of the nervous and muscular systems of the body and their components to adapt to changes in the environment that the body experiences. The activation of dynamic restraints (musculature) can be protective to the joints in response to stimuli in the environment, such as changes in landing surfaces. The body contains a “feedback” mechanism, which allows it to accommodate to different unanticipated events by modifying the muscle activity. The body also has “feed-forward” mechanisms which are protective mechanisms that are used from past experiences in anticipation of a recognized event. These feed-forward mechanisms allow the body to prepare for what it is about to experience. The level of muscle activation, whether it is preparatory or reactive, will affect muscular stiffness, which is a protective dynamic restraint against ACL loading. It has been reported that non-contact ACL injury usually occurs between 17 and 50 ms after initial ground contact takes place. This is an extremely short period of time for reactive feedback to take place to correct potential faulty landing mechanics; which places more importance on preparatory or feed-forward mechanisms.

Cortes, et al. stated that individuals with a high level of experience in an activity, such as landing, plays an important role in the way they land and absorb energy. It is suggested that the sport training and background of an athlete contributes to the neuromuscular and landing strategies that individuals will exhibit. In agreement, Cowley, et. al. found differences in ground reaction forces (GRF) and stance times between female soccer and basketball players when performing a drop landing and a cutting task. An inability to respond to the demands of dynamic activities has been linked with a poor landing technique and risk of ACL injury.
Females often demonstrate less knee, hip, and trunk flexion, greater knee valgus, increased quad muscle activation, and decreased hamstring muscle activation upon landing, which has been shown to increase risk of an ACL injury.\textsuperscript{6,35}

**Joint Positioning Upon Landing**

**“Erect” Landing Position**

Compared with males, females tend to land in a more erect position when landing from a jump.\textsuperscript{34,36,74} An “erect” landing position is associated with higher ground reaction forces and more strain placed on the ACL.\textsuperscript{21,34} High GRFs require a greater amount of eccentric quadriceps activation to counter the force without sustaining a injury.\textsuperscript{34} Quadriceps activity begins prior to landing in anticipation of the event, and occurs throughout the landing phase once contact has been made with the ground.\textsuperscript{70} Females tend to display more quadriceps electromyography (EMG) activity and GRF before and after landing, which may be a factor for their increased risk of ACL injury.\textsuperscript{20,25,34,35,47,71,87} Males, on the other hand, demonstrate greater knee flexion and ankle dorsiflexion at ground contact during landing than females, thus reducing GRFs.\textsuperscript{36} Padua et. al.\textsuperscript{87} suggested that perhaps these neuromuscular differences are due to a difference in how males and females deal with fatigue.\textsuperscript{87} In support of this suggestion, Ortiz et. al.\textsuperscript{88} reported a greater at-risk landing strategy after fatigue occurred.\textsuperscript{88}

**Trunk Flexion**

Increasing the amount of trunk flexion upon landing in physically active participants, Blackburn, et. al.\textsuperscript{34} discovered that the angles of knee and hip flexion also increased.\textsuperscript{34} This increased flexion resulted in a less erect landing position, and the landing forces and quadriceps activity were reduced.\textsuperscript{34} As knee flexion increases during landing, peak vertical forces decrease, as does the load on the ACL.\textsuperscript{25,89} When examining both genders in a stop-jump task, females
exhibited greater anterior shear force at the proximal tibia, as well as a knee extension moment.\textsuperscript{35} This demonstrates that males are more likely to have increased flexion at the knee and less ACL loading during landing tasks.\textsuperscript{35} During landing, impact forces can be as great as 2-12 times the body weight of the individual.\textsuperscript{34,89} Zhang et. al.\textsuperscript{58} reports impact forces during landing as great as 14.4 times the bodyweight of the individual.\textsuperscript{58} Greater knee flexion can help to keep these forces to minimum levels.\textsuperscript{16,89} As the height of the jump increases, there is an increase in velocity of the body downward, and it is suggested that as the height increases, the amount of hip and knee flexion should also increase to decrease the forces that the body must sustain.\textsuperscript{36} Sustaining lower vertical forces upon landing is beneficial to the body and joints, for injury prevention.

**Knee Joint Positioning**

Females are more likely than males to display a greater knee valgus moment upon landing.\textsuperscript{1,31,37,39,41,46,66,67,74} Females who have had a previous ACL injury display a 2.5 times greater knee valgus moment than females who have not injured their ACL.\textsuperscript{1} An additional study found that knee valgus angles were greater by eight degrees in the ACL injured group as compared with the non-injured group.\textsuperscript{39} One study reported that a knee valgus angle of four degrees puts a 15% increase on the ACL than a neutral position.\textsuperscript{55} Knee valgus angle is suggested as a stronger predictor than knee flexion angle for assessing risk of an ACL injury.\textsuperscript{1,67} It has been proposed that a greater valgus positioning at the knee joint is more of a risk for females than for males.\textsuperscript{24,78} According to computer simulations, the ACL can be ruptured with high valgus moments of the low extremity.\textsuperscript{37} Knee extension moments and anterior shear forces were not found to be able to rupture the ligament in isolation.\textsuperscript{37} On the other hand, Chappell, et. al.\textsuperscript{35} found significant differences between recreational male and female athletes in knee flexion,
hip flexion, hip abduction, hip internal-external rotation and knee internal-external rotation, but not varus-valgus motions. This suggests that there is still variability found between studies on ACL injury associated with valgus positioning, and there are likely several other factors that play into the possible risk of experiencing an ACL rupture. Swartz et. al. reported a higher knee valgus as well as greater knee and hip extension upon landing in prepubertal participants (7-10 years old for girls, 8-11 for boys) when compared with adults (19-29 years old). The findings from the Swartz et. al. study suggested that landing strategies may change with physical development, as adults displayed a less at-risk landing position than prepubertal children.

Females are also more likely to exhibit a larger knee abduction moment upon landing as compared with males. A larger knee abduction moment is also linked with an increased risk of ACL injury among females. According to Thomas et. al. quadriceps and hamstring co-activation not only protects against anterior translation of the tibia, but also limits knee abduction and adduction moments. Myer et. al. sought to validate a clinic-based assessment tool used during landing to predict knee abduction moments. The study concluded that high knee abduction moments could be predicted with high sensitivity and specificity when obtaining clinical measures of knee valgus, knee flexion range of motion, body mass, tibia length, and quadriceps-to-hamstring ratio.

Joint positioning gender differences have exhibited that females are less able to keep their knee in a varus position when performing a single-legged squat. Zeller et. al. reported that when performing this task, females had more ankle dorsiflexion and pronation, hip adduction, flexion, and external rotation, and less lateral trunk flexion. Females also exhibited a significantly greater muscle activation throughout the activity as well as maximal activation than
males when performing the single-legged squat.\textsuperscript{75} The position that females exhibit when performing the single-legged squat is one that places an increased amount of strain on the ACL.\textsuperscript{75} This is a concern, because the single-legged squat is a position that is common within sporting activities, and could place females at a greater risk of injury to the ACL if they are unable to protect against the increased strain.\textsuperscript{75}

**Muscle Activation**

**Quadriceps vs. Hamstring Muscle Activation**

Like the gender differences observed when landing from a jump, similar gender differences occur throughout other functional activities between males and females.\textsuperscript{3,15} This suggests that males and females have a specific neuromuscular control strategy that depends on the task being performed, but differs by gender.\textsuperscript{35} For example, females tend to activate their quadriceps muscle group more than males during functional maneuvers such as hopping, cutting, and lunging.\textsuperscript{3,23,25} Myer et al.\textsuperscript{91} examined differences between medial and lateral quadriceps activation ratios between males and females during a task mimicking ACL injury risk movements, and discovered that females activate the lateral quadriceps more and males have a more balanced activation ratio between medial and lateral quadriceps muscles. An unbalanced ratio of muscle activation between medial and lateral quadriceps, specifically greater activation of the lateral quadriceps introduces a greater amount of anterior shear force and knee valgus, which are linked with ACL injury.\textsuperscript{91} Increased quadriceps activity places more strain on the ACL by introducing an increased anterior translation of the tibia, and may predispose these individuals for risk of rupturing the ligament.\textsuperscript{20,34,49,70} Males display a more balanced ratio of quadriceps to hamstrings activation, whereas females usually have a quadriceps dominant activation pattern.\textsuperscript{23,29,49,66} Hamstring muscle activation has been suggested as being able to
decrease the stress on the ACL in all joint positions.\textsuperscript{16,17,68,92} In contrast, other studies state that the hamstrings cannot resist anterior tibial translation when the knee is in or near full extension.\textsuperscript{18} However, it is proposed that when the knee is flexed to greater than 15 degrees of flexion, the hamstrings were able to decrease the forces on the ACL.\textsuperscript{18} Knee flexion of at least 15 degrees when landing may then be ideal for a reduced risk of injury to the ACL. Moul et. al examined Division I collegiate male and females basketball players, and concluded that eccentric hamstring strength, concentric quadriceps strength, and Q-angle were significantly different at 30 degrees of knee flexion between genders.\textsuperscript{16} The range of motion of the knee that introduces the greatest risk is when the knee is near full extension, as Ireland et. al.\textsuperscript{2} states as the “position of no return” when it is combined with hip adduction and internal rotation, external tibial rotation, and landing out of control with the weight on the balls of the feet.\textsuperscript{2}

Interestingly enough, Chappell, et. al.\textsuperscript{25} found that females displayed a greater hamstring muscle activation prior to landing, but the activation levels were lower than males after landing.\textsuperscript{25} The increased hamstring activation demonstrated by males helps to protect the ACL by sensing anterior translation of the tibia, and correcting for it through muscle activation of the hamstrings.\textsuperscript{16,20,49,50,70} Males also tend to have faster muscle activation responses of the hamstrings than females, which could further predispose female athletes to ACL injury.\textsuperscript{20} In contrast to Chappell et. al.\textsuperscript{25}, Bencke et. al.\textsuperscript{68} reported that females display a lower amount of hamstring activity than males 50 ms prior to landing. This finding suggests that females are less able to prepare for landing, and this may influence the amount of hamstring activation that females display even after landing.\textsuperscript{68} Similarly, Zebis et. al.\textsuperscript{9} studied a group of 55 elite, healthy female athletes, and examined EMG activity of the knee flexor and extensors during a side-cutting task. These participants were then followed for two seasons after completing the side-
cutting task, and within those two seasons, five athletes suffered a non-contact ACL injury. All 5 of the participants that sustained an ACL injury had displayed a reduced EMG preactivity of the semitendinosus, as well as an increase in EMG preactivity of the vastus lateralis muscle. This neuromuscular pattern that the injured participants displayed was different from that of the non-injured participants, and suggests that a low preactivity of the semitendinosus combined with a high preactivity of the vastus lateralis muscles may indicate an increased risk of noncontact ACL injury.

