5-2019

HOW VERBAL INSTRUCTIONS AFFECT THE SUCCESS IN LEARNING A NEW LANDING TECHNIQUE AND REDUCING RISK FACTORS FOR ACL INJURY

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HOW VERBAL INSTRUCTIONS AFFECT THE SUCCESS IN LEARNING A NEW LANDING TECHNIQUE AND REDUCING RISK FACTORS FOR ACL INJURY

A Thesis Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Alec Michael Genter
May 2019
ACKNOWLEDGEMENT

I would like to thank my advisor, Dr. Joshua Weinhandl, for the guidance, knowledge, and skills he has imparted to me throughout this process. I have been extremely lucky for his commitment to not only help with this culminating part of my Master’s but also over the two years during my coursework. I also want to thank my committee members, Dr. Songning Zhang and Dr. Jeffrey Fairbrother, who have both provided valuable constructive criticism and guidance along the way, making me not only a better writer, but also a better researcher. I want to thank Shelby Peel for all her help in writing and data collection. She has expanded my knowledge of Biomechanics throughout the past two years, and I am grateful for it. I also want to thank my lab colleagues who have encouraged me and offered constructive criticism and advice during this process. Finally, I would like to thank my family and girlfriend, Sara Stemen, for all their love and encouragement throughout this entire process.
ABSTRACT

Approximately 70-80% of ACL injuries occur via a noncontact mechanism. These noncontact ACL injuries most commonly occur during jumping and/or landing movements. Landing is considered a high-risk movement, as poor landing technique has been linked to ACL injuries via an inability to support rapid changes in acceleration or deceleration concomitantly with high vertical ground reaction forces. The foot and ankle form the initial parts of the lower extremity kinetic chain. Thus, positioning of the foot on the ground may influence the transmission of those forces from the ankle to the knee. Foot progression angle (FPA) is considered a modifiable ACL injury risk variable that can affect both hip, knee, and ankle kinematics and kinetics. The purpose of this study was to examine how introducing a verbal instruction effected the success in practicing and repeating a desired FPA modification during a landing movement, while also examining any changes in knee kinematics and kinetics.

Participants were tested over two days and performed 40 drop-landings on day 1 practicing the desired FPA modification. While on day 2, participants were tested to determine if the FPA modification was retained during five more drop-landing trials and five transfer test trials. Results indicated that participant who received the verbal instruction to promote the desired FPA modification significantly increased FPA and knee abduction angle at landing during practice and retention; whereas, the control group did not. No differences were found between or within groups during baseline or transfer tests. This suggest that while the verbal instruction cue was effective in promoting an increase in FPA and reducing some ACL injury risk factors during practice and retention, this cue may only be effective to tasks similar to what was practiced. The transfer test, however, was more dynamic and involved other goal orientated parts of the movement which is similar to dynamic movements as seen in typical ACL injury settings.
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<td>FPA</td>
<td>Foot Progression Angle</td>
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<td>Hz</td>
<td>Frequency (Hertz)</td>
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<td>LESS</td>
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Chapter 1: Development of the Problem

Background and Rationale

The incidence of anterior cruciate ligament (ACL) reconstructions in the United States rose from 86,687 (32.9 per 100,000 person-years) in 1994 to 129,836 (43.5 per 100,000 person-years) in 2006 (1). Approximately 70-80% of ACL injuries occur via a noncontact mechanism (2-5), meaning that the ACL injury occurs in the absence of any external physical contact with another object. These noncontact ACL injuries most commonly occur during jumping and/or landing movements (6-11). Landing is considered a high-risk movement (7, 9, 12), as poor landing technique has been linked to ACL injuries via an inability to support rapid changes in acceleration or deceleration concomitantly with high vertical ground reaction force (VGRF) (7). Moreover, previous research has established that decreased knee flexion angle, increased knee abduction angle and excessive internal or external tibial rotation angle, as well as increased internal knee adduction moment and decreased internal hip extension moments may increase risk for ACL injuries due to the promotion of medial knee collapse during landing movements (12-16). Along with these kinematic and kinetic variables, previous research has also shown that during landing, peak ACL strain and stress occurs approximately at 40 ms after initial contact (17, 18).

It has been extensively shown that gender discrepancies exist in noncontact ACL injury rates, with females being at 4 to 6 times greater risk compared to their male counterparts (12, 13, 19). Incidence rates for ACL reconstructions in females significantly increased from 10.36 to 18.06 per 100,000 person-years years between 1994 and 2006 (1). This increased risk for ACL injuries in females has been associated with factors such as a larger Q-angle, smaller ACL length and width, hormonal changes, and differences in muscle activation supporting the knee joint (12,
These factors have been suggested to lower the ability to resist higher loads imposed on the ACL. Biomechanically, females have been found to land with decreased knee flexion angle at initial contact as well as increased peak internal hip extensor moment during landing (7, 21). This suggests females land with a more erect posture, thus a lower ability to absorb the high VGRF during a landing movement (13). Hewett et al. (7) reported that females who experienced ACL injuries had 8.4° greater knee abduction angles at initial contact and had 7.6° greater peak knee abduction angles than females who experienced no ACL injuries during landing. This signifies that females possibly have lesser control of frontal plane motion at the knee joint during landing.

Lephart et al. (22) reported that during dynamic movements that required landing, greater hip internal rotation occurs in females as compared to males. Paterno et al. (23) further demonstrated that during the initial 10% of the landing phase participants who sustained an ACL injury experienced a net hip internal rotation moment impulse \((-2.4 \times 10^{-3} \text{ Nm\cdot kg}^{-1})\), whereas participants who did not incur an ACL injury experienced a net external rotation moment impulse \((1.1 \times 10^{-3} \text{ Nm\cdot kg}^{-1})\). This suggests that females might be more prone to land with an internally rotated hip during a landing movement and resulting in an increased risk factor for ACL injury, which indicates the importance of the surrounding musculature of the hip to prevent excessive frontal and transverse planar motion and control compared to males.

Decker et al. (21) demonstrated that females perform 34% less negative work at the hip, indicating that the activation of the hip musculature is also less when absorbing energy during landing (21). Females have also exhibited relatively low recruitment ratio of the hamstrings to quadriceps \((2:1\) to \(2.5:1\)) at peak moments during dynamic movements (7, 12, 24). These findings are supported by previous data showing that females land with a more erect posture (i.e. less knee flexion) and experience stiffer landings. This suggests that females utilize their
quadriceps at a greater rate as compared to their hamstrings when landing, which has been associated with greater stress imposed on the ACL via higher levels of anterior tibial translation (25, 26).

Research has now begun to investigate the role that the ankle and/or foot may play on the knee during landing movements. The foot and ankle form the initial parts of the lower extremity kinetic chain. Thus, positioning of the foot on the ground may influence the transmission of forces from the ankle to the knee (27). Foot progression angle (FPA), is defined as the angular difference between the long axis of the foot and the mid-sagittal plane of an individual at initial foot contact with the ground (28). It is considered a modifiable ACL injury risk variable that can affect both hip, knee, and ankle kinematics and kinetics (28, 29). Padua et al. (28) concluded that landing with an FPA greater than 30° toe-in or toe-out is considered a high-risk position in the Landing Error Scoring System (LESS). However, toe-in landing has been found to promote greater increases in the aforementioned ACL injury mechanisms. Tran et al. (29) reported that a toe-in FPA of 30° produced a knee abduction angle of -0.84° ± 5.9, while toe-out landing produced a knee adduction angle of 6.09° ± 5.6. Furthermore, landing with a toe-in FPA increased initial contact hip adduction angle and peak hip adduction angle and moment, both which are thought to be associated with increased ACL injury risk (30, 31). Landing toe-in was also found to increase initial contact knee internal rotation angle and moment; whereas, toe-out landing position was found to be associated with decreased knee abduction angles and increased knee external rotation angles (29). However, little to no research has compared gender differences between FPA modifications and if this type of landing technique modification is advantageous for one or both genders (12, 13, 19).
As previously stated, females are found to be at a greater risk for ACL injury due to several factors (1, 13, 19, 20, 25). These factors (e.g. decreased knee and hip flexion, increased knee abduction angle, and internal knee rotation angle and moments) that could be potentially reduced by modifying landing technique during movements in order to decrease the risk of ACL injuries (28, 32, 33). Modifications to FPA during landing movements appear to alter lower extremity biomechanics and can be a target for movement modifications to reduce the risk for ACL injuries in females (33, 34). That said, the method as to promoting these modifications ranges from physical targets to verbal instructions each with different results in retention of the new landing movement modification.

