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Using the Landing Error Scoring System (LESS) to Predict the Risk of Lower Extremity Injuries in Athletes

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Department of Physical Therapy

School of Medicine

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Doctor of Physical Therapy

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This Scholarly Project, submitted by Marit Mikkelsen, Anthony Peterson, and Travis Rinkenberger in partial fulfillment of the requirements for the Degree of Doctor of Physical Therapy from the University of North Dakota, has been read by the Advisor and Chairperson of Physical Therapy under whom the work has been done and is hereby approved.

Gary Schindler, PT, PhD, OCS, SCS, LATC, CSCS

David Relling, PT, PhD, Department Chair

PERMISSION

Title: Using the landing error scoring system (LESS) to predict the risk of lower extremity injuries in athletes.

Department: Physical Therapy

Degree: Doctor of Physical Therapy

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Abstract

Introduction: Athletes that participate in any sport are at an increased risk of injury, especially lower extremity injury. In particular, many athletes experience anterior cruciate ligament (ACL) injury during competition and practice sessions. The Landing Error Scoring System (LESS) is a tool used to identify athletes with a higher potential risk for ACL injury.

Purpose: The purpose of this study is to compare vertical jump landing mechanics between genders and among various sports.

Methods: Forty-one participants (21 females, 20 males) were recruited from a NCAA Division I university. Participants were from the following sports: football, volleyball, women's soccer, and men's and women's basketball. Each participant had 18 markers placed on their bilateral (B) acromion, (B) greater trochanter, (B) mid-patella, (B) lateral knee joint line, (B) lateral malleoli, (B) posterior calcaneus, (B) base of 5th metatarsal, (B) 2nd MTP joint, and C7/L4 spinous processes. The VICON Motion Capture system was used to track joint angle displacement of a jump-landing task to identify at-risk landing mechanics. The jump-landing task was performed per the protocol of the LESS: participants jumped off a 30 cm box and landed at a distance of half of their height in front of the box; participants then immediately jumped vertically as high as they could and then landed. Participants were allowed two practice trials prior to three recorded trials.

Results: Four things were found to be significant when comparing between genders. Males had more trunk flexion at initial contact. Females had greater hip flexion at initial contact, medial knee position, and medial knee displacement. When comparing between female sports three things were found to be significant. Soccer had significantly less trunk flexion at initial contact compared to volleyball and basketball. Soccer had significantly more knee flexion displacement compared to volleyball. Volleyball had significantly less hip flexion displacement than both soccer and basketball. Comparing males sports one item was found to be significant. Basketball and significantly less knee flexion at initial contact than football.

Conclusion: The differences of jump mechanics found between genders may place females at a larger risk of sustaining a lower extremity injury compared to males. Soccer players were also seen to show the greatest risk of ACL injury compared to women's basketball and volleyball players. Men's basketball showed a greater risk of ACL injury compared to football. Future studies would benefit from recruiting a larger number of athletes to utilize the LESS in scoring athletes' risk of sustaining a lower extremity injury.

Chapter I

Introduction

Lower extremity injuries are a significant reason for missing playing time in collegiate athletics. An ACL injury leads to significant time away from play and requires a long recovery period. If athletes can be identified as being at-risk for an ACL injury, the likelihood of injury can be reduced via methods of prevention with strength and coordination training.

The Landing Error Scoring System (LESS) is a tool used to identify athletes with a higher potential risk for ACL injury. The LESS measures 17 items that correspond to body biomechanics at various points throughout a jump-landing task. The items are as follows: knee flexion, hip flexion, trunk flexion, ankle plantar flexion, medial knee position, and lateral trunk flexion at initial contact; wide or narrow stance width at initial contact; internal or external rotation of the foot between initial contact and maximum knee flexion; whether or not the feet contact the ground at the same time; knee flexion, hip flexion, trunk flexion, medial knee, and joint displacement; and overall impression of the jump-landing task.[1]

In terms of movement dysfunction during jump-landing tasks, males typically exhibit more errors in the sagittal plane while females exhibit more errors in the frontal plane.[2] Furthermore, females show greater ACL injury rates than males (1.6 per 1000 athlete exposures and 1.3 per 1000 athlete exposures in soccer, respectively; 1.0 per 1000 athlete exposures and 0.7 per 1000 athlete exposures in basketball, respectively).[3] ACL injuries typically occur due to movement errors in the frontal plane[4] with landing mechanics being a major contributor to non-contact ACL injury.[4] Jump-landing knee valgus has been shown to be a risk factor due to extra stress on the ACL.[5] The LESS identifies certain items which may place an individual at increased risk for an ACL injury.. These items include trunk-flexion displacement, hip-flexion displacement, joint displacement, trunk flexion at initial contact, foot position in external rotation, and knee-flexion displacement identified the greatest potential risk of ACL injury.[1] It is important to also recognize that while the LESS is able to separate athletes into high- and low-risk groups for potential ACL injury, it is unable to predict exactly who will or will not suffer an ACL injury.[1] With the use of the VICON system to capture joint motion, this study hopes to relate joint biomechanics to ACL injury among Division I athletes.