One study shows that when trunk extension took place during landing, hamstring forces decreased by 16%. Landing with a high degree of trunk extension is the equivalent of landing in an “erect” position. During trunk flexion upon landing, hamstring forces increased by 13%. Greater hamstring activation is needed, especially in most females in order to balance the quadriceps to hamstring ratio and decrease the strain on the ACL.

**Muscle Activation of the Trunk**

Kulas et. al examined how the specific musculature of the trunk (rectus abdominis, external obliques, internal obliques, and transverse abdominis) responded during drop landings in both males and females. The results indicated that males activate their transverse abdominis and internal oblique muscles more than females, especially during the pre-landing period. Females did not have significant differences between the muscles they activated throughout the landing task. Kulas et. al suggested that this difference in muscle activation could possibly play a role in part of the gender difference of ACL injury. Zazulak et. al. studied neuromuscular control of the trunk, and concluded that a decreased neuromuscular control of the trunk may play a role in a compromised dynamic stability of the knee joint. A decreased ability to dynamically stabilize the knee joint may introduce a higher risk of injury to this area.
Muscular Strength

Hip Abductor Strength

When examining the hip abductor group, females demonstrated lower peak torque than males when landing from a jump. A higher correlation exists between hip abductor strength and landing kinematics in females than in males. As hip abductor strength in females is increased, a decreased valgus joint displacement was observed. Decreasing the valgus angle at the knee joint has been associated with decreasing ACL injury. In a longitudinal study by Myer et. al., three years prior to ACL injury, a young female subject displayed both decreased hip abduction and knee flexor strength when compared with the continual yearly increases in body mass. The ability to maintain neuromuscular control of the hip influences the forces that will be sustained by the knee joint. Hip abductor strength should then be considered in ACL prevention programs due to the predictor of high valgus displacement and ACL injury.

Muscle Stiffness

An additional factor why females may be more susceptible to ACL injuries than males is due to leg spring stiffness and knee joint stiffness. Leg spring stiffness is the ability of all the joints, muscles, tendons, and ligaments of the leg to work together to resist the compression that occurs when landing. Joint stiffness refers to the force that resists mechanical stretch at a certain joint, which includes the ligamentous, tendinous, muscular, bone and all other components that make up the joint. Active muscle creates “muscle stiffness”, that helps contribute to overall joint stiffness. The “stiffer” a muscle is, the more apt it is to quickly react to protect the soft tissue structures around the joint. An indirect way to measure muscle stiffness is by examining dynamic postural stability.
A combined activation of the quadriceps, hamstring, and gastrocnemius muscles increases knee joint stiffness anywhere from 48-400%. Joint stiffness is an important component of stability, and females tend to have less “stiffness” or ability to protect from mechanical stretch, which may result in one reason that females have significantly more ACL tears than males. The ACL itself is responsible for passively resisting anterior tibial translation, and accounts for 86% of the static resistance to this motion. Females also display 25-30% more varus/valgus and internal/external rotation laxity at the knee joint, even if anterior laxity is not found in comparison with males. This increased laxity is associated with a decreased torsional joint stiffness in females when compared with males. A greater amount of joint laxity is highly related with an increased ACL injury risk.

One study reports that an increase seen in hamstring muscle activation displayed a significant increase in muscle stiffness. The amount of muscle stiffness also had a moderate correlation with the level of function that ACL-deficient subjects exhibited. Wikstrom et. al. reports that preparatory muscle activity assists with joint stability.

Blackburn, et. al. examined hamstring stiffness in males and females and determined that males exhibit a greater cross-sectional area of muscle mass, which plays a role in the increased muscle stiffness and better capacity for resisting length changes. Therefore, due to the notion that males generally have a greater cross-sectional area of their hamstrings, they are more likely to adapt to changes in the length of the muscle, which aids in protecting the ACL. Although the greater cross-sectional area of musculature in males may make them stronger, Beutler et. al. reported that muscle strength did not significantly foretell the landing strategies the males and females displayed in this study.
Knee Joint Laxity

Schultz et. al,\textsuperscript{51} studied frontal and transverse hip and knee kinematics, kinetics, and EMG in a group of both males and females with no previous knee injury.\textsuperscript{51} The groups were classified into a high and low laxity group for both males and females, as determined by the KT-2000 and the Vermont Knee Laxity Device.\textsuperscript{51} The high laxity group for both males and females demonstrated different hip and knee kinematics and kinetics than the low laxity groups, specifically greater hip adduction and knee valgus.\textsuperscript{51} These findings suggest that an already inherent laxity in some individuals may predispose them to altered landing mechanics that are associated with ACL injury.\textsuperscript{51}

Previous Knee Injury

Landing strategies among individuals with previous knee injury history shows some differences when compared with individuals with no history of injury.\textsuperscript{17} ACL deficient individuals demonstrate a greater hamstring EMG activity during running and landing.\textsuperscript{17,70,85} Increasing the hamstring activity seems to be an adaptation ACL deficient individuals make in order to gain more dynamic stabilization of the knee joint,\textsuperscript{85} because hamstring muscle activation is a protective mechanism that decreases stress on the ACL.\textsuperscript{17,52,70,94} This is especially essential for ACL deficient individuals due to the increased amount of anterior tibial translation that exists because the ACL is no longer present.\textsuperscript{17,70} In addition to an increased amount of hamstring muscle activity, ACL deficient patients also demonstrate an increased preparatory activity of the hamstring to control the motion of the tibia upon deceleration from a functional task.\textsuperscript{80}

Proprioceptive impairment (an impairment in neuromuscular control) has been reported in ACL injured patients.\textsuperscript{11,95} Neural receptors within the ACL and other intra-articular and peri-articular structures of the knee provide feedback of joint position and muscular stabilization
(proprioception) in all individuals. In female ACL deficient patients, variations that have been reported in muscle activation strategies may be due to deafferented ACL mechanoreceptors or the patient trying to subconsciously compensate for the lack of joint stability. Impairment of proprioceptive ability due to ACL injury has been found to not only influence the ipsilateral limb, but also the neuromuscular control of the contralateral limb. However, it appears that after undergoing ACL reconstruction, an individual’s position sense and proprioceptive ability will be improved from those that do not undergo the surgical procedure.

ACL reconstruction is currently considered the “gold standard” of treatment to restore knee function following an ACL injury. DeMont et. al. found bilateral differences in muscle activity during functional activities within an ACL-deficient group, but not within an ACL reconstructed group, except for in the lateral gastrocnemius muscle. This suggests that undergoing ACL reconstruction procedures may assist with regaining proprioceptive function. Likewise, adolescents with knee injury demonstrated “biomechanically compromised landing mechanics” when compared with others having no injury, even when age and gender were matched. Lysholm et. al. examined ACL deficient (median time from injury was 5 years) and healthy control subjects and their ability to maintain postural control under a combination of stable/unstable surfaces, single/ double leg stances, and eyes open or closed. The findings concluded that the ACL deficient group demonstrated more anterior-posterior sway and a longer reaction time when standing on their injured leg, as compared with the control group.

When landing strategies of the injured and non-injured leg in ACL reconstructed females was investigated, no significant difference was discovered. However, when compared with females that had no previous history, ACL reconstructed females showed different strategies
when performing a drop jump. In addition, Gokeler et. al. found that muscle onset times occur earlier at six months post-ACL reconstruction in the surgical leg when compared bilaterally, and movement patterns are altered when landing. When comparing the non-injured leg muscle onset times of the injured individuals to the non-injured individuals, the onset times were slower. Perhaps slow onset times are a risk factor for injury, and these individuals may have displayed slower onset times even before injury occurred.

Webster et. al. examined NCAA Division I female athletes, and discovered that ACL reconstructed females (average 2.5 years post-surgery) when compared with healthy females, demonstrated postural-control deficits. Time to stabilization (TTS) was used as a measurement of dynamic postural control during a single-leg landing task, and this time as well as GRFs were increased in the ACL reconstructed females, suggesting that these individuals may need more rehabilitation focusing on dynamic stabilization before being released to return to activity.