The use of verbal instructions has shown to be effective in teaching and improving motor skill acquisition or improvements (35-38), as well as reducing biomechanical risk factors for injury to the lower extremity such as the ACL (10, 39). Several studies have investigated how the use of verbal instructions influence the learning of a new movement during a landing task, specifically assessing biomechanical risk factors and the retention and transfer of the movement skills that were taught (40, 41). Modifications of landing techniques have been researched using various strategies such as using verbal instruction cues to teach and modify landing patterns during landing (40-43). Milner et al. (41) found that providing simple verbal instructions can help significantly decrease peak VGRF and increase peak knee flexion and knee range of motion (ROM) during the landing. Additionally, verbal instructions were effective in reducing not only VGRF but also overall peak force on the ACL (17). Welling et al. (40) assessed the effects of various verbal focus instructions when performing a drop-vertical jump from a height of 30 cm. The aim of the verbal instructions were to promote improved LESS scores after 1-week retention test. Within group comparisons demonstrated significantly improved LESS scores from baseline
to retention testing. These results imply that these various forms of providing instruction in learning a new landing technique can be an effective method of teaching (40).

While numerous studies have found effective protocols using verbal instructions for teaching and modifying landing techniques to reduce biomechanical risk factors for ACL injury (2, 40, 41, 44). The current literature does not provide any data as to how verbal instructions could be used as a method to alter FPA landing technique and reduce risk factors and mechanisms for ACL injury over time.

Statement of the Problem

In previous studies, it has been shown that teaching new landing techniques through verbal instructions can be effective in reducing harmful biomechanical risk factors and mechanisms during landing (17, 40, 41, 44). Milner et al. (41) found that a simple verbal instruction focused on the goal of the movement was most effective in reducing VGRF in a drop-landing movement, while also increasing peak knee flexion angle from 87.1° to 94.6°. However, little research currently exists to determine an effective method or instruction to implement FPA landing modifications without constant feedback post skill acquisition, specifically with a female population. Continued research is still needed to better determine an effective protocol that trains an individual to land in a way that reduces ACL injury risk variables without requiring constant feedback over time.

Statement of Purpose

The purpose of this study was to examine how introducing a verbal instruction cue effects the success of practicing and repeating proper foot placement (i.e. external foot rotation) during a dynamic landing movement compared to no instruction. A secondary purpose was to further determine if external foot rotation was effective in reducing known ACL biomechanical risk
factors such as, knee abduction angle, knee flexion angle, and internal knee adduction moment. Lower extremity kinematics and kinetics were measured to determine differences in joint responses between pre and post-test of implementing the verbal instruction cue.

Research Hypotheses

Based on previous research (17, 40, 41), it was hypothesized that introducing a verbal instruction focus cue would increase success of practicing and the retention of proper foot placement during a dynamic landing movement. Moreover, it was hypothesized that introducing a verbal instruction focus cue would lead to increased generalizability (transfer) of proper foot placement during a dynamic landing movement. Finally, it was hypothesized that external foot rotation at landing would produce a greater decrease for known ACL injury risk factors.

Independent Variables

- Instruction condition: Verbal Instruction Focus Cue (VC), Control

Dependent Variables

- Kinematic Variables:
  - Sagittal Plane Joint Angles
    - Initial contact knee flexion angle
  - Frontal Plane Joint Angles
    - Initial contact knee abduction angle
  - Transverse Plane Joint Angles
    - Foot progression angle

- Kinetic Variables:
  - Sagittal Plane Joint Moments
    - Peak knee extension moment
Frontal Plane Joint Moments

- Peak knee adduction moment

Limitations of the Study

- Participants landed from a height of 40 cm. Landing heights may vary in a real-game situation.
- Participants all wore laboratory provided shoes according to size. In a real game, shoes may be based on sport or surface specificity.

Delimitations of the Study

- Participants were between the age range of 18-35 years old.
- Participants that scored lower than 71 out 80 on the LEFS test were excluded.
- Participants that had a self-selected FPA greater than 15° external foot rotation were excluded.
- Participants that had any lower extremity injuries which required surgery were excluded.
- Participants that had any lower extremity injuries within the past 6 months were excluded.
- Participants that had any history of ACL injury were excluded.
- Participants were recreationally active at least 3 times per week for a minimum of 40 minutes each session. One of these sessions included dynamic movements, such as jumping and landing.
Assumptions of the Study

- Participants answered the Lower Extremity Functional Scale truthfully.
- Participants were truthful regarding their activity level and health history.
- The twelve-camera infrared motion capture system (Vicon Motion Analysis, Inc., Centennial, CO, USA) and one force platform (BP600600, Advanced Mechanical Technology, Inc., Watertown, MA, USA) was accurately calibrated for each participant throughout the study.

Significance of the Study

This continued line of research into the reduction of ACL injury risk factors during dynamic movements is paramount in the ability to help clinicians, practitioners, and coaches implement preventive or rehabilitative protocols for an individual. This is especially important since the participation rate in sports has been rising, ACL injuries have continued to rise as well (1). Moreover, females have been identified to be a greater risk for ACL injury as compared to males (12, 19). Therefore, the development of effective protocols in teaching safer landing techniques to help reduce known ACL injury risk factors during dynamic movements is critical.

Operational Definition of Terms

- Noncontact ACL Injury: an injury that occurs in the absence of player-to-player contact, such as single-leg landing, change of direction, or rapid deceleration movements (3, 12, 45, 46).
- Joint Moments or Moment of Force: Tendency of a force to rotate an object about an axis. In this study, internal joint moments of force were defined as the net rotational effect of agonist and antagonist muscle forces about a joint to resist an external load.
- The convention used for joint kinematics and kinetics followed the right-hand rule.
- Hip: flexion (+)/extension (-), adduction (+)/abduction (-)
- Knee: flexion (-)/extension (+), adduction (+)/abduction (-)
- Ankle: dorsiflexion (+)/plantarflexion (-), inversion (+), eversion (c)
- Foot Progression Angle: (+) external rotation, (+) internal rotation

- Initial contact was defined as the instant where vertical ground reaction forces exceed 10 Newtons.
Chapter 2: Review of the Literature

Introduction

The purpose of this study is to examine how introducing verbal instructions effect the success of practicing and repeating proper foot placement during a dynamic landing movement. Additionally, lower extremity kinematics, kinetics, and muscle activation patterns will be measured to determine differences in joint responses between pre and post-test. This chapter reviewed current literature discussing ACL anatomy, biomechanical risk factors associated with noncontact ACL injuries, the role of modifying foot placement angles on knee biomechanics, the neuromuscular risk factors associated with noncontact ACL injuries, gender differences in ACL injuries, and the effectiveness of verbal instructions on practicing and learning proper techniques of a landing movement.

Anatomy of the ACL

The ACL is one of the most commonly disrupted ligaments in the knee (47). It has been previously reported that almost half of all ligamentous knee injuries are located at the ACL (48). The ACL is made of two parts: the anteromedial bundle and the posterolateral bundle (49, 50). Overall, the ACL originates on lateral wall of the femoral intercondylar fossa while inserting on the anterior intercondylar area of the tibia (51). Typically, the ACL is 35-40 mm long and 10-12 mm wide, although males typically have ACLs that are larger in length and width as compared to females (20). The anteromedial fibers lengthen as the knee flexes, and the posterolateral fibers lengthen as the knee extends (52). Although the two fiber bundles work as antagonists in the sagittal plane; when knee motion becomes multiplanar, such as anterior translation and internal tibial rotation, the fiber bundles work together to resist tibial displacement (7). The primary function of the ACL is to resist excessive anterior tibial translation in relation to the femur, along
with a secondary function of resisting frontal and transverse tibial rotation about the femur (53). Previous research has found that the ACL is responsible for 82-90% of the restraining force to anterior tibial translation during the first 30-45 degrees of knee flexion (54).

**ACL Injury Overview**

The incidence of ACL reconstruction in the United States rose from 86,687 (32.9 per 100,000 person-years) in 1994 to 129,836 (43.5 per 100,000 person-years) in 2006 (1). The incidence of ACL reconstructions in females significantly increased from 10.36 to 18.06 per 100,000 person-years between 1994 and 2006 (P= 0.0003), while that in males rose at a slower rate, with an incidence of 22.58 per 100,000 person-years in 1994 and 25.42 per 100,000 person-years in 2006 (1). From 2001-2015, there were 197,577 primary ACL reconstructions performed according to the National Hospital Morbidity Database (NHMD) of the Australian Institute of Health and Welfare (AIHW). The annual number of ACL reconstructions rose from 9,662 in 2000-01 to 16,990 in 2014-15 (55). An injury to the ACL has been defined as the overloading, and ultimate tearing of the ligament (56). ACL injuries can be classified into one of two categories: contact or noncontact injuries (4). Contact injuries are defined as a direct blow to the knee joint, caused by another player. Noncontact injuries are defined as an injury that occurs in the absence of player-to-player contact, such as single-leg landing, change of direction, or rapid deceleration movements (3, 12, 45, 46). Krosshuag et al. (57) used video analysis to distinguish contact and noncontact ACL injuries and found this to be an effective model in determining between the two as a post-event analysis method. Johnston et al. (5) also used video analysis as means to determine the mechanism of lower extremity injury and found that the majority of ACL injuries occur via noncontact mechanisms. Approximately between 70-80% of ACL injuries occur via a noncontact mechanism (2-5, 45).
Previous research (6, 58) has also determined that noncontact ACL injuries are multifactorial, which have been classified into three categories: non-modifiable factors and modifiable factors, or a combination of both. Non-modifiable factors have been described as factors that cannot be changed due to an individual's anatomy and physiology. Factors such as a narrowed intercondylar notch are considered by some authors to be a risk factor, smaller ACL ligament size, hormones, or sex. Modifiable factors have been described as those that can be changed and control by an individual. Factors such as neuromuscular strength in the quadriceps and hamstrings, flexibility, balance, shoes-surface interactions, and training (7, 58-60).