The purpose of this study is to compare vertical jump-landing mechanics between genders and among sports of the same gender. The VICON Motion Capture system is used to obtain more accurate joint measurements. The overall goal is to repeat this testing on a yearly basis to identify at-risk athletes throughout their playing careers. If at-risk athletes can be identified early, each athlete can receive a personalized training program to prevent ACL injury.

Chapter II

Background

Athletes may experience a wide array of injuries throughout their playing careers, but many strength and conditioning programs focus on prevention of ACL injury or stress fractures of the lower extremity. In addition, athletes may experience higher incidence or earlier onset of knee osteoarthritis in life due to previous ACL injury.

This section will analyze lower extremity (LE) biomechanics during drop jump activities. The trunk, hip, knee, and ankle are all moving parts during this task. The potential for an athlete to injure their ACL is not only due to joint biomechanics of their knees. Any joint angle displacement of high magnitude, or lack thereof, of the trunk, hips, knees, or ankles could put an athlete at risk for injuring their ACL during competition.

This research will investigate body and joint positions during initial ground contact while examining maximal displacement. By comparing the participants' biomechanics and contact position to each other, we may be able to predict which participants may be more predisposed to injuries.

Biomechanics of the Lower Extremity

Trunk Motion

Evidence has suggested that trunk stabilization may improve lower extremity control. Haddasetal[6] investigated the relationship between volitional preemptive abdominal contraction (VPAC) during a drop vertical jump test and how it alters lower extremity biomechanics. VPAC is used to increase trunk-muscle activation, increase lumbar spine stability, and reduce pelvic motion. This strategy is thought to alter lower extremity neuromuscular control and improve pelvic stability.[7] This improved pelvic stability may increase abduction and external rotation control of the hip which may have an effect on knee valgus.[7] Their results partially supported their hypothesis of VPAC improving neuromuscular and biomechanical control and decreasing risk of ACL injury. The trunk muscles must be recruited during the landing phase to control trunk momentum and increase intra-abdominal pressure which in turn improves spinal stability.[8]

Hip Motion

Excessive frontal plane motion at the hip can be a factor in developing both traumatic and chronic injuries at the knee.[9] Limitations in available range of motion can also influence motion at the joints below the hip. During a drop landing task, athletes with limitations in external rotation at the hip accounted for 16.3% of the cause of knee valgus motion.[9] Furthermore, this may place athletes in a more internally rotated position at the point of initial contact, increasing their risk of injury. When examining the hip abductor strength, hip strength demonstrated no correlation with the amount of knee excursion during the drop landing task.[9]

Knee Motion

A study conducted by Leppanen et al[10] found having a greater knee flexion-extension moment during a vertical drop jump test is associated with an increased risk of ACL injury in young female athletes.[10] Participants who landed with a higher peak external knee flexion moment were at an increased risk of sustaining an ACL injury compared to individuals with lower knee moments. This supports the current evidence that sagittal plane knee biomechanics have an influence on risk of ACL injuries. The athletes who injured their ACLs had higher peak external knee flexion moments which suggests they likely had increased quadriceps forces. Research conveys that the quadriceps muscles are able to produce significant ACL loading, especially at low knee flexion angles.[10] In addition, reduced hamstring muscle activation during landing reduced dynamic joint stability. Impaired muscle activation during landing may cause anterior tibial shear forces. Anterior tibial translation is a result from large joint-compression and shear forces. These forces are produced when an athlete lands at initial contact with reduced knee flexion between 0-30 degrees.[6]

Ankle Motion

Limitations in ankle dorsiflexion may cause compensations among multiple joints. A study by Sigward et al[9] found limited dorsiflexion accounted for 10.8% of the variance in knee motion during a vertical drop landing task. Limited ankle ROM during landing may lead to less absorption of ground-reaction forces which may ultimately be transmitted to the knee.[10] Increased available ankle dorsiflexion ROM was associated with smaller ground reaction forces and more knee-flexion displacement during a drop jump task, which reduce forces applied to the ACL.[11] In addition, Hagins et al[12] found that restricting dorsiflexion by landing on an anterior inclined surface increased knee valgus compared to landing on a flat surface. Devita and Skelly [13] examined joint angles and ground reaction forces during a landing task with a soft landing and a stiff landing. During the soft landing, the participants made initial contact with their ankles in five degrees more dorsiflexion compared to when they did a stiff landing. Stiff landing during the drop required 14% more work from the ankle plantarflexor muscles compared to the soft landing.[13] Furthermore, there was less work from knee and hip extensors increased ground reaction forces by 23% during stiff landing.[13]