Fatigue

Fatigue is also a factor that may play into ACL injuries, specifically of the non-contact origin. Fatigue is defined as a failure to complete a task, and is a protective mechanism of the body alerting it to slow down. Neuromuscular fatigue is defined as a reduction in maximal voluntary contraction, where individuals may continue the task, but performance may be reduced. Neuromuscular fatigue is a result of decreased central and peripheral nervous system processing which leads to a reduction of work at the skeletal muscle level. Results of neuromuscular fatigue can include a decrease in proprioception and an increase in baseline joint laxity, which may increase the risk for injury. As the muscles around a joint become fatigued, it is suggested that the dynamic restraints to protect the joint will decrease, therefore resulting in less muscle stiffness or joint stability, and more joint laxity. Within the knee joint,
this could ultimately mean less protection of the ACL through muscular activation.\textsuperscript{92} Fatigue could result in differences in not only muscle activation, but also joint stiffness and knee kinematics, altered proprioception and biomechanics, and delayed muscle responses could potentially place a fatigued individual in a common position of ACL injury.\textsuperscript{4,32,63,92} Neuromuscular fatigue could also result in an impaired performance due to a reduction in muscular contractile force leading to altered coordination.\textsuperscript{84} An altered neuromuscular control of the extremities due to neuromuscular fatigue has been linked with a decreased ability for muscles to absorb energy, leading to higher GRFs and an increased amount of anterior tibial translation, and a decreased stabilization of the knee during landing.\textsuperscript{77,84}

In a study by Chappell et. al.\textsuperscript{77}, both males and females had significantly greater anterior shear force, knee valgus angles, and decreased knee flexion when performing stop-jump tasks after a fatiguing protocol. It has been reported that performing a box drop cutting maneuver after fatigue displays an increase in gluteus medius activity.\textsuperscript{67} Shenoy et. al.\textsuperscript{67} states that the increase shown on EMG of the gluteus medius may exacerbate valgus forces at the knee, leading to increased risk of ACL injury. Smith et. al. also reported an increased knee valgus and varus motion in fatigued individuals during landing.\textsuperscript{32}

Individuals demonstrating faulty landing mechanics before fatigue are likely to exhibit even more dangerous landing mechanics after fatigue.\textsuperscript{4,63} Thomas et. al\textsuperscript{4} examined healthy males and females when performing a single leg hop onto a force plate before and after a quadriceps and hamstrings fatiguing protocol. The results from this study revealed that upon initial contact after fatigue, participants displayed greater hip internal rotation, knee extension, and knee external rotation.\textsuperscript{4} Peak vertical GRF for females were also larger than that for males after the fatiguing protocol.\textsuperscript{4} These findings are all indicative of positions or risk factors for ACL injury,
and demonstrate that neuromuscular fatigue plays a role in altering biomechanics that may lead to ACL injury.4,98

Examining hip rotator and triceps surae fatigue and their effects upon landing biomechanics, Thomas et. al.98 concluded that each induced kinematics related to noncontact ACL injury. However, the authors also stated that fatigue of only these muscle groups was unlikely to increase ACL risk alone, and that more gross lower extremity fatigue would be more likely representative of increased ACL risk.98 In contrast, Melynk et. al.92 reported an increased knee instability with submaximal fatigue of the hamstring muscles.

**Interventions**

Due to the high number of ACL injuries that occur each year, and the extensive research done on risk factors, several screening tools have been developed in order to identify at-risk individuals. One of the tools that has been developed is the Landing Error Scoring System (LESS).61 The LESS was designed as an objective ACL injury-risk-factor screening tool.61 The LESS is a technique in which jump-landing techniques are assessed by videotaping the individual from both a frontal and sagittal view.61 When reviewing the videotape, an examiner “scores” the landing techniques according to 17 different criteria.61 High scores (greater than a score of 6) indicate a poor jump-landing technique as compared to low scores (less than or equal to a score of 4) which indicate excellent jump-landing techniques, and decreased risk for injury.60,61

The LESS has exhibited a moderate to excellent validity when compared to using a three dimensional motion analysis system.15,60 It is stated that it is a “…valid and reliable tool for identifying potentially high-risk movement patterns during a jump-landing task”.60 Anterior cruciate ligament injuries often take place when landing from a jump, therefore this tool is an
effective and practical way to assess individuals that may be at risk for ACL injury. An additional advantage of the LESS is that minimal time is required to train individuals to use the tool. Onate, et. al reported an excellent inter-rater reliability between novice and expert examiners.

After identifying high risk individuals, it is important to use the information about ACL injuries and incorporate it into a program aiming to decrease the risk of injury. When examining the modifiable risk factors for ACL injury, it is apparent that neuromuscular responses play a role on landing performance. For this reason, prevention programs have been implemented with at-risk individuals and teams participating in high-risk sports. Swanik et. al suggests that the four main concepts to focus on to promote neuromuscular control are proprioceptive and kinesthetic awareness, dynamic stability, preparatory and muscle characteristics, and conscious and unconscious functional motor patterns. Ingersoll et. al states that the altered motor patterns found in ACL injured patients may last well after ACL reconstruction takes place, so neuromuscular function is an important aspect to address in rehabilitation, as well as prevention.

The focus of many prevention programs is on neuromuscular training. DiStefano et. al implemented an ACL prevention program in youth soccer players and found that participants with the highest LESS scores at baseline levels improved their score, and ultimately their landing strategies the most. Not surprisingly, the males in this study exhibited less landing errors at baseline. However, both male and female participants responded similarly to the prevention program that was implemented. This demonstrates that prevention programs can be beneficial for improving at-risk landing positions, specifically knee flexion at initial ground contact, knee flexion displacement, and trunk flexion at initial contact. These motions all take place in the
sagittal plane, but large improvements were not seen in frontal or transverse planes after the prevention program.\textsuperscript{6} Valgus positioning of the knee, reported to be a high-risk position for ACL injury, did not show much improvement in this program.\textsuperscript{6}

Herman et. al.\textsuperscript{10} reports that incorporating plyometrics, balance, and strength training into a preventative ACL program has prospectively displayed a decreased incidence of ACL injury in females. When examining a strength training program combined with visual and verbal feedback on landing mechanics in recreational female athletes, peak GRFs decreased, hip flexion and abduction angles increased, and knee flexion angles increased.\textsuperscript{10} The control group who received no strength training showed an increase in anterior shear force, whereas the strength training group displayed a decrease in anterior shear force, despite both groups undergoing feedback instruction.\textsuperscript{10} The combination of both strength training and feedback on landing mechanics allows patients to learn what they are doing incorrectly, and also use their “new” strength to correct the maneuver.\textsuperscript{10} The adaptations that participants made after strength training and feedback instruction are improvements in landing mechanics, and are likely to decrease the risk of ACL injury.\textsuperscript{10}

Zebis et. al.\textsuperscript{74} examined the effects of a neuromuscular ACL prevention program on the EMG, joint angles, and GRF during a sidecutting task. The study revealed that following a season long prevention program, participants (elite female athletes) demonstrated an increased EMG activity of the semitendinosus muscle.\textsuperscript{74} Quadriceps muscle activation remained unchanged following the prevention program, which combined with the increased hamstring activity is a beneficial adaptation for protecting the ACL against anterior tibial translation and knee valgus.\textsuperscript{74}

Other studies have discovered a high correlation between valgus knee position and ACL injury, and prevention programs often focus on teaching individuals to stay out of this
Programs that focus on both valgus knee position and hip and knee flexion angles may prove to be more effective than a program that only incorporates one of these concepts. Often times prevention programs teach individuals proper landing techniques to avoid the excessive valgus position. A key component in any intervention program for ACL prevention is to increase the amount of knee and hip muscle activation, in order to increase knee joint stiffness and in turn decrease the risk of injury upon landing.

Plyometric training has been established to play a part in correcting injury-risk landing and cutting positions through adaptations that occur to the sensorimotor system. Plyometrics are exercises that involve an eccentric loading that is directly followed by a concentric contraction of the muscle. Chimera et al. focused on plyometric training in a group of collegiate female athletes, and discovered that the group performing plyometrics displayed an increased hip adductor EMG and abductor-to-adductor coactivation prior to landing, as compared with the group not performing plyometric training. The participants had the same workout schedule other than the plyometric training. This suggests that the plyometric training helped to establish preprogrammed landing strategies in these female athletes which could perhaps aid in decreasing poor landing strategies. This study demonstrates how plyometric training can help in establishing a feed-forward mechanism by the change that was reported in muscle activity prior to landing. These neuromuscular adaptations through plyometric training may help to establish more knee stability during athletic movements, and possibly lower the risk of injury. Irmischer et al. conducted a nine week plyometric training program with female subjects randomly designated into the control and experimental groups. All subjects performed a step-land protocol at baseline and post-training or control. Irmischer et al. found that when comparing baseline and post-training step-landings, that the post-training landing exhibited less
GRF. This modified landing not observed in the control group is beneficial for decreasing lower extremity injury, specifically noncontact ACL injury.\textsuperscript{71}

Wilderman et. al.\textsuperscript{53} conducted a six week agility training program within female college-aged intramural basketball players.\textsuperscript{53} After six weeks, the training group exhibited greater medial hamstring activity from baseline when performing a side-step pivot maneuver.\textsuperscript{53} Agility training programs may help decrease mal-alignments during side-step pivoting within the lower extremity, and may lower ACL injury risk.\textsuperscript{53}

**Environmental Risk Factors**

Environmental modifiable risk factors include the playing surface, meteorologic conditions, type of footwear worn by the athlete, and opposition from opponents.\textsuperscript{12} Different types of playing surfaces might include artificial turf, grass, hardwood floor (wood), rubberized surfaces, etc. Many different surfaces are used for athletic activity, and several aspects go into the development of these surfaces.\textsuperscript{102} Details related to injury prevention (impact absorption and friction/traction) are extremely important when creating a surface, but so are details related to performance, the game itself (such as how the ball will move across the surface or bounce on the surface.)\textsuperscript{102,103}

Artificial outdoor surfaces were developed as an all weather alternative to natural surfaces.\textsuperscript{103,104} These surfaces are also beneficial in that they require less maintenance than natural grass fields.\textsuperscript{103} When comparing the cost of maintenance between artificial and natural turf surfaces, natural surfaces require a 3.6 times greater cost on a “per hour of use” basis, even when including the cost of installation of an artificial turf field.\textsuperscript{103}

Artificial turf and other rubber surfaces demonstrate an increase in the coefficient of friction (COF) between the footwear and the playing surface as compared to natural surfaces like
Increasing the coefficient of friction between the footwear and the playing surface leads to an increased incidence of ACL injury.\textsuperscript{1,59,102} An increased COF not only may increase injury, but may increase the level of athletic performance as well.\textsuperscript{59,102,105} As friction between the shoe and surface increases, speed, agility, and contact forces tend to increase as well.\textsuperscript{59,102}

In a study by Pedroza et. al.\textsuperscript{105}, participants completed an agility maneuver on COFs of 0.3 to 0.7. Generally, as the COF of the surface increased, time required by participants to complete the trial increased, as well as an increase observed in peak force.\textsuperscript{105} The greatest changes in time and peak force were observed between COF levels of 0.3 and 0.4.\textsuperscript{105}

A desired range of frictional properties is ideal for athletic activity.\textsuperscript{59} A low COF surface might be slippery and result in sliding or falling, whereas a high COF surface will likely increase the forces that the body must absorb.\textsuperscript{59} One study suggests the ideal range of COF for athletic playing surfaces to be 0.31 or lower, and states that a COF of 0.49 or higher is not safe.\textsuperscript{11} Newton et. al.\textsuperscript{59} examined wrestlers under combinations of new or old mat, new or old shoes, and wet or dry surface. The findings were that new shoes and new mat conditions had higher COF than old shoes or mats, and that wet surfaces decreased the COF.\textsuperscript{59}

Injuries reported for the National Football League (NFL) also found that older versions of AstroTurf showed higher rates of ACL injury.\textsuperscript{1} Older generations of artificial turf have been linked with increased levels of impact, joint movement patterns that are altered, greater eccentric muscle activity, and a difference in sliding resistance.\textsuperscript{103} Artificial turf can be categorized into three different groups.\textsuperscript{104} When artificial turf was first developed in the 1960’s (first-generation turf), it had a short pile length, a minimal amount of padding, and an overall high frictional coefficients.\textsuperscript{104} In the 1980’s, second-generation artificial turf was created, and its physical
characteristics included a longer pile length than first-generation, as well as sand or rubber infill and increased padding that allowed the surface to have more cushion. Third-generation artificial turf came out in the late 1990’s, and has the longest pile length, most cushion due to infill characteristics, and the least amount of friction.