Over the past several decades, researchers have devoted time and effort to determine the mechanisms and etiology of ACL injuries. Although multiple factors have been cited in previous literature (8, 9, 12, 47), the exact mechanisms of ACL injury varies between each situation and overall it is still not well understood on how to prevent these mechanisms of noncontact ACL injuries (8, 10, 11).

*Biomechanical ACL Risk Factors and Injury Mechanisms*

As previously mentioned, 70-80% of ACL injuries are considered noncontact injuries, with a substantial amount occurring during jump or drop landings (9, 13, 14, 25, 61, 62). It has been shown that landing is considered a high-risk movement, as poor landing technique has been linked to ACL injuries (7). In general, risk factors for ACL injury during landing movements include: sex, age, neuromuscular control, and drop-height (12-14, 25, 63, 64). Sex is a primary ACL injury risk factor, as females have been found to be either 2 to 3 or 4 to 6 times more likely to incur an ACL injury (7, 12, 65). This is because females typically have smaller ACLs, a larger Q-angle, and hormonal changes, resulting in a lower ability to resist higher levels of force and stress imposed at the knee joint (20). Females also tend to land with a more erect posture which
increases certain kinematic and kinetic variables that have been found to increase the chance for ACL injury, which will be further discussed (31, 63, 66). Age has also been identified as an ACL injury risk factor due to a high prevalence of injuries occurring to those younger than 20 and over 40 years of age (1, 67). These age ranges have demonstrated higher rates of ACL injury in part due to either the lack of fully developed ACLs (people younger than 20 years of age) or decreased knee joint stability. A decreased ability to control neuromuscular function has also been found to be a risk factor ACL injuries because of an individual’s inability to properly provide support, absorb energy, and help regulate rapid changes in acceleration at the knee joint during landing (7). Additionally, large differences between quadriceps-hamstring activation have also been identified as a risk factor because of role these muscle groups play in negotiating anterior tibial translation and knee flexion (68, 69). These risk factors all promote kinematic and kinetic alterations that increase injury mechanisms such as medial knee collapse (70).

Furthermore, during landing, as the height of a jump or drop to the ground increases, the risk for injury to the lower extremities and the ACL increases due to the increased vertical ground reaction forces and an asymmetry in landing between dominant and non-dominant legs (64). Oggero et al. (64) also suggested that as drop height increases, people should land with greater hip and knee flexion because of the increases in velocity and resultant kinetic energy, supporting previous research (71). This landing strategy will also help decrease joint stiffness during landing.

Increased joint stiffness (18, 71), large VGRF, and medial knee collapse (70) have been found to be injury mechanisms of the ACL during landing movements. These mechanisms during the overall landing movement as well as during each phase of landing have also been studied over the years to better help determine if they are preventable (8-10). The landing phase
is defined as the point of initial contact to the moment when the body’s center of mass reaches its lowest point (70). The hip and knee aid in the absorption of energy by producing greater flexion in order to dissipate the energy experienced during the landing phase (15). Landing tasks also require the body to utilize other movement patterns to absorb the body's energy when landing. Two of the major strategies used when landing from a jump is toe landing first (forefoot) or heel landing (rearfoot) first. Athletes often have their own unique landing strategies based on preference and task demands. Butler et al. (16) reported that knee joint stiffness and ACL strain is related to landing on the toes, which can be mitigated through proper hip and knee movement patterns. The corresponding hip and knee biomechanical landing variables that influence the aforementioned injury mechanisms, such as medial knee collapse, large vertical ground reaction forces, and knee joint stiffness have been researched extensively (12, 15, 30, 32, 47, 72, 73).

Large VGRF have been shown to contribute to knee instability and are a primary injury mechanism during landing (7, 15). Prior to any injury, participants who sustain ACL ruptures exhibit 20% larger peak vertical ground reaction forces during landing than participants who remain healthy (7). Increased joint stiffness has also been shown to promote a greater risk of injury to the knee and ACL if presetting the landing was not accomplished (71). Presetting is done by increasing the net flexor moments at the hip and the knee prior to floor contact to produce a more stable body posture and a flexed knee position at initial floor contact, aiding in the absorption of energy (71).

Based on previous simulated landing studies, the ACL reaches peak strain approximately 40 ms after initial contact, signifying in most cases ACL injury will occur during that time frame (72, 73). This indicates that there must be some biomechanical abnormalities that follow at the knee during initial contact. Specifically, during drop-landings, these abnormalities include a
combination of increased hip adduction and internal rotation, decreased knee flexion, increased knee abduction and excessive internal or external tibial rotation, termed medial knee collapse, as previously mentioned an injury mechanisms that may increase the risk of ACL injury (7, 12, 30-32).

Cadaver studies have been performed to simulate motions such as internal tibial rotation, knee abduction, and lower hip and knee flexion that are experienced to those who experience ACL injuries during dynamic movements (34, 53, 72, 73). The ACL loading patterns were reported to be consistent with previous studies (74). As such, the mechanics of the lower extremity when performing a landing movement have been studied in order to continually identify when and how to reduce the mechanisms of ACL injuries and/or determine the effectiveness of ACL prevention programs (7, 60). Kinematic, kinetic, and neuromuscular variables such as increased internal tibial rotation angle, knee abduction angle, decreased hip and knee flexion angles, increased tibial shear force, toe-in landing placement, knee internal adduction moment, and unbalanced co-activation of the hamstrings and quadriceps have all been found to promote medial knee collapse which poses a greater risk of injury or rupture of the ACL during landing movements (12, 29, 33, 46, 47, 60, 75-77).

Hewett et al. (7) reported that knee abduction angle during bilateral jump landing was 8° greater in ACL injured compared to uninjured athletes. ACL injured athletes also had a 20% higher ground reaction forces, and stance time was 16% shorter; hence, the motion, forces, and moments occurred more quickly (7). Furthermore, peak ACL relative strain was 192% greater under internal tibial moments combined with a knee adduction/abduction moment (7.0% ± 3.9% and 7.0% ± 4.1%, respectively) than under an external tibial moment with the same moments (2.4% ± 2.5% and 2.4% ± 3.2%, respectively) (7). The external knee abduction moment
increased ACL strain due to the slope of the tibial plateau inducing mechanical coupling (i.e., internal tibial rotation and knee abduction moment). This indicates that increased internal tibial moment combined with an increased external knee abduction moment is highly detrimental to ACL loading condition. Hewett et al (7) also found that athletes who sustained ACL injuries did so by landing with a high knee abduction angle at initial contact during a drop vertical jump when compared to uninjured athletes. Additionally, their study demonstrated that knee abduction moments predicted ACL injuries with 73% specificity and 78% sensitivity. Ultimately, it was determined that internal tibial rotation moment primarily causes increased ACL strain (78). McLean et al. (79) reported that peak internal knee adduction moments are dependent on initial contact knee abduction angle; a greater abduction angle at initial contact increases the valgus alignment at the knee. A greater valgus alignment promotes the increase of an internal knee adduction moment and ACL strain during the weight-bearing portion of a movement.

All of the previous research detailed in the above section has demonstrated how the lower extremity and ACL responds to externally applied loads in various environments and different dynamic movements; however, all of this research has assessed noncontact, dynamic movements due the high prevalence of noncontact ACL injuries (2-5, 45). Boden et al. (47) further explained that one of the key elements in noncontact ACL injuries is foot position on the ground at the time of injury.

Foot Progression Angle Landing Techniques

ACL injury prevention has been studied extensively, yet there is still a rising trend of ACL injury occurrence (80). Researchers have now begun to investigate the role the ankle and/or foot may play on the knee during dynamic movements, especially in landing. Previous studies have attempted to determine how foot placement on the ground during landing may decrease the
influence risk of injury (51, 52, 63, 64). The foot and ankle form the initial parts of the lower extremity kinetic chain during landing, and the position of the foot may influence the transmission of forces from the ankle to the knee (27). A limited number of studies have analyzed the influence of the foot on ACL injuries, but with differing results. Cortes et al. (76) analyzed the sagittal plane foot position on hip and knee kinematics and kinetics, specifically assessing the differences between forefoot (toe-first landing technique), rear-foot (heel first landing technique), and self-preferred landing techniques. They found that landing with a forefoot landing technique significantly decreased initial contact hip flexion (35.79° ± 11.78°) compared to rear foot techniques (43.15° ± 11.77°). While a rear-foot landing technique significantly decreased knee flexion at peak vertical ground reaction forces (26.77° ± 9.49°) compared to subjects using the forefoot technique (58.77° ± 20.00°). Both results are considered risk factors for ACL injury. However, these results have only been documented in the sagittal plane, which has been shown to not be enough to cause ACL injury (81). Further examination in the frontal and transverse plane is necessary to better understand how the foot influences the potential for ACL injuries during landing.