Landing Error Scoring System

The Landing Error Scoring System was developed to determine individuals who may have high-risk of injuries during a drop jump task. The LESS examines 17 different criteria with 2-dimensional video assessment. The criteria are as follows: knee flexion, hip flexion, trunk flexion, ankle plantar flexion, medial knee position, and lateral trunk flexion at initial contact; wide or narrow stance width at initial contact; internal or external rotation of the foot between initial contact and maximum knee flexion; whether or not the feet contact the ground at the same time; knee flexion, hip flexion, trunk flexion, medial knee, and joint displacement; and overall impression of the jump-landing task.[1] When compared to 3-dimensional motion analysis, the LESS has proven to be valid, as well as having good inter- and intrarater reliability.[14-17] Scoring for the LESS is divided into four categories: excellent (≤4), good (>4 to ≤5), moderate (>5 to ≤6), and poor (>6).[16] Using the LESS allows for reliable identification of individuals with movement patterns at risk for an ACL injury, however, the LESS is unable to predict ACL injury.[18] Researchers demonstrated that athletes with a LESS score of 5+ had a risk ratio of 10.7 compared to athletes who scored <5, however, LESS was unable to identify specific athletes that would get injured.[1]

Injuries of the Lower Extremity

Anterior Cruciate Ligament Tear

Anterior cruciate ligament injuries can be disabling, costly, and require a lengthy rehabilitation process. In addition, ACL injuries have been associated with increased risk of developing knee osteoarthritis as one ages.[19] It is estimated that as many as 80,000-250,000 ACL injuries occur each year, in which many of these individuals are young athletes.[19] Certain lower extremity movements have been associated with ACL injuries and have been identified using the drop vertical jump test. These movements include increased valgus or abduction angle at the knee, increased intersegmental abduction moment at the knee, greater ground-reaction force, shorter stance time, lower activation of the semitendinosus muscle, and increased activation of the vastus lateralis muscle.[19] The ACL is more prone to injury when the hip is adducted and internally rotated in combination with knee valgus and flexion.[4]

Following ACL reconstruction, researchers identified athletes as having a 12-26% chance of re-tearing their ACL. Re-tearing of the ACL can occur to the ipsilateral or contralateral ACL.[17] Athletes that were evaluated with the LESS after an ACL reconstruction after being cleared to return to sport averaged a score of 6.7. A score greater than 6 puts the participant in the poor category and at higher risk for an ACL injury.[18] Scoring for the LESS is divided into four categories: excellent (≤4), good (>4 to ≤5), moderate (>5 to ≤6), and poor (>6).[16] After examining the frequency of errors made by those with an ACL reconstruction, 63% had lateral trunk flexion error. Of those that had lateral trunk lean, 88% leaned to the contralateral limb.[17] This forces the uninvolved limb to handle larger ground reaction forces. When the uninvolved side is required to do a greater proportion of work, fatigue can occur and place the uninvolved limb at higher risk for a lower extremity injury.[20] Lateral trunk flexion was not gender specific and could be more specific to anterior cruciate ligament reconstruction (ACLR) populations.[17]

Lower Extremity Stress Fractures

The LESS has also been used to determine the incidence rate of lower extremity stress fractures. A study by Cameron et al[21] investigated the jumping mechanics of 1772 subjects at the US Service Academy with no prior history of lower extremity stress fractures. They used the LESS to record their baseline jumping mechanic motion analysis. They used a follow-up period of four years. During this period, there were incidences of 94 lower-extremity stress fractures. For every additional movement error recorded at baseline there was a 15% increase in the incidence rate of lower extremity stress fractures. Ankle flexion, stance width, asymmetrical landing, and trunk flexion all at initial contact along with overall impression were significantly correlated with the incidence rate of stress fractures. They also found a correlation with participants who landed flat-footed or heel-to-toe to have a 2.33 times more likely to sustain a stress fracture. Individuals who consistently showed asymmetric landing at initial contact were at a 2.53 times higher risk of sustaining a stress fracture. This study illustrated how the LESS may be helpful in predicting the risk of an individual sustaining a lower extremity stress fracture during jump landing.[21]

Knee Osteoarthritis

An important factor to address is whether or not people who sustain an ACL injury are predisposed to future knee problems. As knee osteoarthritis affects many people as they age, research has been conducted to determine whether or not people are more likely to endure knee osteoarthritis if they previously injured their ACL. According to Suter et al [22] people who suffer an ACL injury before 25 years of age have a greater risk of developing an earlier onset of osteoarthritis in the affected knee. The ability to prevent ACL injuries would consequently reduce the incidence of knee osteoarthritis in these patients. The ability to use the LESS to address an athlete's risk level of ACL injury is an important factor in injury prevention strategies.

Chinzei et al [23] investigated the means by which ACL injury affects incidence of osteoarthritis on a molecular basis. Chinzei et al [23] found ACL injuries may affect chondrocyte homeostasis, which may lead to changes in cartilage at the cellular level.[23] These changes in the cartilage imply that ACL damage may increase the likelihood of osteoarthritis development.