Dragoo et. al. did a review of the literature on injury rates on different playing surfaces. This review concluded that first-generation artificial turf surfaces exhibited more injuries per game than games played on natural grass, specifically a greater amount of injuries to both the knee and ankle. Dry first-generation AstroTurf surfaces compared with wet surfaces also showed a significantly higher rate of injury.

Second-generation artificial turf surfaces progressed to possessing an infill to help minimize friction and increase cushion properties. However, second-generation artificial turf surfaces still seem quite similar to first-generation surfaces when examining injury rates compared to natural grass. Both knee and ankle sprains injuries were found to be significantly higher on these artificial turf surfaces versus grass. One study examining collegiate football players found that 35% of players conditioning only on the artificial turf developed an injury, whereas only 13% of players conditioning on artificial turf and in a pool developed an injury. Similar to first-generation turf surfaces, second-generation turf injuries were higher in domed stadiums when compared with open stadiums. This finding demonstrates that wetness/dryness and temperature of the field may also play a role in the occurrence of injury on these surfaces.

The purpose for the development of third-generation artificial turf surfaces was to decrease the coefficient of friction from previous turf surfaces, aiming to also decrease injury rates on this surface as compared with grass. The literature seems to conclude that developers of this third-generation surface met their goal, because incidence of overall injury seems to be
similar between natural grass and third-generation artificial turf surfaces.\textsuperscript{102,104,106} Similarly, Ekstrand, et. al. studied a group of elite European football (soccer) players, and injury incidence between third-generation artificial turf and natural grass, and discovered that there was no difference in overall injury (during matches or training) between the two different surfaces.\textsuperscript{107} When examining for the specific type of injury, males seem to have significantly more ankle, foot, and joint injuries on third-generation artificial turf, whereas females exhibited a significantly lower amount of ligament and cartilage injuries on artificial turf as compared with grass.\textsuperscript{104} This is in contrast to a statement by Silvers, et. al\textsuperscript{72} stating that females have a greater ACL risk than males when performing activity on artificial surfaces, although Silvers, et. al.\textsuperscript{72} did not specify which generation of artificial turf this statement was in regards to.

Artificial turf is subject to wear and tear, and as degradation of the surface occurs with age, the frictional properties of the turf are subject to change.\textsuperscript{108}

Grass has always been the standardized outdoor athletic surface that artificial turf manufacturers attempt to mimic.\textsuperscript{104} This is a difficult task, as grass fields are extremely variable within themselves.\textsuperscript{104} Grass fields can be different in both dryness/wetness factors, but also the species of grass that is growing on the field.\textsuperscript{104} Some common types of grass species are Kentucky bluegrass, Bermuda grass, and ryegrass.\textsuperscript{109} Of these, ryegrass seems to display the lowest amount of shoe-surface traction.\textsuperscript{103,109} Significantly higher rates of ACL injury were reported in the Australian Football League (AFL) on fields with drier grass.\textsuperscript{103,104} High evaporation rates, high temperatures, and low humidity increased the risk of ACL injury by 2.8 fold, and fields with low rainfall had a 1.93 fold greater risk of injury.\textsuperscript{104} Another study reported 1.7 injuries per game on wet/slippery fields and 3.3 injuries per game on fields in “good” condition.\textsuperscript{104} Dryer fields seem to increase ground hardness and overall COF, which has been
linked with an increase in ACL injury risk.\textsuperscript{83,104} Hardness and traction of the surface are two components that have been linked with injury when playing on natural grass surfaces.\textsuperscript{103} It has been suggested that when using cleated shoes on hard surfaces, the shoe-surface interaction will be greater, which will increase the risk of injury.\textsuperscript{103}

When comparing wooden floors and artificial court surfaces with a rubber component, females were found to have twice as great a risk of injury on artificial court surfaces when compared with wood surfaces.\textsuperscript{104} This difference in injury risk may be due to a difference in the COF, as artificial surfaces are generally believed to have a higher COF.\textsuperscript{104} On court surfaces, dust and water (or other liquids, such as sweat) could be potential hazards.\textsuperscript{110} Dust and/or water particles decrease the frictional interaction between the surface and shoes.\textsuperscript{59,110}

Dowling et. al.\textsuperscript{1} examined movement strategies during a sidestep cutting task relative to two surfaces with different coefficients of friction.\textsuperscript{1} A high coefficient of friction (COF) surface interaction displayed a greater medial distance of the center of mass (COM) away from the support limb during activity.\textsuperscript{1} When the distance of an individual’s COM from the supporting limb is great, a link is shown between COM and the risk for an ACL injury.\textsuperscript{1} However, the COF of the surfaces that were used were not as high as some artificial athletic surfaces have been reported to be.\textsuperscript{1} Therefore, lowering the COF of surface interaction may decrease the risk for ACL injury. This concept establishes a link between both neuromuscular risk factors as well as possible environmental risk factors of ACL injury. In agreement with these findings, Ford et. al. suggested that different playing surfaces could affect athlete’s movements, and ultimately the incidence and severity of injury.\textsuperscript{106}

Athletic shoes with a high COF show an increased risk of ACL injury as well.\textsuperscript{1,11} A high COF of the shoe indicates that the individual will land with a decreased knee flexion angle and
an increase in the valgus positioning of the knee joint.\textsuperscript{1} These positions have been known as common mechanisms of injury for ACL tears.\textsuperscript{1,72} Shoe-surface interaction has also been speculated to impact the translational and rotational forces that the lower limb joints must encounter during cutting and turning activities.\textsuperscript{106} The amount of cushioning that the shoe contains may also impact vertical forces transmitted through the lower extremity bones and soft tissue during athletic maneuvers.\textsuperscript{106}

Shoe-surface interaction is also hypothesized to be influenced by the ambient temperature.\textsuperscript{109} Orchard et. al.\textsuperscript{109} found that incidence of ankle and knee injury in the NFL was reduced in cold weather in outdoor stadiums (both natural grass and AstroTurf stadiums).\textsuperscript{109} The authors suggest that the reason for the reduced injury rates is due to a decreased shoe-surface traction in cold weather (<70 degrees F).\textsuperscript{109} Weather conditions did not have any effect on injury risk in domed stadiums.\textsuperscript{109} An increase in ACL injuries has also been reported with longer cleats that are placed more peripherally.\textsuperscript{109 102}

Uneven surfaces may also contribute to an increased risk of ACL injury, but this has not yet been validated.\textsuperscript{72} During hopping on unexpected hard and soft surfaces, athletes will passively adjust their “leg stiffness” by ultimately adjusting the joint angle at landing.\textsuperscript{57} When landing on soft surfaces, humans tend to reduce the amount of flexion at the hip and knee joints, which results in a higher impact force that must be absorbed.\textsuperscript{56}

It has also been found that dry fields and warm weather conditions may pose a greater risk for injury.\textsuperscript{1} Dry fields as compared with wet fields have a greater coefficient of friction.\textsuperscript{1} When examining the noncontact ACL injuries that occurred over five seasons in the NFL 95.2\% of them occurred on dry fields.\textsuperscript{1} Studies examining NFL knee and ankle injuries reported more injuries to these joints in cold weather versus warm weather.\textsuperscript{1}
Hughes, et. al. examined GRF and joint angles in males and females upon landing from a block jump in volleyball. From this study, the authors concluded that during opposed trials, participants exhibited larger GRFs as well as a decreased amount of knee flexion at initial contact and at maximum knee flexion. Increased GRF and decreased knee flexion have both been linked with an increased risk of ACL injury upon landing, which leads the authors to conclude that prevention programs should incorporate opposition during landing.

Although different surfaces in combination with landing maneuvers have been studied, it has not yet been identified how landing strategies differ when examining the same individuals landing on different surfaces using the LESS as an evaluation tool.

**Conclusions**

Although ACL research has been extensive, limited research has focused on examining environmental risk factors of ACL injury. Neuromuscular responses and control seems to play a significant role in the risk of suffering an ACL injury. Landing strategies have been assessed across all types of populations, including genders, training levels, and history of ACL injury. However, research is limited on how the type of surface affects landing strategies. The studies that have been done on landing on different surfaces have been performed in a laboratory setting, and did not utilize real athletic playing surfaces. What we do not know is how different surfaces affect landing strategies as assessed by the LESS evaluation tool. Therefore, the purpose of this study is to investigate the differences in landing strategies while landing on different surfaces.
CHAPTER 3

METHODS

Design Statement

The purpose of this study is to examine the influence of landing strategies during a JRLT and the interaction between common playing surfaces within college-aged, physically active individuals. Independent variables: gender (male & female) and landing surface (wood and multi-purpose court). Dependent variables: landing strategies (assessed by the LESS).