Foot progression angle (FPA), or the angular difference between the long axis of the foot and the mid-sagittal plane of an individual during foot contact with the ground is a modifiable variable of that can affect both hip, knee, and ankle kinematics and kinetics (28, 29). Padua et al. (28) concluded that landing with an FPA greater than 30° toe-in or toe-out is considered a high risk position in the LESS. Recent research has supported this conclusion demonstrating that landing with excessive toe-in or toe-out can be detrimental for ACL injuries (75, 82). Teng et al. (82) found that as toe-out of the foot increases, so does the peak internal knee abduction moment during a drop-landing movement. Furthermore, toe-in and neutral foot placements were found to
be similar in peak internal knee abduction moments; suggesting that there is no detrimental effect on internal knee abduction loading when landing with a foot rotation angle of 6° relative to the pelvis (82). Additionally, in a study by Ishida et al. (75), they reported increased tibial internal rotation angle as well as increased tibial internal angular velocity immediately after landing with a toe-out FPA. Greater tibial internal angular velocity has been shown to increase the ACL strain rate during landing movements (78). The strain rate notably affects mechanical properties of the ACL in that as strain rate increases, so does the stress imposed on the ligament (83). This increased stress on the ACL can increase the ligament’s susceptibility to injury during landing. Therefore, excessive toe-out landing could present greater risk of ACL injury than natural landing and should be avoided (75).

Conversely, Tran et al. (29) found that a toe-in FPA to be a more detrimental landing technique and promote increased risk factors for ACL injury. Toe-in FPA produced a knee adduction angle of 0.84° ± 5.96°, while toe-out landing produced a knee abduction angle of -6.09° ± 5.65°. Furthermore, landing with a toe-in FPA increased initial contact hip adduction angle (-1.86° ± 4.66°) and peak hip adduction moment (0.42 Nm·kg⁻¹ ± 4.40), which are associated with increased risk of ACL injury (30, 31). Landing toe-in was also found to increase initial contact knee internal rotation angle and moment; whereas, toe-out landing position was found to be associated with decreased knee abduction angles and increased tibial external rotation angles (29). These results were supported by Ishida et al. (33) who previously showed that increases in toe-in FPA lead to increases in knee internal rotation angle.

Changing foot landing position appears to significantly alter lower extremity biomechanics for both men and women during a double-leg jump landing, and can be a target for movement pattern modification in both sexes (29, 75). It has been well documented that ACL
injury risk factors include medial knee collapse and internal tibial rotation. However, as there are unclear results as to which FPA is more appropriate for safe landing, more research is warranted.

**Muscle Activation Risk Factors for ACL Injury**

Electromyography is a diagnostic process that records the electrical activity of muscles and provides a means for quantifying magnitude and timing of muscle activation. Recording electrical activity of muscles, specifically patterns of activation, has become common in musculoskeletal research to better understand physical activity, injuries, and rehabilitation. One of the more common methods to noninvasively quantify muscle activation has been through surface electromyography. Quantification of the muscle activity surrounding the knee joint provides insight as to if those muscles are contracting at the proper time of the movement and with sufficient magnitude to support the knee joint during dynamic movements. Coordination and activation deficits in muscles responsible for knee joint stability during dynamic movements may contribute to ACL injury – especially muscles in the thigh. Altered neuromuscular timing and recruitment during dynamic movements may lead to increased knee abduction and excessive anterior tibial translation (84).

Co-activation and coordination of the hamstrings and quadriceps has been proposed as one mechanism to protect the knee joint against excessive anterior tibial translation as well as against excessive knee abduction and medial knee collapse (85). Besier et al. (85) demonstrated that the central nervous system generates two generalized activation strategies for the body to respond with and counter any load that is applied to a joint. The first method is known as “selected activation” of muscles, which recruits muscles around a joint with moment arms that are most effective in countering an external load. The second method, “generalized co-contraction”, involves the general activation of antagonistic muscles at a joint without selecting
specific muscles to contract. Besier et al. (67) found that both strategies stabilized the knee joint via quadriceps-hamstring co-activations to reduce three-dimensional moments. However, which neural strategy is used depends upon whether the task was anticipated or unanticipated. To further reduce the load on the knee, anticipated movements provide time for the central nervous system to alter preprogrammed activation patterns. However, poor or abnormal activation and coordination of the muscles supporting knee joint during dynamic movements has been linked as a primary contributor to ACL injuries (7).

The ACL may experience potentially hazardous three-dimensional forces during landing and rotating sporting movements if the musculature that supports the knee joint does not sufficiently dissipate the accompanying moments and forces (7). During a landing movement, there is an increase in quadriceps muscle activation just before initial contact in order to prepare the joint for loading and prevent it from collapsing in the sagittal plane (48, 86). However, at initial contact when the quadriceps activity is near maximum and hamstrings activity is decreased, significantly higher anterior shear forces are experienced at the knee joint—thus inducing more strain on the ACL (87, 88). Demorat et al. (89) demonstrated that anterior tibial translation was produced when the knee is near full extension and the quadriceps are progressively loaded, indicating that the potential for ACL injury increases when knee flexion is below 30° with higher quadriceps activity (90). Kernozek et al. (65) found that during a single-leg drop-landing movement, mean knee flexion angle was approximately 15° at initial contact. Their results demonstrated that single-leg landing produced potentially compromising knee flexion angles, combined with increased knee abduction angles. Additionally, landing with decreased knee flexion at the most critical phase of landing, initial contact, is when ACL injuries typically occurred (91). Pollard and colleagues (92) found that landing with a lower knee and hip
flexion induces greater vastus lateralis electromyographic activity, resulting in less energy absorption and greater knee abduction during landing. Landing with greater knee abduction and increased vastus lateralis activation could be an attempt to prevent a medial knee collapse by activating the lateral musculature surrounding the knee joint. However, a combination of decreased knee flexion and increased muscle activation of the quadriceps without the increase activation of hamstrings may promote greater risk for injury to the ACL.

Activation of the hamstring muscles assist the knee ligaments in maintaining joint stability by acting as an antagonist to the quadriceps muscles. Hamstring activation reduces ACL strain by resisting anterior tibial translation forces and creating posterior translation forces. Hamstring activation and ability to reduce ACL strain is dependent upon knee flexion angle (48, 84). ACL strain is reduced when the knee being is flexed greater than 30°, because of the increased activation of the hamstrings. Conversely, when the knee is flexed less than 30°, hamstrings activity is not great enough to counteract the quadriceps activation. These previous conclusions were supported when hamstring muscle activity was reported to be lower when knee flexion is between 15-25° during a jump-landing task (93). This decrease in hamstring activation indicates a decrease in hamstring force production during the movement, which has been associated as a potential mechanism for ACL injury (93). Weinhandl et al. (94) found that ACL loading increased with a decrease in hamstring strength because of the reduced posteriorly directed shear force. These findings support previous research and hypotheses that the hamstrings can decrease anterior tibial translation.

Quadriceps and hamstrings function and their effect on the loading of ACL are well documented and examining not only their co-activation patterns but strength ratios have become a common way of identifying any neuromuscular imbalances that may affect the ACL.
Typically, there is a 1.5:1 to 2:1 ratio of isokinetic quadriceps strength to hamstring strength (Q:H). This ratio has been used as a marker for muscular stability about the knee during dynamic movements, as well as an indicator of potential risk of injury at the knee (24). This ratio signifies that a larger force is produced by the quadriceps compared to the hamstrings. As Q:H ratio increases the anterior shear force will increase, resulting in greater loading of the ACL. When the quadriceps and hamstrings co-activation is imbalanced, there is a greater need placed on the knee ligaments to resist sagittal and frontal plane movements to maintain joint stability. This phenomenon has been called “passive stability” (24, 48). Hamstrings activation have been routinely demonstrated as the critical muscle groups to counteract the activation levels of the quadriceps, which may lessen the load on the ACL (93, 95).

As quadriceps force production increases, so does shear force on the ACL via anterior tibial translation. The hamstrings lessen the magnitude of the anterior pull by quadriceps. This is done via a posteriorly directed force on the tibia when the hamstrings contract, thus reducing the anterior tibial translation and overall load on the ACL. The identification and neuromuscular strengthening of any quadriceps and hamstrings imbalances has become a critical component of protecting the ACL from excessive strain and possible injuries.