Suter et al [22] completed a meta-analysis of 4,108 patients to determine the rate of osteoarthritis development following ACL reconstruction surgery. Twenty-years following the surgery, the model-estimated proportion of patients with knee osteoarthritis was an average of 51.6%.[22] In addition, chronic ACL injuries and higher age of patients at the time of surgical repair, identified greater chances of developing knee osteoarthritis.[22] Therefore, even with surgical repair to the ACL, there may still be a high risk for developing knee osteoarthritis later on in patients' lives.

Motion Analysis

VICON System

The VICON motion capture has been viewed as a gold standard for analyzing movements, and it was found that the VICON system served to be more reliable than a 3D motion capture system in a research setting.[24] When compared to the VICON, it is possible that other systems are not as reliable due to the fact that they work on a different basis than the VICON system, as shown with some statistical differences in the measurement of various kinematic variables.[24]

One particular study assessed intrarater and interrater reliability of marker placement while utilizing the VICON system, and it was determined that there was better intrarater reliability than interrater reliability with use of the VICON system.[25] This is an important finding, as it implies that there is more reliability with the use of only one rater to place markers on participants when using the VICON.

It is also to be noted that when using the VICON system, certain recording parameters were found to be more efficient than others. One of these parameters includes the use of large markers (25mm) without lens filters during marker placement to increase the precision and accuracy of the motion capturing performance.[26]

LESS Motion Recording Technology

A hallmark of the LESS is that it is a tool that is designed to be quick and easy to use, while also being inexpensive compared to more advanced technology like the VICON system. The standard of the LESS is to use two video cameras, one positioned to record frontal plane motions and the other to record sagittal plane motions.[27] One study found that validity of the LESS compared to 3D motion capture systems was dependent on which item of the LESS was being analyzed.[14] ACL injuries can happen in a matter of milliseconds, which can be difficult to assess with the naked eye or even 2D video data; consequently, validity levels can be different depending on the LESS item that is being scored.[14] This same study addressed the interrater reliability between novice and expert athletic trainers in scoring the LESS and found that there was excellent reliability between raters for overall LESS scores.[14]

In addition to utilizing two cameras with views of the frontal and sagittal planes to assess jump-landing body mechanics for the LESS, one study found that the use of an iPad with an app that assesses biomechanics had excellent within-session and good-to- excellent between-session intertrial reliability that is consistent with past research.[28] In addition, It when accounting for experience level, interrater reliability of the LESS was strong, with standard errors of measurement of less than 2° between raters.[28]

Ortiz et al[29] identified two different methods of 2-dimensional measures of frontal plane kinematics that correlated well with 3-dimensional motion analysis during a vertical drop jump task to measure dynamic knee valgus. The Knee-to-Ankle Separation Ratio (KASR) was measured with reflective markers on the lateral femoral epicondyles and on the lateral malleoli. To calculate this ratio, the horizontal distance between the epicondyles was divided by the horizontal distance between the malleoli. A ratio of 1.0 indicates the knees are in line with the ankles. A ratio of less than 1.0 indicates a knee valgus position, and more than 1.0 indicates a knee varus position. The KASR had excellent correlation (ICC=0.96) with 3D motion analysis and excellent inter- and intrarater reliability (>0.96). The Knee Separation Distance (KSD) measured the distance between the lateral femoral epicondyles during two different points during the landing phase, one at initial contact and at maximal knee flexion during ground contact. The KSD was the difference between peak flexion and initial contact. Negative values represented knee valgus and positive values represented knee varus. The KSD had excellent correlation (ICC=0.96) with 3D motion analysis.[29]

Chapter III

Methods

Participants

Participants were athletes from a NCAA Division I school. The athletes were recruited from volleyball, men's and women's basketball, women's soccer, and football teams via emailing coaches and strength coaches for the involved sports. Inclusion criteria consisted of being an athlete for men's or women's basketball, volleyball, football, and women's soccer. Exclusion criteria consisted of previous lower extremity surgery. Forty-one participants (FB = 12, MBB = 8, WBB = 3, VB = 12, Soccer = 6) took part in the study. The participants consisted of 21 females and 20 males with a mean age of 19.68 years old (± 1.3 SD).

Procedure

All participants reviewed and signed an informed consent (Appendix A). Informed consent consisted of informing the athletes about completing the jump-landing task, tracking the athletes through their athletic career to keep track of any ACL injuries, discussing confidentiality of participant information, and obtaining relevant information to create unique participant ID number (mother's birth date and last three digits of their home ZIP code). Participants arrived and had VICON markers placed on various points on their body (Figure 1). All markers were applied to participants by the same researcher, an experienced physical therapist, to ensure for consistent methods of locating and placing markers on bony landmarks. 18 VICON sensors were utilized (bilateral (B) acromion, (B) greater trochanter, (B) mid-patella, (B) lateral knee joint line, (B) lateral malleoli, (B) posterior calcaneus, (B) base of 5th metatarsal, (B) 2nd MTP joint, and C7/L4 spinous processes). All sensors were applied directly to skin and/or spandex clothing was worn to avoid interference with the sensors. Following marker placement, the participants were instructed on the task and were allowed two practice trials followed by three recorded trials. The participants jumped from a 30 cm box onto a designated spot that was half of the participant's height in front of the box. Following landing, the participants immediately performed a maximum vertical jump. Sensors were then removed with trials being coded and scored at a later date.