Participants

Twenty to thirty physically active, healthy, college-aged males and females will be included in this study. The number of participants was determined based on establishing statistical power and a median effect. This was calculated using the number of trials per condition for each participant. Physically active is defined as anyone exercising 3 times a week for at least 30 minutes. Participants will be excluded if they had any history of cardiovascular disease, pulmonary disease, neuromuscular disorders, systemic conditions, history of ACL injury, ligamentous instability, or history of any lower extremity surgery in the past 2 years. Participants will also be excluded if they had any history of lower extremity injury within the last 6 months, as determined by the health history questionnaire and orthopedic exam. Participants will be recruited through the use of flyers (Appendix A) and announcements located around Indiana State University. Undergraduate students will be informed of the study through
announcements given in Physical Education 101 and Health 111 courses by the principal investigator. Persons interested in participating in the study will attend an information session, in which they will be given an informed consent form to fill out and bring to the data collection session if they are still interested in participating. All participants will read and sign an approved informed consent (Appendix B) form prior to participation in the study.

**Procedures (Experimental Conditions)**

Upon arrival to each site, participants will turn in their completed approved informed consent form (Appendix B), and will complete a health history questionnaire/physical activity questionnaire (Appendix C). After completing this paperwork, the principal investigator will review the health history questionnaire to ensure all participants meet the inclusion/exclusion criteria. Participants that meet the inclusion criteria will then undergo an orthopedic exam which will be performed by an ATC (certified athletic trainer). Height and weight of participants will then be collected.

On the day of testing, participants will be asked to arrive in a t-shirt and snug-fitting shorts that end above the level of the knee joint. Participants will wear their own athletic shoes, as this is a preliminary study that is more focused on examining landing mechanics on surfaces. Further studies should repeat the procedures of this study while controlling for shoe type. Each participant will perform the JRLT on each of the different landing surface conditions. The four landing surfaces are a wood (basketball court), grass field, artificial turf, and a multi-purpose court. The locations for the surfaces are all located on the ISU campus and are as follows: wood basketball court in the South Gymnasium, grass field in the center of the track, artificial turf in the weight room of the Arena Building, and the multi-purpose court in the North Gymnasium. The testing of each surface for each participant will take place all in one day. There will be no
formal familiarization session in which the participants physically complete the JRLT prior to the day of testing. Surface order will be randomized between participants to control for learning effect. Randomization will take place by having participants pick a card out of a pile of previously made cards with all different orders of surfaces.

Participants will be instructed on how to complete the JRLT, standardized instructions will be verbally given to participants (Appendix D). The JRLT will begin from atop a 30 cm (approximately 1’) box. The participant will then perform a horizontal jump down onto an “X” (previously measured out at a distance of 50% of their height away from the box). Immediately upon landing on the “X”, participants will perform a maximum vertical jump. After instructions are given on how to perform the task, participants will be allowed to perform the task until they feel comfortable with the skill. Minimal feedback concerning landing mechanics will be given to participants during the trials, so as to not influence the way participants would normally land. No controls will be in place for auditory feedback, in hopes of reflecting a real-life game or practice type situation.

When participants feel comfortable with the jumping task, 3 successive acceptable trials will be obtained and recorded for each participant on each surface. An acceptable trial consists of the following: 1) jumping off both feet from the box, 2) jumping forward to reach the “X”, not a vertical jump, 3) completing the task in a fluid motion (no stumbling or falling), and 4) performing a vertical jump immediately following landing from the initial jump. A 15 second resting period will be given to each participant between each of the 3 trial jumps. A stopwatch will be used to standardize the time allotted between jumps.
Each trial performed will be videotaped from frontal and sagittal views of the participant. The recorded video will later be examined by one researcher to examine landing strategies using the LESS.

An athletic trainer (ATC) will be on-site in case of an injury. Padding will be placed around the landing surfaces to ensure a safe landing environment. The landing and experimental protocol has been deemed safe during use in previous research; no injuries have been reported.60

**Measurements/ Instrumentation**

Participant demographic information, such as age, height, and weight will be collected and recorded. Descriptive statistics (mean, standard deviation, and/or percentages) will be collected on environmental conditions such as ambient temperature during testing sessions.

Two Panasonic FZ100 digital video cameras (Osaka, Japan) will be used to record the JRLT of each participant to be later analyzed for LESS data. A stopwatch will be used to record the time between JRLT trials in order to standardize rest times between participants.

The LESS will be used to assess the video collected from the participant’s JRLT trials. The LESS has been found to be valid and reliable, and demonstrated a moderate to excellent validity as compared to a 3-dimensional motion analysis system.61 Its intra and inter-rater reliability ranged from good to excellent (ICC=0.91 and ICC=0.84 respectively), and it is a valid tool for “identifying high-risk movement patterns during a jump-landing task.”60 The LESS is scored by examining 17 different criteria (Appendix E). These criteria will be examined by only the principal investigator to eliminate any potential unreliable results. Each criteria is given a score of 0, 1, or 2. The total score is analyzed, and high scores indicate a poor landing technique. The following categories explain the level of landing techniques: excellent score is ≤4, good is >4 and ≤5, moderate is >5 and ≤6, and poor is a LESS score of >6.
Statistical Analyses

This study is a repeated-measures within group design to investigate the difference between landing mechanics on different surfaces as evaluated by the LESS. A factorial ANOVA with repeated measures will be used, and the dependent variable will be treated separately. SPSS (version 18) will be used to analyze and input data.
The Effects of Playing Surface on Landing Mechanics During a Jump Rebound-Landing Task

Anterior cruciate ligament (ACL) injury affects approximately 250,000 individuals each year.\textsuperscript{1,111,112} Of these, an estimated 100,000 undergo reconstructive surgery to correct this injury.\textsuperscript{113} Both the short-term and long-term effects of ACL injury may be detrimental to individuals with a physically active lifestyle.\textsuperscript{3,6-11,111-114} Therefore, it is important to investigate the causes of ACL injury in order to develop and implement prevention programs.\textsuperscript{9,11,13,111,112,114}

Literature suggests ACL risk factors can be classified as modifiable or non-modifiable.\textsuperscript{12} Modifiable risk factors include neuromuscular factors (muscular strength, muscle activation patterns, muscle stiffness, physical fitness and muscle fatigue) and environmental factors (playing surface, footwear, meteorologic conditions, referees, etc.).\textsuperscript{12} Non-modifiable risk factors are factors that are not easily changed.\textsuperscript{12} These types of factors include demographics of the individual (age, injury history, familial history, genetics, gender, height, and race), anatomical factors (Q-angle, navicular drop, notch size, ACL geometry and properties, tibial slope angle, etc.), hormonal influences (menstrual cycle and hormone concentrations), and environmental considerations (playing situation, opponent behavior, unanticipated events during play).\textsuperscript{12}
Ford et al. suggested that athlete’s movements ultimately effect the incidence and severity of injury. All athletic playing surfaces have their own unique frictional properties, such as coefficient of friction (COF), which may play a role in the movements or mechanics that occur upon landing.

ACL injuries often occur from a noncontact mechanism, such as landing from a jump. Poor landing mechanics are linked with an increased risk of ACL injury. Therefore it is important to examine how individuals land on different surfaces in order to provide recommendations for types of athletic playing surfaces. The Landing Error Scoring System (LESS) was used to assess landing mechanics in this study. We chose to use the LESS because previous literature has indicated that it is a valid method for assessing landing mechanics, and is practical as well as time and cost-efficient for clinicians.

The purpose of this study was to determine if landing mechanics differ when landing on a wood basketball court as compared with a volleyball sport court. These surfaces were chosen because they are commonly used surfaces especially among physically, active individuals. Also, by using indoor surfaces, environmental factors such as weather and ambient temperature were easily controlled.

Methods

A repeated-measures within participant design to investigate the effect playing surface has on landing mechanics. The independent variable was playing surface with two levels; a wood basketball court and a volleyball sport court. The dependent variable was landing mechanics, determined by LESS scores.
Participants

Thirty-two healthy, physically active individuals participants were recruited (14 males, 18 females) to participate in this study. Only twenty-eight of the thirty-two participants completed the entire study. The data for 3 of the twenty-eight participants were excluded due to faulty camera set up and poorly recorded video footage, therefore the data of 25 participants (9 males, 16 females) (mean age=20±2; mean height=171.7±10.0; mean mass=70±14) was analyzed. Physically active was defined as exercising 3 days per week, 30 minutes at a time, for the past 3 months. Participants were recruited through flyers and class announcements on a university campus. Each participant completed a health history questionnaire and orthopedic examination to rule out exclusion criteria. The university’s Institutional Review Board approved this study and all participants completed the written informed consent process during a familiarization session before any other information was collected.

Instrumentation

Cisco Flip video cameras (3 UltraHD and 1 MinoHD) (Irvine, CA) were used to record participants landing on each of the surfaces from the front and side. All video cameras had a sampling rate of 30 frames per second. The LESS scoring system was used to analyze each jump. The LESS was designed as an alternative method to laboratory-based motion analysis systems. This tool is an inexpensive and time-efficient method to identify high-risk movement patterns upon landing from a jump. The LESS involves videotaping individuals landing from frontal and sagittal views and using a scoring system of 17 criteria to rate the overall landing technique. Higher LESS scores indicate a more “faulty” landing technique, which is linked with a higher predisposition to ACL injury. Each score can be categorized as excellent (≤4), good (>4 and ≤5), moderate (>5 and ≤6), or poor (>6).
Literature has shown the LESS to be a valid and reliable tool for assessing “errors” in landing, and having an excellent inter-rater reliability (ICC=.835) between novice and expert examiners of overall LESS scores. The PI in this study viewed and scored numerous JRLTs in order to establish reliability (P=.092)

**Procedures**

Each participant attended a short familiarization session; signed an informed consent form and completed a health history questionnaire ruling out exclusion criteria. Height, weight, and age were measured for all participants that met the eligibility criteria for the study. Additionally, participants completed an orthopedic examination assessing for equal range of motion of the ankle, knee, and hip bilaterally as well as a negative sign for ankle and knee ligamentous testing (Lachman’s, valgus/varus stress testing, anterior drawer of knee and ankle, and inversion/eversion stress tests). Range of motion was measured by visually observing for a gross difference bilaterally. Participants were excluded if range of motion was not equal bilaterally, or a positive test was found when assessing ligaments of the knee and ankle. No participants were excluded on the basis of range of motion or ligamentous laxity. Eligible participants were scheduled for a data collection session. The primary investigator and one research assistant (senior athletic training student) administered all familiarization sessions.