**Gender Differences in ACL Injury**

The rate of injury to the ACL in females has been reported to between 4 to 6 times higher or 2 to 3 times higher than males (7, 12, 96, 97) when participating in the same sport According to Prodromos et al. (19) females have a roughly 3 times greater incidence of ACL tears/injury in soccer and basketball versus male. As to what may be the cause for the higher rate of ACL injury incidences in females has been debated and investigated for decades. Haycock and Gillette (98) attributed most differences in injury rates to differing levels of training and coaching, and not to
anatomic or physiologic differences. However, some reports attribute injury rate differences to physiologic differences such as increased joint laxity or intercondylar notch width among women (26). As previously discussed, it has been determined that noncontact ACL injuries are multifactorial, which have been classified into two categories: non-modifiable factors and modifiable factors. (6, 58). Investigators have begun to focus on modifiable factors in order to better understand the differences in ACL injury incidences between males and females so that future changes could be made to reduce ACL injuries.

**Biomechanical Differences between Genders**

Lower extremity biomechanics is one area of interest when comparing differences between males and females related to ACL injury mechanisms. Females tend to land with a more erect posture compared to males at initial contact. In the sagittal plane, Huston et al. (66) found that females demonstrated significantly lower knee flexion at initial contact from a drop-landing as the height of the drop increased as compared to males. Peak external hip flexion moments were also reportedly significantly increased in females who sustained ACL injury (Injured: 147.9 ± 33.5 Nm, Uninjured: 106.8 ± 45.3 Nm), resulting in a lower energy absorption throughout the lower extremity and leading to higher vertical ground reaction forces experienced at the ankle and knee (7).

Hewett et al. (7) further demonstrated that in the frontal plane, female knees that experienced ACL injury had 8.4° greater knee abduction angles at initial contact and had 7.6° greater peak knee abduction angles than the non-injured knees of the female control group during landing. Significant, moderate correlations between knee abduction angle and peak vertical GRF were observed in ACL-injured but not in uninjured athletes (7). Females who experienced an ACL injury also had a greater stance phase peak external knee abduction moment (−45.3 ± 28.5
Nm), compared to uninjured females (−18.4 ± 15.6 Nm) (7). Ford et al. (99) found that there were dominant versus non-dominant differences in hip stabilization during landing for females. Women demonstrated greater hip external adduction moment and decreased hip flexion angle in the non-dominant limb during landing. The hip abductor muscles have been found to play an important role in controlling excessive abduction motion and moment in female athletes (12, 99). Female athletes typically have greater external hip adduction moments during landing. This increased external hip adduction moment could signify that women have difficulty controlling the hip, especially opposing adduction, during dynamic sports movements (12, 99). The inability to resist hip adduction combined with knee abduction angle motion can lead to medial knee collapse positions during landing for females.

The hip is an important controller of knee joint stability during dynamic movements in female athletes (10). Decreased ability to proximally stabilize the lower extremity can lead to load bearing alterations and result in higher forces and moments experienced at the knee in all three planes of motion. Lephart et al. (22) reported that during dynamic movements that required landing, greater hip internal rotation occurs in females as compared to males, which has been shown to influence ACL injury risk. Paterno et al. (23) further demonstrated that during the initial 10% of landing, participants who sustained an ACL injury experienced a net hip internal rotation moment impulse (−2.4 × 10⁻³ Nms·kg⁻¹), whereas participants who did not incur an ACL injury experienced a net hip external rotation moment impulse (1.1 × 10⁻³ Nms·kg⁻¹). These results demonstrate the importance of hip rotation during landing, specifically in the transverse plane. The net hip external rotation moment impulse in non-injured participants may act to resist internal hip rotation during the landing phase. This ability to resist internal hip motion in non-injured participants has identified as a kinematic movement pattern that could
reduce potential risk factors for ACL injury (23). However, females have been shown to have less ability to control and resist hip motion during dynamic movements, as will be further explained below (100).

Muscle Activation Differences between Genders

Another area of interest in identifying ACL injury risk differences between males and females is the neuromuscular activation and coordination of the lower extremity. Females have demonstrated relatively low recruitment of the hamstrings compared to the quadriceps during dynamic movements (7, 12). Due to a decreased ability to coordinate the muscle activity between the hamstrings and quadriceps through positions of high joint loading, females are at higher risk for ACL injury (7). During dynamic movements, such as landing that require flexion at the knee, females utilize a higher activation of their quadriceps relative to their hamstrings due to the more erect landing posture, creating higher anterior loads (34, 66). This inability to balance the co-activation of the quadriceps and hamstrings in females decreases their neuromuscular control of decelerating during a landing task. This landing strategy has been shown to increases medial knee collapse and anterior tibial translation and rotation which increases the possibility for ACL injury (26, 66).

Additionally, gender differences in knee abduction angles have been shown to be indicative of altered neuromuscular control of the lower extremity in the frontal plane. These kinematic differences have been attributed to gender differences in contraction patterns of abductors and adductors of the hip and flexors and extensors of the knee (13, 99). Decker et al. (21) found that female athletes experienced higher ground reaction forces at the lower extremity during landing because of decreased use of the hip musculature to absorb these forces. Females performed 34% less negative hip work than males, demonstrating that females did not utilize the
hip in energy absorption as much as males (21). The hip abductor muscles also have been shown to play a role in controlling excessive medial knee collapse and rotation, especially in females (100). These results suggest that increased ability to recruit and strength in the hip abductor muscles could lead to control over excessive medial knee collapse during landing movements.

In conjunction to muscular strength, the firing rate of the lower extremity muscles may play a role in ACL injury differences between genders. Rozzi et al. (101) reported that female athletes demonstrate a disproportionate firing of their biceps femoris compared with male athletes during the deceleration of a jump landing. Females have also been found to have an unbalanced vastus medialis to vastus lateralis firing, with the vastus medialis firing at decreased proportion compared to the vastus lateralis (101). This creates greater lateral condylar pressure in the knee and limited resistance to anterior tibial translation (34, 100). The combination of these muscle activation characteristics poses a greater risk for medial knee collapse and tibial translation (34, 101). This unbalanced neuromuscular activation strategy of the thigh musculature during dynamic movements has been linked to greater abduction motion and moments in the knee, which are risk factors for ACL injuries and a potential explanation as to why females are at greater risk for ACL injury than males (84, 99). Muscle strength, coordination, and balance have been shown to have direct effects on ACL loading and protection against injury (48, 95).

Decker et al. (21) suggest that it is plausible to assume that females land with a gender-specific strategy that may put them at greater risk for ACL injury. Females tend to land with a more erect posture than males with increased initial contact knee extension, greater energy absorption in the ankle and knee, and reduced knee flexion ROM (66). Protective mechanisms against anterior tibial translation and knee abduction include proper balance and coordination of
the hamstrings and quadriceps, as well as greater knee and hip flexion at initial contact (12, 26). The ability to modify and promote these protective mechanisms in females through new prevention and training programs may help reduce the stark differences ACL injuries between genders.

Effect of Attentional Focus on Motor Skill Learning

Over the past two decades, the motor learning literature on attentional focus has explored the effects of internal focus strategies versus external focus strategies. Most of this line of research has investigated which might be more effective in promoting the learning of new performance movements or motor skills. An external focus has been defined as directing the attention of an individual to externally focus on the effect of a movement on the environment (e.g., focusing on the lower corner of the goal in soccer or the flight of the ball in golf) (37, 43, 102). Internal focus has been defined as directing attention to internally focus on the motion of the body itself (e.g., focusing on the motion or placement of the legs in soccer or the swing of the arms and trunk in golf) (37, 43, 102). The exact mechanisms underlying how the effects of attention on skilled performance is still debated. The constrained-action hypothesis suggests that focusing attention internally creates top-down constraints on the coordination of movement, although it is not clear how these top-down constraints manifest in terms of biomechanical changes (36). Lohse et al. (103) has also recently suggested that attention acts to increase precision by allocating it along dimensions of the motor system. When attention is allocated externally to focus on the goal of the movement, the motor system works to optimize performance by reducing variation in the goal dimension. When attention is allocated internally to focus on one's own body mechanics, the motor system works to optimize function and reducing the number of degrees of freedom during the movement or task. This effect essentially
reduces the body's ability to make compensatory adjustments during a performance and has been termed the nodal-point hypothesis. One of the biggest questions that still remain in the attentional focus literature is when and how attentional foci affect motor performance (104).

Instruction is one of the most common forms of directing attention and is used comprehensively when teaching motor skills. Coaches and practitioners typically use visual instructions to help build up motor representations. However, they also use verbal instructions to help guide the learner to the most efficient and effective solution (104). A number of recent studies have shown the external focus of attention directed through instruction or feedback introduced by the experimenter improves performance relative to control conditions with no direction of focus of attention (35, 43). A few other recent studies have found conversely that internally directed focus of attention only has detrimental effects in “over-learned”, automated tasks, which typically only effects experts of a given task or performance situation (37, 38). In that, internally or externally directed focus of attention can benefit the learning of a new motor skill or movement modifications (37, 38). This suggests that internal focus or external focus instructions, visual or verbal, can have a positive effect on learning and performance for novice learners. However, for expert learners, an external focus of attention has been the only effective method of increased learning (91, 96).