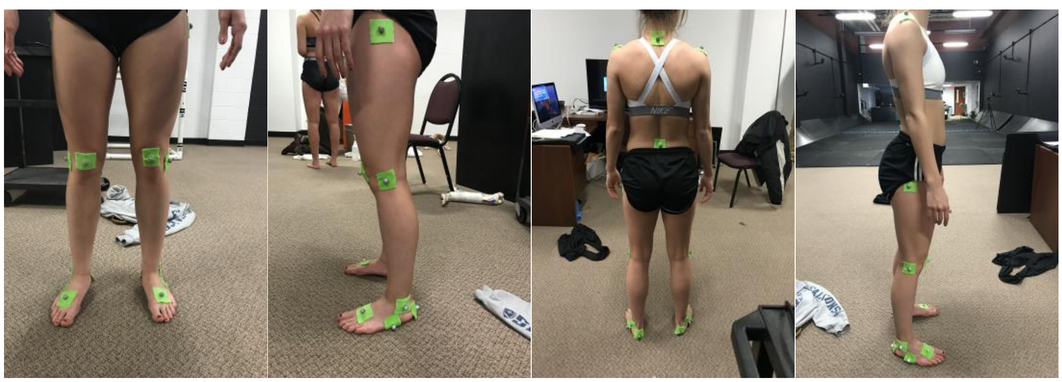

Figure 1. VICON Marker Placement

Sensors were applied to the participant's acromions, spinous process of C7 and L4, greater trochanters, patellas, lateral knee joint line, lateral malleolus, posterior calcaneus, base of 5th metatarsal, and head of 2nd metatarsal.

LESS

The LESS has 17 scored items that are used to examine the landing in the frontal and sagittal planes. Nine variables were examined: 1) Knee flexion at initial contact (IC), 2) Hip flexion at IC, 3) Trunk flexion at IC, 4) Ankle plantar flexion at IC, 5) Medial knee position at IC 6) Knee flexion displacement (DSP), 7) Hip flexion DSP, 8) Trunk flexion DSP, and 9) Medial knee DSP. The score indicates the number of errors identified during the landing task. A higher score indicates more errors made and poorer jump-landing technique. The LESS has good interrater reliability with an ICC value of 0.84 and has excellent intrarater reliability with an ICC value of 0.91.[16]

Instrumentation

Aerial Performance Analysis System, VICON Nexus

VICON, a video analysis software, was utilized in this study to assess a jump-landing task. This system uses a series of 10 cameras that record infrared data from sensors placed on the subject to determine joint positions during the jump-landing task.

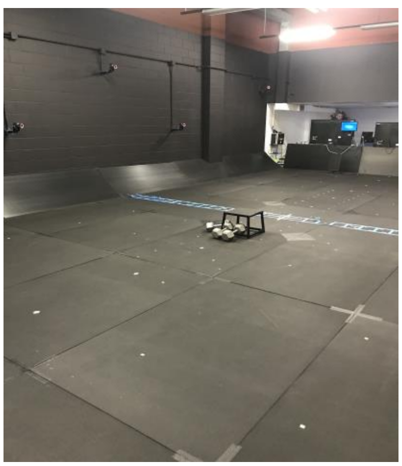

Figure 2. A 30 cm tall box that was positioned approximately half of the participants behind the designated landing area.

Data Collection and Statistical Analysis

Data was extracted by one researcher using the VICON system for analysis. This was to ensure consistent data collection throughout the entire process. T-tests were used to examine the differences regarding the nine variables mentioned in the LESS section between men and women and between FB and MBB. ANOVA tests were used to analyze for differences among three female sports (VB, WBB, and women's soccer.

Chapter IV

Results

This study consisted of 41 athletes (20 male, 21 female). The sports represented were women's soccer (n=6), women's volleyball (n=12), women's basketball (n=3), men's football (n=12), and men's basketball (n=8). Of the athletes represented, 19 were freshmen, 9 were sophomores, 10 were juniors, and 3 were seniors. The height of the athletes ranged from 63 inches to 80 inches. The age ranged from 18 years to 23 years. Of the athletes that participated in the study, 4 had previous surgery and 37 did not previously have surgery. The VICON analysis data was analyzed by the Statistical Package for Social Sciences (SPSS) with an independent t-test to determine biomechanical differences between gender and between male sports (MBB and FB) In addition, ANOVA tests were used to determine differences among female sports (WBB, VB, and Women's Soccer). Both analyses were completed during a vertical jump-landing task per the setup of the LESS.