Participants arrived to the data collection session wearing a t-shirt, shorts that ended above the knee joint, and their choice of their own athletic shoes that they would normally work out in. The surface that participants would land on first (either the wood basketball court or volleyball sport court) was randomly assigned.

Flip cameras, tripods, and a plyometric box were set in the gyms according to the protocol used during previous research. Figure 1 illustrates the set up for data collection. The
side camera was placed on the right side for all participants in order to remain consistent. Padding was placed around the jump landing site to ensure participant safety. The PI (a certified athletic trainer) was present at all data collection sessions to ensure patient safety and immediate response in case of injury.

![Diagram of equipment placement](image)

Figure 1

Equipment placement during data collection sessions

Verbal instructions were provided to all participants on how to complete the JRLT (Figure 2). Participants completed as many practice JRLTs (typically 1-3) as they needed to feel comfortable with the task. Once participants were comfortable in performing the task, each participant performed 3 acceptable trials, which were videotaped from frontal and sagittal views. We defined an acceptable trial as 1) jumping off the box with both feet; 2) jumping horizontally, not vertically to reach the “X” (50% of participant’s height away from the box); 3) landing with both feet on the “X”; 4) completing the JRLT in a fluid motion. Prior to each jump participants held a card with their assigned ID number toward each camera to allow the PI to identify each
participant upon analyzing the video footage. We provided each participant with a 30 second rest period between each JRLT trial.23 A stopwatch was used to standardize the rest period.

Figure 2

Visual representation of the JRLT from side view

Upon completion of three acceptable JRLT trials on the first surface, a 5 minute resting period was allotted before completing practice trials (if desired) and 3 acceptable trials on the second surface. After data collection was complete, the PI scored all 3 jumps for each participant according to the LESS, and used the mean of the 3 jumps for statistical analysis. Prior to data collection the PI assessed several jumps on multiple occasions in order to assure intra-rater reliability.

Statistical Analysis

A paired samples t-test was used to compare each participant’s LESS scores between the basketball and volleyball court surfaces. Significance was set at p<0.05 a priori. A paired samples t-test was also run to determine PI intra-rater reliability (p=0.092) at assessing JRLTs using the LESS.

Results

We identified no differences (P=0.22, t=1.27) between the LESS scores on the wood basketball court surface (6 ±1) and the LESS scores on the volleyball sport court surfaces (6 ±2).
We also ran frequencies to identify the number of participants that had LESS scores in each scoring category on each surface (Figure 3).

Figure 3

Frequencies of LESS categories on wood (left) and volleyball (right) courts

Discussion

The purpose of this study was to determine if an individual’s landing mechanics (as assessed by the LESS) differ when landing on a wood basketball court surface as compared with a volleyball sport court surface. Previous studies suggest that artificial court surfaces introduce a higher risk of ACL injury due to an increase in the COF between the footwear and playing surface as compared with natural surfaces. The increased COF is suggested to lead to an increased incidence of ACL injury. In contrast, we identified no differences between LESS scores on a volleyball sport court (artificial surface) and wood basketball court (natural
surface) within participants. Our findings suggest that the two surfaces studied did not affect participant landing mechanics.

Dowling et. al.\textsuperscript{1} examined movement strategies during a sidestep cutting task relative to two surfaces with different COF.\textsuperscript{1} The high COF surface interaction displayed a greater medial distance of the center of mass (COM) away from the support limb during activity, which is linked with a greater risk of ACL injury.\textsuperscript{1} However, the COF of the surfaces that were used were not as high as some artificial athletic surfaces have been reported to be.\textsuperscript{1} Unlike Dowling et. al.\textsuperscript{1}, we used actual athletic playing surfaces in order to relate our results directly to athletics. However, a limitation of our study was that we did not measure the COF of each surface examined. We also had participants complete a JRLT and not a sidestep cutting task. Most research suggests that the COF would be higher on the volleyball sport court surface, as artificial surfaces generally have a higher COF.\textsuperscript{1,102,103} However, we have no measurement to support this, and perhaps there was no difference found in LESS scores because the COF was similar between surfaces.

Another limitation of this study is that the shoe worn by participants was not standardized. As friction between the shoe and surface increases, previous research indicates that an increased COF may not only increase injury, but may increase the level of athletic performance (such as speed and agility) as well.\textsuperscript{1,59,102,105} Athletic shoes with a high COF show an increased risk of ACL injury.\textsuperscript{1,11,59,105} Shoe-surface interaction has been speculated to impact the translational and rotational forces that the lower limb joints must encounter during cutting and turning activities.\textsuperscript{106} Although we do not know what role the shoes worn by our participants played in each individual’s landing mechanics, we allowed participants to wear their own shoes as an attempt to make our results more relatable to physically active individuals.
Lastly, the participant number used was quite small, and only included healthy, physically active individuals. Utilizing an injured population or a population with past history of injury could potentially alter the results.

To our knowledge, there have been no previous studies investigating landing mechanics between actual athletic surfaces as assessed by the LESS. The results of the present study indicate that surface type (specifically wood versus sport court) does not influence landing mechanics. Alone this study alone does not provide sufficient evidence to form recommendations for playing surface or footwear. However, future research should examine landing mechanics on different athletic surfaces (with the COF identified) in order to establish an ideal COF range with the ideal balance between safety and optimal performance for a surface. Also, specialized shoes such as cleats for soccer, football, softball, etc. should be examined for interactions on the respective sport surface.

Conclusion

The findings of this study demonstrated no differences in landing mechanics between a wood basketball court and volleyball sport court surface when landing from a jump. This study was an observational field study intended to provide a basis for further studies in the area of environmental risk factors associated with ACL injury. Future research needs to examine how surfaces such as grass and artificial turf compare to each other and to the surfaces examined in this study, as well as how standardizing shoes among surfaces affects LESS results.
REFERENCES


APPENDIX A: RECRUITMENT FLYER

WE NEED YOUR HELP!

Where: Indiana State University, Terre Haute, Indiana

Purpose: To study landing on different common athletic playing surfaces.

Study: You will attend a short (15 minutes) familiarization session prior to participation in the study. You will then come to a data collection session (approximately ½ hour) taking place on ISU’s campus. You will be asked to complete a jumping and landing maneuver on two different surfaces.

Criteria: ISU individuals (18-25 year old males & females) that are healthy and engage in physical activity 3 times a week for at least 30 minutes at a time for the last 3 months. Ineligible if: you are pregnant or think you may be pregnant, you have a history of cardiovascular or pulmonary diseases, neurological disorders, or systemic conditions. Must have NO history of an injury to the back, leg, ankle, or foot within the last 6 months, a surgery in the last 2 years, or any history of ACL injury or surgery.

Compensation: You will receive $5 for your participation in this study.

Contact:
Kayla Stankowski  kstankowski@sycamores.indstate.edu  715-212-5468
Dr. Timothy Demchak  812-237-8496
APPENDIX B: INFORMED CONSENT FORM

CONSENT TO PARTICIPATE IN RESEARCH

The Effects of Playing Surfaces on Landing Mechanics during a Jump Rebound Landing Task (JRLT)

You are asked to participate in a research study conducted by Kayla Stankowski (and Dr. Timothy Demchak), from the Department of Applied Medicine and Rehabilitation at Indiana State University. This study is being conducted as part of a graduate student research thesis. Your participation in this study is entirely voluntary. Please read the information below and ask questions about anything you do not understand, before deciding whether or not to participate.

You have been asked to participate in this study if you are a student at Indiana State University and exercise at least 30 minutes 3 times per week for the last 3 months, such as running, lifting weights, and/or team sports. You must not have experienced an injury to your back, leg, ankle, or foot within the last 6 months, or a surgery to any of these areas within the past 2 years. Individuals with a history of ACL injury or surgery, any lower extremity instability, cardiovascular disease, pulmonary disease, neurological disorders, systemic conditions, or women who are pregnant, or think that they are pregnant will also be excluded.

* PURPOSE OF THE STUDY

The purpose of this study is to examine the influence of landing from a box and then jumping again on different athletic playing surfaces (wood and volleyball sport court) within healthy, college-aged physically active individuals. The results of this study may be an important contribution to further understand knee injury risk and how it relates to the playing surface.

* PROCEDURES

If you volunteer to participate in this study, you will be asked to do the following things:

Upon arrival to the Applied Medicine and Rehabilitation Research Lab (SS15) for the familiarization session, you will complete an informed consent form. Before signing the informed consent form, an investigator will point out the potential risks and discomforts of participating in this study, as well as what will happen if an injury would occur. If you choose not to sign the informed consent form, you will not have to continue completing anything else, and you will be free to leave. If you do complete the informed consent form, you will then complete a health history questionnaire. After completing this paperwork, the investigator will review the health history questionnaire to ensure that you meet the inclusion/exclusion criteria of the study. If you meet the inclusion criteria you will then undergo an orthopedic exam which will be performed by an athletic trainer (AT) or athletic training student who is competent and proficient in the skills. Your height, weight, and age will also be collected. After the orthopedic exam, an investigator will review the orthopedic exam form, and if any of the range of motion tests are not equal, and/or if any of the special tests show a positive result, you will be excluded from continuing in the study. At the end of the familiarization session, you will set up a time to attend a data collection session with the investigators.

On the day of the data collection session, you will be asked to arrive in a t-shirt, athletic shoes, and snug-fitting shorts that end above the level of the knee joint. You will be reminded of the possible risks of participating in this study. You will then be asked to perform a jump on each of two different

Date of IRB Approval: 3/27/2012
IRB Number: 12-073
Project Expiration Date: 03/14/2013
landing surface conditions. The two landing surfaces are a wood (basketball court) and a volleyball sport court. The locations for the surfaces are all located on the ISU campus and are as follows: wood basketball court in the South Gymnasium and volleyball sport court in the South Gymnasium. The testing of the wood and volleyball sport court will take place in one day. To determine which surface you will jump on first, you will be randomly designated to one of the two surfaces (wood or volleyball sport court).