The advantages for directed focus of attention holds true for both healthy individuals and clinical patients with musculoskeletal injuries (105). Rehabilitation and training programs have typically focused on a joint ROM, balance, strength and neuromuscular exercises. Instruction and feedback in these types of settings typically have consisted of internal focus of attention, using phrases like “keep your knee over the toe” during exercises such as a squat. Recent studies have utilized externally directed focus of attention strategies when implementing training and
rehabilitation programs to reduce injury risks and return athletes to sport. Myer et al. (39) demonstrated the verbal instructions that externally direct focus of attention to the goal of the movement during plyometric and dynamic stabilization exercises can help increase knee flexion. Myklebust et al. (10) found that external visual and verbal instructions aimed to help teach and improve neuromuscular balance and body position for cutting and landing movements were more effective by decreasing vertical ground reaction forces. These findings, firstly, help demonstrate that external instructions, regardless of focus on the goal of movement versus focus on mechanics of the movement, can help promote learning of desired movements patterns and goals of an action. Secondly, these results showed improvements in changing and decreasing vertical ground reaction forces without altering performance negatively. Employing newly advanced targeted instructional and feedback techniques, may further help improve outcomes from training or rehabilitation programs.

**Effects of Instruction on Landing**

The use of verbal instructions has shown to be effective in teaching and improving motor skill acquisition or improvements (35-38), as well as reducing biomechanical risk factors for injury to the lower extremity such as the ACL (10, 39). However, the majority of ACL prevention or training programs use verbal instructions that are directed toward the focus on specific body movements (10). A more ample approach to adapt ACL prevention and training programs to help create long terms effectiveness without the need for constant instruction after the initial program would be to adopt a motor learning approach (42). DiStefano et al. (106) showed the effectiveness of learning in order to optimize drop jump landing technique using the LESS. The investigators divided participants into a short-term training group (~3 months) and extended-term training group (~9 months) providing internal focus verbal instructions for
improving landing technique. While both groups improved their LESS scores, only the extended-term group retained the proper landing technique after 3 months of ceasing to train. These results suggest that internal focus verbal instructions result in a better landing technique initially, but that high number of repetitions are needed when learning movement skills with internal focus verbal instructions. This necessity for higher number of repetitions might require too much time commitment, and therefore potentially decreasing compliance in coaches and athletes (106). Additionally, it has been found that focusing one’s attention on motor skills can be counterproductive in automating movement skills (107, 108). External focus verbal instructions, however, have been shown to be less attention demanding, while also improving skill retention and transfer to a sport and optimizing performance without the skills becoming highly transient (102, 107). Furthermore, external focus instructions, verbal or visual, have been found to improve motor performance, technique, and neuromuscular coordination (108). McNair, Prapavessis, & Callender (109) found that the use of verbal instructions with an external focus of attention can help reduce the vertical ground reaction forces experienced when performing landing maneuvers. Makaruk et al. (44) reported that groups utilizing external focus strategies to perform jump and landing movements demonstrated greater knee flexion and overall knee ROM as compared to both control and internal focus groups. This study provides further evidence as to the validity of implementing knowledge from motor learning to enhance ACL injury prevention and training programs (44).

Several studies have also investigated how the use of verbal instructions influence performance during a landing task, specifically assessing biomechanical risk factors and the retention and transfer of the movement skills that were taught (40, 41). Welling et al. (40) assessed the effects of both verbal internal focus instructions versus external focus instructions
when performing a drop-vertical jump from a height of 30 cm. Adopting from previous studies with robust results, the internal focus verbal instruction (internal focus) group was to direct participants to pay attention to the body, i.e. “extend your knees as rapidly as possible after the landing on the force plate”. The external focus verbal instruction (external focus) group was to direct participants to pay attention to the effect of the movement, i.e. “push yourself as hard as possible off the ground after landing on the force plate” (42, 44). A video instruction and control groups were also used in this study as well; the video instruction (video instruction) group was implemented because of previous literature suggesting its positive effect on improving LESS scores (107). The instruction was given after every five trials, landing technique was scored using the LESS scale, and a 1-week retention test was performed to see if there were differences among the groups. The results of the study demonstrated that visual instruction was most effective for both genders in performing and retaining the new landing technique. While the internal focus and external focus groups differed, within in group comparisons showed that from beginning of acquisition to the end and after retention, there were improvements in their LESS scores. These results imply that these various forms of providing instruction in learning a new landing technique can be an effective method of teaching (40).

Milner et al. (41) reported that using simple verbal instructions can help significantly decrease peak vertical ground reaction forces and increase peak knee flexion and knee ROM during the landing of a countermovement jump. Participants performed a countermovement jump control trial first followed by a counterbalanced series of three simple verbal instructions. The simple verbal instruction that was seen to have the most significant effect on these biomechanical variables was, "land as softly as possible", with no instruction in how to land soft or any other type of assistance. When performing countermovement jump with the “soft landing” instruction,
the participants landed at 94.6° of peak knee flexion on average as compared to 87.1° for the control trials. Additionally, when performing the “soft landing” instruction jump, participants landed with a vertical ground reaction force of 847.2 N on average as compared to 1005.9 N when receiving the “knee over toes” verbal instruction (which is considered an internal focus verbal instruction). These results support previous research in that using verbal instructions that direct the attention of an individual to focus on the effect of the movement is more effective in reducing risk factors associated with ACL injuries. Laughlin et al (17) found that using verbal instructions were effective in reducing peak force on the ACL. Additionally, an increase in hip and knee flexion resulted from the verbal instruction at initial contact (107). Both of these studies further support the idea of altering landing technique using simple verbal instruction may result in lower extremity alignment that decreases resultant load on the ACL.

While it has been clearly demonstrated that external focus based verbal instructions are effective in modifying knee kinematics and kinetics during landing movements, previous research has also shown that regardless of internal or external directed focus simple verbal instructions have been effective in the learning of new motor skills (37, 38, 41). Investigators (40-42, 109) over the years have provided evidence as to the validity of using verbal instructions to modify knee kinematics and kinetics during landing movements. There is little research if this knowledge from the motor learning field is effective in modifying foot placement angles during landing movements while also retaining any improvements of safe landing techniques. Specifically, that if verbal instruction cues introduced during practice can effectively create mechanical modifications and retain safe landing techniques in the long term.
Summary

ACL injuries are harmful and have become the most common ligamentous knee injury to athletes, resulting in over a 43% increase (54 per 100,000 persons-year to 77.4 per 100,000 persons-year) of reconstructions between 2000-2015 (55). Additionally, ACL injuries have been identified as a risk factor for developing future issues such as knee osteoarthritis (110).

Understanding the risk factors associated with ACL injuries during dynamic movements has and will continue to help develop injury prevention programs to reduce the number of ACL injuries. Specifically, how manipulating foot placement angle influences knee kinematics and kinetics during landing. Just like any other injury, effective prevention protocols are essential in reducing the number of ACL injuries. Determining if verbal instructions are effective, in not only teaching and improving foot placement angle, but retaining the safe landing techniques long-term during dynamic movements could help potentially reduce the number of ACL injuries in the future.
Chapter 3: Methods

The purpose of this study was to examine how introducing verbal cues effect the success of learning the proper foot progression angle during a dynamic landing movement. This chapter describes the methods implemented to conduct the study.

Participants

Participants were recruited either via flyers, emails, or word of mouth. Flyers were also provided to anyone who shows interest via word of mouth.

An *a priori* power analysis (G*Power, v3.1.9.1) was performed to determine the appropriate sample size for this study. Using data from existing literature for initial contact knee abduction angle and peak knee adduction moment (29), 6 participants per group were determined to be adequate to achieve 80% power at a statistical significance criterion of 0.05 with a large effect size ($f=0.40$) using Cohen’s $f$. As a result, 14 healthy, recreationally active female participants (age: $24.6 \pm 3.7$ yrs, height: $1.66 \pm 0.78$ m, mass: $62.01 \pm 9.46$ kg) were recruited from the university’s student body and surrounding community. Recreationally active was defined as being physically active at least three days per week for a minimum of 40 minutes each session. One of these sessions included dynamic movements, such as jumping and landing. Participants were excluded from the study if they had an injury at the time of study, had history of lower extremity injuries (i.e. sprains, ligament tears, or general pain) in the past six-months, or had a history of surgical intervention to the lower extremities (i.e. ligament rupture, meniscus repair, or fractures). All procedures were approved by the University Institutional Review Board (IRB) prior to the start of the study and all participants provided informed consent. Participants were then asked to fill out a Lower Extremity Functional Scale (LEFS) (111) which determined if a participant had any lower extremities difficulties with activities of daily living and athletic
tasks. The minimum detectable change and minimal clinically important difference of the LEFS is 9 scale points (with 90% confidence). Suggesting that if a participant scored lower than a 72 out of 80 on the LEFS they had a clinically meaningful change in lower extremity function, and were therefore excluded from the study. Participant age, height, and other demographic information were recorded. Participant weight was recorded from the static trial.