Between-Gender Differences

When analyzing the joint biomechanics during the drop jump task between male and female athletes, four categories were found to be statistically significant. Statistically significant results included 1) females (50.6°) having had greater hip flexion at initial contact than males (45.7°, $p<0.015$), 2)females (87.7°) having had greater medial knee displacement than males ((58.0°, $p<0.007$), 3) females (59.6°) having had greater medial knee position (30.1°, $p<0.002$), and 4) males (70.5°) having had greater trunk flexion at initial contact than females (66.0°, p<0.030). refer to Table 1 for differences between gender.

Table 1. Significant differences found between genders.

Between Gender Difference	Female	Male	Significance
Hip Flexion at IC	50.6	45.7	0.015
Medial Knee Displacement	87.7	58	0.007
Medial Knee Position	59.6	30.1	0.002
Trunk Flexion at IC	66	70.5	0.03

When comparing the hip flexion at initial contact values to the scoring criteria on the LESS, zero participants scored in the abnormal category. Medial knee displacement values compared to the scoring criteria on the LESS identified forty participants whom would have scored abnormal according to the LESS standards. Comparing medial knee position values to the scoring criteria on the LESS, thirty-eight of the participants would have scored abnormal. These results are of importance because a majority of the athletes' medial knee position values were in the abnormal range, so the VICON Motion Capture system may yield too precise of results to be used in conjunction with the LESS. Values of trunk flexion at initial contact to the scoring criteria on the LESS, zero of the participants were in the abnormal category.

Differences Among Sports

Women's sports that took part in this study were soccer, volleyball, and basketball. There was a statistically significant difference in trunk flexion degrees between soccer and volleyball (mean 62.0° and 67.7°, respectively) with a significance level of p<.006. In addition, significant differences were found between soccer (62.0°) and basketball (mean

(67.7°,p<.039). However, no significant differences were found between volleyball and basketball. Furthermore, there were statistically significant differences in knee flexion displacement between soccer and volleyball (mean 30.7° and 21.6°) with a significance level of p<.034. However, no significant difference were noted between soccer and basketball or basketball and volleyball. Regarding hip flexion displacement, there were significant differences between volleyball (4.8°) and soccer (16.2°), with a significance level of p<.000 and volleyball (4.8°) and basketball (12.3°) with a significance level of p<.039. However, there was no significant difference between soccer and basketball. Finally, there were no significant differences among women's soccer, volleyball, and basketball in the categories of knee flexion, hip flexion, ankle plantarflexion, medial knee position, trunk flexion displacement, and medial knee displacement(see Table 2).

Table 2. Significant differences found between female sports

Between Sport Differences	Soccer	Volleyball	Basketball	Significance
Trunk Flexion at IC	62°	67.7°		0.006
Trunk Flexion at IC	62°		67.7°	0.039
Knee Flexion Displacement	30.7°	21.6°		0.034
Hip Flexion Displacement	16.2°	4.8°		0.000
Hip Flexion Displacement		4.8°	12.3°	0.000

When investigating MBB and FB a significant difference was noted. A significant increase was identified with knee flexion in FB athletes (65.9°) compared to MBB athletes (57.1°). No statistically significant differences were found between men's basketball and football in the categories of hip flexion, trunk flexion, ankle plantarflexion, medial knee position, knee flexion displacement, hip flexion displacement, trunk flexion displacement, and medical knee displacement were assessed (see Table 3).

Table 3. Significant differences found between male sports.

Between Sport Differences	Basketball	Football	Significance
Knee Flexion at IC	57.1°	65.9°	0.004

Even though there were significant differences between genders and among sports, some of these significant values would not be scored abnormally on the LESS, while some of the values would be. It is important to differentiate between abnormal scores of the LESS versus statistical significance of the VICON system in practical application of working with athletes.

Chapter V

Discussion

Conclusion

The purpose of this study is to compare vertical jump landing mechanics between genders and sports of the same gender. Biomechanical risk factors for noncontact ACL injury are multiplanar in nature, and clinical assessment of jump-landing biomechanics should reflect this fact. Four categories were found to be significant when comparing genders. Females were found to have significantly greater hip flexion at initial contact, medial knee displacement, and medial knee position. Males were found to have significantly more trunk flexion at initial contact. These findings may place females at a greatest risk for sustaining ACL injuries compared to males.

When comparing female athletics, there was a significant difference for trunk flexion between soccer and volleyball and between soccer and basketball, with soccer having statistically less trunk flexion displacement than both volleyball and basketball. Knee flexion displacement was significantly greater in soccer players than in volleyball players. Hip flexion displacement was also significantly less for volleyball players than soccer players, as well as significantly less for volleyball players than basketball players. Men's sports only saw one significant difference; knee flexion displacement between football and basketball, where basketball players showed less knee flexion displacement than football players.

Limitations

This study was limited by the small number of participants. The results of this study would be more consistent and applicable with a greater pool of participants for each gender and across sports. For instance, women's basketball only had three participants, which limited the ability to interpret the data and apply it to female basketball players, as this small number of participants compared to soccer (n=6) and volleyball (n=12) could have skewed the results. Another limitation of the study is that three athletes with previous lower extremity surgery participated in the study, which was part of the exclusion criteria. With previous lower extremity injury and surgery, these athletes may be more susceptible to future injury, which can contribute to inaccurate results.