You will be instructed on how to complete the jump, and shown an example. The jump will begin from atop a 30 cm (approximately 1') box. You will jump down off the box onto a designated area marked with an “X”. Immediately upon landing on the “X”, you will perform a maximum vertical jump. After instructions are given to you on how to perform the task, you will be allowed to perform the task until you feel comfortable with the skill. Attached is a visual representation of how to perform the jump.

When you feel comfortable with the jumping task, you will be asked to perform 3 more acceptable trials, and all of the jumps will be videotaped from both a front and side. You will be allowed at least 30 second rest period between each of the 3 jumps. This procedure will then be repeated on the second surface. You will be allowed at least a 5 minute resting period between each surface. Total participation time is approximately 15 minutes for the familiarization session, and 30 minutes for the data collection session.

♥ POTENTIAL RISKS AND DISCOMFORTS

As a result of this study, you may experience muscle soreness up to 72 hours after participation in this study has ended. During performance of the jumping task, there is a chance that you could fall if you lose your balance. However, the risk of injury is minimal because you will perform the landings from a box that is only 11.8” (30 cm) high. The demands are no greater than that experienced when you are physically active. The landing and experimental protocol has been deemed safe during use in previous research; no injuries have been reported. This study has no long-term and minimal short term risks.

In case of injury, a Certified Athletic Trainer will be present to provide first aid, further medical advice, and referral. If injury occurs, participants will be automatically disqualified from further participation in the study.

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the study, and will be responsible for any additional medical costs. Padding will be placed around the landing surface area in order to facilitate safe landing environment for all participants. All participants will undergo an orthopedic screening prior to data collection to ensure knee and ankle ligaments are stable.

♥ Potential Benefits to Subjects and/or to Society

There are no direct benefits to you for participating in this study. The results of the study will be useful to researchers to develop a basis for future studies to further examine how the surface may or may not contribute to knee injury, and how these findings can be incorporated into injury prevention programs.

♥ Payment for Participation

You will receive a $5 incentive for attending the data collection session. The incentive will be provided to you whether you complete the session or not. You will complete a participant reimbursement form and return it to the Applied Medicine and Rehabilitation Department secretary (Julie Dininger) the day of your scheduled data collection session. A check will then be mailed to your address. Since you will be reimbursed the department secretary and bursar’s office will know you participated in this study.

Please note: Foreign nationals on visas other than F-1 or J-1 may not be eligible to receive payment for participation in this study.

♥ Confidentiality

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. Confidentiality will be maintained by means of assigning you a confidential ID number so that your information will not be readily identifiable. All forms including data collected will only be tied to you via the ID number. The faculty sponsor will keep the key code of ID numbers assigned to each participant name, and it will be destroyed following data analysis.

The videotaped footage of the jumping tasks will be kept on memory cards that will be accessible only to the investigators. This videotaped footage will also be saved on the primary investigator’s password protected computer. The health history questionnaire and informed consent forms will be stored in a locked cabinet in a locked room in the Applied Medicine and Rehabilitation Research Lab (SS15), and will be destroyed 1 week after completion in this study. Videotaped footage saved onto the computer will be erased after data analysis is completed. Upon completion of the project informed consent forms will be kept safely locked in a cabinet in the Applied Medicine and Rehabilitation Research Lab (SS15) until three years have passed. After three years have passed, they will be destroyed.

♥ Participation and Withdrawal

You can choose whether or not to be in this study. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind or loss of benefits to which you are otherwise entitled. You may also refuse to answer any questions you do not want to answer. There is no penalty if you withdraw from the study and you will not lose any benefits to which you are otherwise entitled.

Date of IRB Approval: 3/27/2012
IRB Number: 12-073
Project Expiration Date: 03/14/2013
IDENTIFICATION OF INVESTIGATORS

If you have any questions or concerns about this research, please contact:
Dr. Timothy Demchak
Sycamore Center for Wellness and Applied Medicine
Rm 249
812-237-8496
timothy.demchak@indstate.edu

Kayla Stankowski
715-212-5468
kstankowski@sycamores.indstate.edu

Additional investigators are:
Dr. Matt Gage
Sycamore Center for Wellness and Applied Medicine
Rm 260

Dr. Adam Yoder
Sycamore Center for Wellness and Applied Medicine
Rm 247

RIGHTS OF RESEARCH SUBJECTS

If you have any questions about your rights as a research subject, you may contact the Indiana State University Institutional Review Board (IRB) by mail at Indiana State University, Office of Sponsored Programs, Terre Haute, IN 47809, by phone at (812) 237-8217, or e-mail the IRB at irb@indstate.edu. You will be given the opportunity to discuss any questions about your rights as a research subject with a member of the IRB. The IRB is an independent committee composed of members of the University community, as well as lay members of the community not connected with ISU. The IRB has reviewed and approved this study.

I understand the procedures described above. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

Printed Name of Subject

Signature of Subject Date

Leave this amount of space for IRB approval stamp (unless you plan to include the approval information in the text of the ICD)

Date of IRB Approval: 3/27/2012
IRB Number: 12-073
Project Expiration Date: 03/14/2013
APPENDIX C: HEALTH HISTORY QUESTIONNAIRE

Name: ___________________________ Subject ID #: ___________________________

Indiana State University
Department of Applied Medicine and Rehabilitation

HEALTH HISTORY QUESTIONNAIRE

<table>
<thead>
<tr>
<th>Study Title: The Effects of Playing Surfaces on Landing Mechanics During a Jump Rebound-Landing Task</th>
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Please answer the following questions to the best of your knowledge:

1. Do you regularly exercise 30 minutes at least three times a week for the last 3 months? YES NO
2. Are you currently under a doctor’s care? YES NO
3. **Women only:** Are you pregnant or do you think you might be? YES NO
4. Do you have a pacemaker or automatic implanted cardiac defibrillator (AICD)? YES NO
5. Do you have, or suspect that you have, any circulatory problems or vascular (problems with your veins or arteries) disorders, conditions, disorders, or diseases? YES NO
6. Do you have, or suspect that you have, any rheumatoid (joint) or muscular conditions, disorders or diseases? YES NO
7. Do you have, or suspect that you have, a mitral valve prolapse, or any other disease, condition, or disorder that may be aggravated by participating in this study (see attachment for clarification)? YES NO
8. Do you have, or suspect that you have, any pulmonary diseases such as chronic obstructive pulmonary disease? YES NO
9. Do you experience numbness, tingling, or decreased sensation in extremities, or have other neurological problems, conditions, disorders, or diseases? YES NO
10. Do you have any problems, conditions, disorders or diseases that affect your ability to keep your balance? YES NO
11. Have you suffered from an abdominal, lower extremity, or low back injury in the past 6 months? YES NO
12. Have you had an abdominal, lower extremity or low back surgery in the past two years? YES NO
13. Have you ever had an ACL injury or surgery? YES NO

*If you answered "YES" to any question or you are unsure about your answers, you will be asked for more detail to help the investigators better assess whether your condition increases your risk for participation. The questions and responses will be recorded on the back of this page.*

I certify that all the information provided is correct.

_________________________ Date

Participant Signature
APPENDIX D: STANDARDIZED PARTICIPANT INSTRUCTIONS FOR THE JUMP REBOUND-LANDING TASK

The following are instructions that will be read to each participant before performing the JRLT. The items mentioned in the instructions will be pointed out to the participant as they come up in the instructions.

1) You will start on top of this box.
2) Next you will jump forward off of both feet to land on this “X”.
3) Immediately after landing on the “X”, you will jump as high as you can straight up in the air.
4) You should end up landing on the “X” after this jump as well.
5) Do you have any questions?
6) You will now have time to perform as many practice trials as you would like in order to become familiar with this task.

Instructions adapted from Padua et. al. in order to suit this study
APPENDIX E: LESS SCORING CRITERIA

The following pages are the 17 criteria that will be used to score each landing. These criteria come from Padua et. al.\textsuperscript{60} in which the LESS was shown to be a valid and reliable tool for assessing faulty landing mechanics.