**Experimental Protocol**

**Participant Setup**

All testing was performed in the Biomechanics/Sports Medicine Laboratory at the University of Tennessee, Knoxville. Participants came into the lab for two data collection days to complete testing. Each day of participation and testing lasted approximately two hours. For both days of testing, participant setup consisted of the same procedures. Participants were asked to wear compression shorts and a fitted athletic t-shirt to accurately identify bony landmark locations for anatomical marker placement. Each participant was given 5 minutes to stretch and complete a warm-up jog on a treadmill at a self-selected pace. Anatomical retro-reflective markers were then placed bilaterally on bony landmarks of the participants’ lower extremities to define their segment coordinate systems. To define the pelvis, anatomical markers were placed on the right and left iliac crest as well as the right and left greater trochanters. Anatomical markers were also placed bilaterally on the lateral and medial femoral epicondyles, lateral and medial malleoli and first and fifth metatarsal heads. Five semi-rigid thermoplastic shells, each containing four retro-reflective markers, were then placed on the posterior pelvis between the posterior superior iliac spines, as well as bilaterally on the thighs and shanks, both approximately 50% between the proximal and distal anatomical markers. Finally, two semi-rigid thermoplastic
shells, each containing four retro-reflective markers, were placed bilaterally on the posterior heels.

A static trial was then collected, which consisted of the participant standing quietly with their arms crossed over their chest. Once the static trial was collected, the anatomical markers were removed and only the tracking markers remained. A dynamic ROM trial was then collected to auto-label the tracking markers during post-capture data processing. The dynamic ROM trial consisted of the participant extending the right leg, from the right hip, anteriorly, anteriolaterally at a 45° angle, laterally, posterolaterally at a 45° angle, and posteriorly. Between each position, the right leg was brought back to a standing position. Following these movements, the participant flexed their right hip and knee to 90°. The participant then flexed and extended the knee three times. With the right knee still bent at 90°, the participant plantarflexed and dorsiflexed the ankle three times. These ROMs were then repeated for the left leg. Finally, the participant stood with both feet on the ground and rotated their pelvis in a complete clock-wise circle, and finish in a quite standing position. Once the dynamic ROM trial was collected, data collection began.

Protocol

Testing consisted of two days (i.e. Day 1 and Day 2), scheduled within 24 hours of each other. Day 1 of testing consisted of five baseline trials and forty acquisition trials of bilateral drop-landings from 40 cm high. Day 2 of testing consisted of five retention trials of drop-landings from a box 40 cm high and five transfer trials of a stop-jump and land task.

On Day 1, participants were randomly assigned to one of two groups: control (C) or verbal instruction focus cue (VC). The verbal instruction cue was provided before every trial of acquisition testing. The VC was provided as follows: “land with 30 degrees of external rotation.” The control group participants was instructed to land at a self-selected FPA at the beginning of
acquisition, not every trial. Before testing began, the participant first performed five baseline bilateral drop landings from a 40 cm box onto the force plates with no instructions or advice provided to determine if their self-selected FPA was greater than 15°. If self-selected FPA was greater than 15° the participant was excluded from the study. Next, acquisition trials began with the participant either performing 40 drop-landings from a box onto the force plates receiving the verbal instruction focus cue before every trial or the control landing condition. Using a customized MATLAB code (MathWorks, Natick, MA, USA), FPA was calculated during each drop-landing trial using marker coordinate data. Feedback to help facilitate learning was then provided to the verbal instruction group in the form of a terminal feedback schedule (112). Feedback was provided after trials 1, 3, 6, 10, 15, 21, 28, 36. Each time feedback was given, the participant was given knowledge of what their FPA was (i.e. how much many degrees too wide or too narrow they landed, “2° too narrow.”).

On Day 2, each participant performed five retention trials of drop-landings from 40 cm high. However, no instruction or feedback was provided during these drop-landings. Once the retention testing was completed, participants performed a transfer test which consisted of a two-step stop and jump task. The participant took two steps towards the force plates, stopped before stepping onto the force plates, jumped as high as they could trying to touch a target above, and bilaterally landed onto the force plates. Participants were given 1 practice attempt to acclimate with the distance needed to step and determine target height. Five trials of the transfer test were performed. FPA was also recorded during retention and transfer testing.
**Instrumentation**

A twelve-camera infrared motion capture system (240 Hz, Vicon Motion Analysis Inc., Centennial, CO, USA) was used to collect static and dynamic movement trials. All cameras were calibrated before data collection to a minimum of 6,000 wand counts in order to ensure accurate marker tracking during data collection. Two 60x60 cm AMTI Force Platform (2000 Hz, BP600600, Advanced Mechanical Technology, Inc., Watertown, MA, USA) were used to measure ground reaction forces. Both force plates were zeroed and calibrated to ensure no excess noise and proper baseline was present during data collection.

**Data Reduction and Analysis**

Raw marker coordinate and ground reaction force data from the experimental protocol were imported into Visual3D software suite (v6, C-Motion, Inc., Rockville, MD, USA) to compute kinematic and kinetic data for the lower extremities. Since non-contact ACL injuries typically occur 40 ms after initial contact, only data during initial contact to 100 ms after initial contact were analyzed (70, 71). A VGRF threshold of 10 N indicated initial contact. Raw marker coordinate and ground reaction force data were low-pass filtered using a fourth-order, zero lag Butterworth filter with a cutoff frequency of 10 Hz (74). A seven-segment kinematic skeletal model, consisting of the pelvis, right and left thigh, shank, and foot was created using the standing static trial. Three-dimensional angles were calculated using the joint coordinate systems approach (113). Hip joint center approximations were located according to Weinhandl and O’Connor (114). The knee joint centers were determined as the midpoint between the lateral and medial epicondyle markers (113) and the ankle joint centers were determined as the midpoint between the lateral and medial malleoli markers. Internally applied three-dimensional joint kinetics were calculated using a Newton-Euler approach (115) and projected to the joint.
coordinate system (116). Body segment masses were estimated from Dempster et al. (117) and segment moment of inertias were estimated from Hanavan (118).

**Statistical Analysis**

Means and standard deviations for dependent variables (i.e. initial contact knee abduction and flexion angle, initial contact foot progression angle, and peak knee internal adduction and extension moments) were calculated for each participant. Group means and standard deviations were computed for the five trials of baseline, last five of acquisition, and the five trials of retention and transfer to create four blocks of time across testing points of analysis. A repeated measures (2 x 4) ANOVA with planned contrasts was used to compare the control and VC groups across the time. In the event of a significant main effect, baseline was compared to the acquisition, retention, and transfer blocks. In the event of a significant interaction, a paired samples t-test was done to compare baseline to acquisition, retention, and transfer within each group. An independent samples t-test was also performed to compare between groups within each testing block. Significance for all variables was determined with an alpha set at p ≤ 0.05.

All statistical analyses were performed using SPSS (v25.0, SPSS Inc., IL, USA). Cohen’s $d$ for pairwise comparisons were performed in G*Power to determine effect size.
Chapter 4: How Verbal Instructions Affect the Success in Learning a New Landing Technique and Reducing Risk Factors for ACL
Abstract

Approximately 70-80% of ACL injuries occur via a noncontact mechanism. These noncontact ACL injuries most commonly occur during jumping and/or landing movements. Landing is considered a high-risk movement, as poor landing technique has been linked to ACL injuries via an inability to support rapid changes in acceleration or deceleration concomitantly with high vertical ground reaction force. The foot and ankle form the initial parts of the lower extremity kinetic chain. Thus, positioning of the foot on the ground may influence the transmission of those forces from the ankle to the knee. Foot progression angle (FPA) is considered a modifiable ACL injury risk variable that can affect both hip, knee, and ankle kinematics and kinetics. The purpose of this study was to examine how introducing a verbal instruction effected the success in practicing and repeating a desired FPA modification during a landing movement, while also examining any changes in knee kinematics and kinetics.