Recommendations for Future Research

Future studies may benefit and have more relevance with a larger group of subjects from various athletic teams. One goal would be to recruit at least half of the athletes from each athletic team, wherein the sport involves contact or jump-landing tasks. This could provide a better framework of the sports that may experience more frequent ACL injuries and the possible mechanisms of those injuries. Following the creation of such a framework, strength and conditioning coaches could better equip athletes to handle the stresses of their sports by tailoring their strength programs to better prevent injury. Future studies should also ensure that inclusion and exclusion criteria is followed closely to prevent any skewing of data, as mentioned in the limitations.

Appendix A.

Participant Consent Form

THE UNIVERSITY OF NORTH DAKOTA
CONSENT TO PARTICIPATE IN RESEARCH

TITLE: *Using the Landing Error Scoring System (LESS) to Predict the Risk of Lower Extremity Injuries in Athletes*

PROJECT DIRECTOR: *Gary Schindler*

PHONE # *701-777-6081*

DEPARTMENT: *Physical Therapy*

STATEMENT OF RESEARCH

A person who is to participate in the research must give his or her informed consent to such participation. This consent must be based on an understanding of the nature and risks of the research. This document provides information that is important for this understanding. Research projects include only subjects who choose to take part. Please take your time in making your decision as to whether to participate. If you have questions at any time, please ask.

WHAT IS THE PURPOSE OF THIS STUDY?

You are invited to be in a research study that is interested in investigating how the Landing Error Scoring System (LESS) may vary among collegiate athletes and how it may correlate to a predisposed increase in chance of injury. The primary investigators will be working closely with UND's Department of Sports Medicine and the individual sport's Certified Athletic Trainers. Movement patterns are important and modifiable factors that may influence the risk of ACL and other serious lower extremity injuries. Movement screening may be used for non-contact injury prediction and to guide injury prevention programs. This research may assist in selecting training programs to best compliment the need of the athlete based on their movement screen while improving movement patterns to reduce the risk of injury. This study will hopefully identify players at high risk of lower extremity (LE) injury using a standardized tool for detecting the presence of multiple high-risk movement patterns. The LESS is an inexpensive and quick standardized test to screen for high-risk movement patterns during landing and jumping movements. This study aims to investigate differences in LESS scores to determine potential risk of injury. Injuries will be communicated to the primary investigator via the team's athletic trainer during the year in order to investigate to LESS score with the type of injury to determine if certain scores correlate with injury. Only injuries occurring following your baseline LESS score will be listed. No specific information or further medical information will be requested or needed. You have been identified as a potential participant because you are collegiate athlete at the University of North Dakota and meet this study's inclusion criterion.

Approval Date: NOV 13 2017
Expiration Date: OCT 19 2018
University of North Dakota IRB

Date: __________
Subject Initials: __________

The purpose of this research study is to investigate the LESS scores and to assist in identifying players at high risk of lower extremity (LE) injury using a standardized tool for detecting the presence of multiple high-risk movement patterns.

HOW MANY PEOPLE WILL PARTICIPATE?

A minimum of 30 participants will be take part in this study at the University of North Dakota. Each participant will complete a one-time jumping analysis. Data collected will include two practice jumps and three test jumps from a 30 cm box. Participants will be instructed to land on a designated spot that is half of the individual's height away from the starting position and will perform a maximal vertical jump upon landing. Prior to jumping the participant will complete a 3 minute warm-up include dynamic stretching. The APAS and video camera will assess multiple joint and angles. These include: knee flexion, hip flexion, trunk flexion, ankle plantar flexion, medial knee position, lateral trunk flexion, stance width, foot position, initial foot contact symmetry, knee flexion /hip flexion/trunk flexion and medial knee and joint displacement. Following the warm-up the practice and test jumps will be completed. The jumps should take only approximately 3-5 minutes to complete. Research will take place in the performance laboratory at the University of North Dakota Department of Kinesiology.

HOW LONG WILL I BE IN THIS STUDY?

Your participation in the study a one-time data collection which will take approximately 10-15 minutes for sensor placement, warm-up, and practice/test jumps. Jumps will be video taped and researches will utilize the Aerial Performance Analysis System (APAS) to calculate accurate and valid joint movements and angles.

WHAT WILL HAPPEN DURING THIS STUDY?

Those who choose to participate will be screened to determine qualification to participate in the study according to the inclusion criteria which includes: no previous lower extremity surgery. If you are included in this research, this study will include a one-time data collection which will take approximately 10-15 minutes. A dynamic warm-up will take place followed by sensor placement. Participants will then complete two practice jumps from a 30 cm box followed by three test jumps. The participant will be asked to jump as high as possible when landing on the ground. APAS will be used as well as a video camera to capture the changes in joint angle and alignment. No personal identifications are used on any written document and all descriptions of participants are anonymous. By signing this consent form, you give the primary investigators permission to obtain information regarding any lower extremity injury which may occur that creates a loss of participation (loss of practice, playing, or strength/conditioning time).