<table>
<thead>
<tr>
<th>LESS Item</th>
<th>Operational Definition</th>
<th>Camera View</th>
<th>Error Condition</th>
<th>LESS Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Knee flexion angle at initial contact</td>
<td>At the time point of initial contact, if the knee of the test leg is flexed more than 30 degrees, score YES. If the knee is not flexed more than 30 degrees, score NO.</td>
<td>Side</td>
<td>No</td>
<td>Y=0</td>
</tr>
<tr>
<td>2 Hip flexion angle at initial contact</td>
<td>At the time point of initial contact, if the thigh of the test leg is in line with the trunk then the hips are not flexed and score NO. If the thigh of the test leg is flexed on the trunk, score YES.</td>
<td>Side</td>
<td>No</td>
<td>N=1</td>
</tr>
<tr>
<td>3 Trunk flexion angle at initial contact</td>
<td>At the time point of initial contact, if the trunk is vertical or extended on the hips, score NO. If the trunk is flexed on the hips, score YES.</td>
<td>Side</td>
<td>No</td>
<td>Y=0</td>
</tr>
<tr>
<td>4 Ankle plantar-flexion angle at initial contact</td>
<td>If the foot of the test leg lands toe to heel, score YES. If the foot of the test leg lands heel to toe or with a flat foot, score NO.</td>
<td>Side</td>
<td>No</td>
<td>N=1</td>
</tr>
<tr>
<td>5 Knee valgus angle at initial contact</td>
<td>At the time point of initial contact, draw a line straight down from the center of the patella. If the line goes through the midfoot, score NO. If the line is medial to the midfoot, score YES.</td>
<td>Front</td>
<td>Yes</td>
<td>Y=1</td>
</tr>
<tr>
<td>6 Lateral trunk flexion angle at initial contact</td>
<td>At the time point of initial contact, if the midline of the trunk is flexed to the left or the right side of the body, score YES. If the trunk is not flexed to the left or right side of the body, score NO.</td>
<td>Front</td>
<td>Yes</td>
<td>N=0</td>
</tr>
<tr>
<td>7 Stance width - Wide</td>
<td>Once the entire foot is in contact with the ground, draw a line down from the tip of the shoulders. If the line on the side of the test leg is inside the foot of the test leg then greater than shoulder width (wide), score YES. If the test foot is internally or externally rotated, grade the stance width based on heel placement.</td>
<td>Front</td>
<td>Yes</td>
<td>Y=1</td>
</tr>
<tr>
<td></td>
<td>Description</td>
<td>Side</td>
<td>Front</td>
<td>Y</td>
</tr>
<tr>
<td>---</td>
<td>-----------------------------------------------------------------------------</td>
<td>-------</td>
<td>-------</td>
<td>---</td>
</tr>
<tr>
<td>8</td>
<td>Stance width - Narrow&lt;br&gt;Once the entire foot is in contact with the ground, draw a line down from the tip of the shoulders. If the line on the side of the test leg is outside of the foot then score less than shoulder width (narrow), score YES. If the test foot is internally or externally rotated, grade the stance width based on heel placement.</td>
<td></td>
<td></td>
<td>Y=1</td>
</tr>
<tr>
<td>9</td>
<td>Foot position - Toe In&lt;br&gt;If the foot of the test leg is internally more than 30 degrees between the time period of initial contact and max knee flexion, then score YES. If the foot is not internally rotated more than 30 degrees between the time period of initial contact to max knee flexion, score NO.</td>
<td></td>
<td></td>
<td>Y=1</td>
</tr>
<tr>
<td>10</td>
<td>Foot position - Toe Out&lt;br&gt;If the foot of the test leg is externally rotated more than 30 degrees between the time period of initial contact and max knee flexion, then score YES. If the foot is not externally rotated more than 30 degrees between the time period of initial contact to max knee flexion, score NO.</td>
<td></td>
<td></td>
<td>Y=1</td>
</tr>
<tr>
<td>11</td>
<td>Symmetric initial foot contact&lt;br&gt;If one foot lands before the other or if one foot lands heel to toe and the other lands toe to heel, score NO. If the feet land symmetrically, score YES.</td>
<td></td>
<td></td>
<td>Y=0</td>
</tr>
<tr>
<td>12</td>
<td>Knee flexion displacement&lt;br&gt;If the knee of the test leg flexes more than 45 degrees from initial contact to max knee flexion, score YES. If the knee of the test leg does not flex more than 45 degrees, score NO.</td>
<td>Side</td>
<td></td>
<td>Y=0</td>
</tr>
<tr>
<td>13</td>
<td>Hip flexion at max knee flexion&lt;br&gt;If the thigh of the test leg flexes more on the trunk from initial contact to max knee flexion angle, score YES.</td>
<td>Side</td>
<td></td>
<td>Y=0</td>
</tr>
<tr>
<td>14</td>
<td>Trunk flexion at max knee flexion&lt;br&gt;If the trunk flexes more from the point of initial contact to max knee flexion, score YES. If the trunk does not flex more, score NO.</td>
<td>Side</td>
<td></td>
<td>Y=0</td>
</tr>
<tr>
<td>Item</td>
<td>Description</td>
<td>Measurement</td>
<td>Front</td>
<td>Score</td>
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<tr>
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<td>-------------</td>
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</tr>
<tr>
<td>15</td>
<td>Knee valgus displacement</td>
<td>At the point of max knee valgus on the test leg, draw a line straight down from the center of the patella. If the line runs through the great toe or is medial to the great toe, score YES. If the line is lateral to the great toe, score NO.</td>
<td>Front</td>
<td>Yes</td>
</tr>
<tr>
<td>16</td>
<td>Joint displacement</td>
<td>Watch the sagittal plane motion at the hips and knees from initial contact to max knee flexion angle. If the subject goes through large displacement of the trunk, hips, and knees then score SOFT. If the subject goes through some trunk, hip, and knee displacement but not a large amount, then AVERAGE. If the subject goes through very little, if any trunk, hip, and knee displacement, then STIFF.</td>
<td>Side</td>
<td>Average or Stiff (double penalty for Stiff)</td>
</tr>
<tr>
<td>17</td>
<td>Overall impression</td>
<td>Score EXCELLENT if the subject displays a soft landing and no frontal plane motion at the knee. Score POOR if the subject displays a stiff landing and large frontal plane motion at the knee. All other landings, score AVERAGE.</td>
<td>Side, Front</td>
<td>Average or Poor (double penalty for Poor)</td>
</tr>
</tbody>
</table>

Note: Number and percent of subjects scored positive on each item. For items 1-15, a positive score was defined as an Error on at least 2 of the 3 trials. For items 16 & 17, a positive score was defined as Average on at least 2 of 3 trials or Poor/Stiff on at least 1 of 3 trials.
APPENDIX F: PARTICIPANT RECEIPT OF PAYMENT

REQUEST FOR RESEARCH PARTICIPANT REIMBURSEMENT

Participant Name: _________________________________________________________

ISU ID: 991-____________

Mailing address: __________________________

Phone: __________________________

Email: __________________________

Amount to pay: $5

Date of Completion: __________________________

Index #: __________________________

Research Project Name:

- The Effects of Playing Surfaces on Landing Mechanics During a Jump Rebound-Landing Task

Brief Description of what the Research Subject did:

- The subject arrived to the data collection session. Participants volunteered 45 minutes of their time for this study.

Participant Signature________________________ Date__________________

Principal Investigator Signature________________________ Date__________
### APPENDIX G: RAW DATA

Data Collection LESS Scorings: Vball Court

| Subject ID # | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | Overall |
|-------------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|--------|
| 1           | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 5   |
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|             | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 7   |
| 2           | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 4   |
|             | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 5   |
|             | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 5   |
| 3           | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1   |
|             | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1   |
|             | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1   |
| 4           | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 5   |
|             | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 6   |
|             | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 6   |
| 5           | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 7   |
|             | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 7   |
|             | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 4   |
| 6           | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 4   |
|             | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 3   |
|             | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 4   |
| 7           | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 7   |
|             | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 6   |
|             | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 6   |
| 14          | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 8   |
|             | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 7   |
|             | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 7   |
| 18          | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 7   |
|             | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 6   |
|             | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 5   |
| 26          | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1   |
|             | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1   |
|             | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1   |
| 10          | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 5   |
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|             | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 5   |

69

3.666667

5.666667

4.666667

4.333333

7.333333
|   | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| 16| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
|   | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 2 |
| 17| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 5 |
|   | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 4 |   |   |   | 4 |
| 18| 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 4 | 5 |
|   | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |   |   | 4 |
| 19| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 8 |   | 6 |
|   | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 6 |   | 6 |
| 20| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |   |   | 6 |
|   | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |   | 6 |
| 21| 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 2 | 9 |   |   |   |   |   |   | 9.666667 |
|   | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 2 | 9 |   |   |   |   |   |   | 9.666667 |
| 22| 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 2 | 11 |   |   |   |   |   |   |   |
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|   | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 |   | 6 |
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|   | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 4 |   |   |   | 4.666667 |
| 29| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |   |   |
|   | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |   |   |
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|   | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |   |   |
| 31| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |   |   |
|   | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |   |   |
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1.666667

Error
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5.666667

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6.666667

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6.333333

|   |   |   |   |   |   |   |   |   |   |   |   |   |
|---|---|---|---|---|---|---|---|---|---|---|---|
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6
### Data Collection LESS Scorings - Basketball Court

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<td>0</td>
</tr>
</tbody>
</table>
### Subject Demographics

#### Gender

<table>
<thead>
<tr>
<th></th>
<th>Frequency</th>
<th>Percent</th>
<th>Valid Percent</th>
<th>Cumulative Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valid</td>
<td>18</td>
<td>56.3</td>
<td>56.3</td>
<td>56.3</td>
</tr>
<tr>
<td>Male</td>
<td>14</td>
<td>43.8</td>
<td>43.8</td>
<td>100.0</td>
</tr>
<tr>
<td>Total</td>
<td>32</td>
<td>100.0</td>
<td>100.0</td>
<td></td>
</tr>
</tbody>
</table>

#### Descriptive Statistics

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age in years</td>
<td>32</td>
<td>18</td>
<td>25</td>
<td>20.22</td>
<td>1.879</td>
</tr>
<tr>
<td>Height in cm</td>
<td>32</td>
<td>157.5</td>
<td>193.0</td>
<td>172.134</td>
<td>9.6751</td>
</tr>
<tr>
<td>Weight in kg</td>
<td>32</td>
<td>43</td>
<td>99</td>
<td>71.19</td>
<td>13.679</td>
</tr>
<tr>
<td>Valid N (listwise)</td>
<td>32</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tbody>
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#### Statistics

<table>
<thead>
<tr>
<th></th>
<th>Average of Vball LESS scores</th>
<th>Average of Wood LESS scores</th>
<th>LESS category</th>
<th>LESS category</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>Valid</td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Missing</td>
<td>7</td>
<td>7</td>
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</tbody>
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## Statistics

### Paired Samples Statistics

<table>
<thead>
<tr>
<th>Pair</th>
<th>Measure</th>
<th>Mean</th>
<th>N</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pair 1</td>
<td>Average of Wood LESS scores</td>
<td>6.00</td>
<td>25</td>
<td>1.258</td>
<td>.252</td>
</tr>
<tr>
<td></td>
<td>Average of Vball LESS scores</td>
<td>5.72</td>
<td>25</td>
<td>1.621</td>
<td>.324</td>
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</tbody>
</table>

### Paired Samples Correlations

<table>
<thead>
<tr>
<th>Pair</th>
<th>Measure</th>
<th>N</th>
<th>Correlation</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pair 1</td>
<td>Average of Wood LESS scores &amp; Average of Vball LESS scores</td>
<td>25</td>
<td>.736</td>
<td>.000</td>
</tr>
</tbody>
</table>

### Paired Samples Test

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
<th>95% Confidence Interval of the Difference</th>
<th>t</th>
<th>df</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pair 1</td>
<td>.280</td>
<td>1.100</td>
<td>.320</td>
<td>-1.74</td>
<td>1.273</td>
<td>24</td>
<td>.215</td>
</tr>
<tr>
<td></td>
<td>Average of Wood LESS scores - Average of Vball LESS scores</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>