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WHAT ARE THE RISKS OF THE STUDY?

There are no foreseeable risks of physical, emotional, or financial risks to the participants with this study; however, since physical activity is taking place there may be a chance of muscle strains, fatigue, delayed onset muscle soreness (DOMS), or a general pain response, but minimal risk is anticipated. A certified athletic trainer, licensed physical therapist, sports/orthopedic specialist, and certified strength and conditioning specialist will be on site for all training sessions to answer any questions and to direct activity progression to limit adverse reactions. If adverse reactions occur the participant will be evaluated by the primary investigator and will be referred for further medical evaluation if deemed necessary.

WHAT ARE THE BENEFITS OF THIS STUDY?

Each participant may not benefit personally from being in this study. However, we hope that, in the future, other people might benefit because a better understanding of how landing may contribute to injuries and how biomechanically different certain sports may differ from each other. By understanding how the participants LESS scores may predispose them to future injuries may change the direction of overall strengthening procedures and activities that will overall hopefully reduce the risk of injury. Therefore, possible modifications could be made during physical therapy treatment and strength and conditioning that will improve function and pain levels. Furthermore, movement patterns are important and modifiable factors that may influence the risk of ACL and other serious lower extremity injuries. Movement screening may be used for non-contact injury prediction and to guide injury prevention programs. This research may assist in selecting training programs to best compliment the need of the athlete based on their movement screen while improving movement patterns to reduce the risk of injury. This study will hopefully identify players at high risk of lower extremity (LE) injury using a standardized tool for detecting the presence of multiple high-risk movement patterns. The LESS is an inexpensive and quick standardized test to screen for high-risk movement patterns during landing and jumping movements. This research may lead to alterations in exercise training that may lead to less future injuries.

WILL IT COST ME ANYTHING TO BE IN THIS STUDY?

You will not have any costs for participating in this research study.

WILL I BE PAID FOR PARTICIPATING?

You will not be paid for participating in this research study.

WHO IS FUNDING THE STUDY?

Approval Date: NOV 13 2017
Expiration Date: OCT 19 2018
University of North Dakota IRB

Date: __________
Subject Initials: _________

No funding is needed for this study. The University of North Dakota and the research team are receiving no payments from any agencies, organizations, or companies to conduct this research study.

CONFIDENTIALITY

The records of this study will be kept private to the extent permitted by law. In any report about this study that might be published, you will not be identified. Your study record may be reviewed by Government agencies, the UND Research Development and Compliance office, and the University of North Dakota Institutional Review Board.

Any information that is obtained in 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. You should know, however, that there are some circumstances in which we may have to show your information to other people. For example, the law may require us to show your information to a court or to tell authorities if we believe you have abused a child, or you pose a danger to yourself or someone else. Confidentiality will be maintained with anonymous surveys conducted. All data collections will be kept anonymous by means of a 5-digit code that will include the participant's mother's or father's day of birth and the last three digits of their zip code while in high school. Consent forms will be kept in a locked and secure location for a minimum of three years, with only Gary Schindler having access to the consent forms and personal data.

If we write a report or article about this study, we will describe the study results in a summarized manner so that you cannot be identified.

IS THIS STUDY VOLUNTARY?

Your participation is voluntary. You may choose not to participate or you may discontinue your participation at any time without penalty or loss of benefits to which you are otherwise entitled. Your decision whether or not to participate will not affect your current or future relations with the University of North Dakota.

If you decide to leave the study early, we ask that you inform Gary Schindler that you would like to withdraw.

CONTACTS AND QUESTIONS?

Approval Date: NOV 13 2017
Expiration Date: OCT 19 2018
University of North Dakota IRB

Date: ________
Subject Initials: ________

The researchers conducting this study are Gary Schindler. You may ask any questions you have now. If you later have questions, concerns, or complaints about the research please contact Gary Schindler at 701-777-6081 or at gary.schindler@med.und.edu.

If you have questions regarding your rights as a research subject, you may contact The University of North Dakota Institutional Review Board at **(701) 777-4279** or **UND.irb@research.UND.edu.**

- You may also call this number about any problems, complaints, or concerns you have about this research study.
- You may also call this number if you cannot reach research staff, or you wish to talk with someone who is independent of the research team.
- General information about being a research subject can be found by clicking "Information for Research Participants" on the web site: http://und.edu/research/resources/human-subjects/research-participants.cfm

Your signature indicates that this research study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You will receive a copy of this form.

Subjects Name: ____

___________________________ ________________

Signature of Subject Date

I have discussed the above points with the subject or, where appropriate, with the subject's legally authorized representative.

___________________________ ________________

Signature of Person Who Obtained Consent Date

Approval Date: NOV 13 2017
Expiration Date: OCT 19 2018
University of North Dakota IRB

Date: ________
Subject Initials: ________

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