Participants were tested over two days and performed 40 drop-landings on day 1 practicing the desired FPA modification. While on day 2, participants were tested to determine if the FPA modification was retained during five more drop-landing trials and five transfer test trials. Results indicated that participant who received the verbal instruction to promote the desired FPA modification significantly increased FPA and knee abduction angle at landing during practice and retention; whereas, the control group did not. No differences were found between or within groups during baseline or transfer tests. This suggest that while the verbal instruction cue was effective in promoting an increase in FPA and reducing some ACL injury risk factors during practice and retention, this cue may only be effective to tasks similar to what was practiced. The transfer test, however, was more dynamic and involved other goal orientated parts of the movement which is similar to dynamic movements as seen in typical ACL injury settings.
Introduction

The incidence of anterior cruciate ligament (ACL) reconstructions in the United States rose from 86,687 (32.9 per 100,000 person-years) in 1994 to 129,836 (43.5 per 100,000 person-years) in 2006 (1). Approximately 70-80% of ACL injuries occur via a noncontact mechanism (2-5), most commonly occur during jumping and/or landing movements (6-11). Landing is considered a high-risk movement (7, 9, 12), as poor landing technique has been linked to ACL injuries via an inability to support large decelerations concomitantly with high vertical ground reaction forces (VGRF). Previous research has found numerous factors that may increase the risk for ACL injuries during landing movements such as decreased knee flexion angle, increased knee abduction angle, excessive internal or external tibial rotation angle, increased internal knee adduction moment, and decreased internal hip rotation moments all of which promote medial knee collapse (12-16).

It has been extensively shown that gender discrepancies exist in noncontact ACL injury rates, with females reportedly being 2 to 6 times greater injury risk compared to their male counterparts (12, 13, 19). Biomechanically, females have been found to land with decreased knee flexion angle at initial contact as well as increased peak internal hip extension moment during landing (7, 21, 22). Females demonstrated significantly less knee flexion at landing as compared to males, 17.4º ± 12.9 vs 31.1 º ± 9.9 (22). This suggests females land with a more erect posture, thus a lower ability to absorb the high VGRF during landing (13). Additionally, females have been found to land with increased initial contact knee abduction angle and peak knee adduction moment as compared to males (7, 32). This suggests that females possibly have lesser control of frontal plane motion of the knee joint during landing, which may put them at greater risk for possible known ACL injury mechanisms like medial knee collapse.
Research has now begun to investigate the role that the ankle and/or foot may play on the knee during landing movements, as foot positioning on the ground may influence the transmission of forces from the ankle to the knee (27). Foot progression angle (FPA), is defined as the angular difference between the long axis of the foot and the mid-sagittal plane of an individual at initial contact during foot contact with the ground (28). FPA is considered a modifiable ACL injury risk variable that can affect both hip, knee, and ankle kinematics and kinetics (28, 29). Tran et al. (29) found that landing at a toe-in FPA of 30° promoted greater increases in ACL risk factors such as increased peak internal knee adduction moment, initial contact knee abduction and hip adduction angles compared to landing with a toe-out FPA of 30°. Modifications to FPA during landing movements appear to alter lower extremity biomechanics and can be a target for movement modifications to reduce the risk for ACL injuries in females (33, 34). That said, the method of implementing these modifications has ranged from physical targets to verbal instructions but with no results as to the efficacy retention of the new landing movement modification.

The use of verbal instructions has shown to be effective in teaching and altering motor skill acquisition or improvements (35-38), as well as reducing biomechanical risk factors of lower extremity injuries, such as the ACL (10, 39). Milner et al. (41) found that simple verbal instructions were most effective in reducing VGRF in a drop-landing movement while also increasing peak knee flexion angle from 87.1° to 94.6°. Additionally, an increase in hip and knee flexion angles at initial contact were found from the use of verbal instructions (105). Laughlin et al., (17) further demonstrated that using verbal instructions were effective in reducing peak ACL loading. Determining effective verbal instructions is critical for teaching and improving foot placement angle, as well as retaining the safe landing techniques long-term during dynamic
movements. However, little research currently exists to determine an effective method of instruction to implement a safe FPA landing modifications without constant feedback post skill acquisition, specifically with a female population.

The purpose of this study was to examine how introducing a verbal instruction cue effects the success of practicing and repeating proper foot placement (i.e. external foot rotation) during a dynamic landing movement compared to no instruction. A secondary purpose was to further determine if external foot rotation is effective in reducing known ACL biomechanical risk factors such as initial contact knee flexion and abduction angles, and internal knee extension and adduction moments. Our first hypothesis was that introducing a verbal instruction focus cue would increase the success of practicing and repeating the desired FPA modification, while also leading to increased transfer of FPA modification to a secondary landing task. Lastly, our second hypothesis was that external foot rotation at landing would produce a greater decrease for known ACL injury risk factors: initial contact knee abduction and flexion angles, and peak knee internal adduction and extension moments.

Methods

All procedures were approved by the Institutional Review Board prior to commencing the study and all participants provided written informed consent. Fourteen healthy, recreationally active females (age: 24.6 ± 3.7 yrs, height: 1.66 ± 0.78 m, mass: 62.01 ± 9.46 kg) volunteered to participate in the study. Recreationally active was defined as engaging in physical activity three days per week for a minimum of 40 minutes per session. While one session including running or jumping. An a priori power analysis was performed using data from existing literature for initial contact knee abduction angle and peak knee adduction moment (29) to determine 6 participants per group was adequate to achieve 80% power at a statistical significance criterion of 0.05 with a
large effect size ($f = 0.50$) using Cohen’s $f$. Inclusion criteria included the followings: injury free at the time of the study, no lower limb injuries for the past six months, no history of lower extremity surgical intervention or ACL injuries, and scoring 72 or better on the Lower Extremity Functional Scale (LEFS). The minimal detectable change and minimal clinically important differences on the LEFS is 9, which suggests that a change of greater than 9 scale points on the LEFS is a true change in lower extremity function (111). If a participant scored lower than a 72 out of 80 on the LEFS, that participant was excluded from the study.

Testing occurred over a two-day period. Participants were required to complete their second testing session within 24 hours of their first scheduled testing session. For both testing sessions, participants wore compression shorts, a fitted athletic t-shirt, and a standardized laboratory shoe (Nike Pegasus). Prior to data collection, participants were asked to complete a five-minute warm-up at a self-selected pace on a treadmill, 18 retro-reflective anatomical markers were placed on the right and left acromion processes, right and left iliac crests, the right and left greater trochanters, bilaterally on the lateral and medial femoral epicondyles, lateral and medial malleoli and first and fifth metatarsal heads (Figure 1). Clusters of four non-collinear markers on rigid thermoplastic shells were attached to the posterior pelvis, lateral thigh, and lateral shank using neoprene straps to track segment movement during motion trials. A three-second static trial was then collected, and the 18 anatomical markers were removed. Three-dimensional marker coordinate and force plate data were collected using a 12-camera infrared motion capture system (240 Hz, Vicon, Inc., CO, USA) while ground reaction force data were collected synchronously with two AMTI Force Platform (2000 Hz, Advanced Mechanical Technology, Inc., MA, USA).
On Day 1, each participant performed five baseline bilateral drop landings from a 40 cm box onto the force plates with no instructions provided to determine if their self-selected FPA was greater than 15°. If self-selected FPA was greater than 15° the participant was excluded from the study. Participants were then assigned to one of two groups (Table 1), using a counterbalance method: control or verbal instruction focus cue (VC). Next, acquisition trials began with the participant performing 40 trials of drop-landings from a box onto the force plates. Using a customized MATLAB code (MathWorks, MA, USA), FPA during each trial was calculated using marker coordinate data and recorded for both groups. The control group participants were instructed to land at a self-selected FPA only at the beginning of acquisition. The VC group was provided a verbal instruction cue as follows: “Land with 30 degrees of external rotation.” The verbal instruction cue was provided before every trial of acquisition testing. A terminal feedback schedule to help facilitate learning was provided to the VC group (112). Feedback was provided after trials 1, 3, 6, 10, 15, 21, 28, 36. Feedback was given in the form of knowledge of FPA error (i.e. how much many degrees too wide or too narrow they landed, “2° too narrow.”). After 40 trials, day 1 testing concluded.

On Day 2, participants performed five retention trials of drop-landings. However, no instruction or feedback was provided to either group during these trials. Participants then performed a transfer test which consisted of a two-step approach, jump for maximum height and bilateral landing onto the force plates. Participants were given 1 practice attempt to acclimate with the distance needed to step and jump. Five trials of the transfer test were then performed.

Marker coordinate and force plate data from the experimental protocol were imported into Visual3D software suite (v6, C-Motion, Inc., Rockville, MD, USA) to compute kinematic and kinetic data for the lower extremity. Raw marker coordinate and ground reaction force data
were low-pass filtered using a fourth-order, zero lag Butterworth filter with a cutoff frequency of 10 Hz (74). Hip joint center approximations were located according to Weinhandl and O’Connor (114). The knee joint centers were determined as the midpoint between the lateral and medial epicondyle markers (113) and the ankle joint centers were determined as the midpoint between the lateral and medial malleoli markers. Since non-contact ACL injuries typically occur 40 ms after initial contact, only data during initial contact to maximal knee flexion was analyzed (70, 71). Initial contact was defined as the instant vertical ground reaction force exceeded a threshold of 10 N. Three-dimensional kinematics were calculated using a joint coordinate systems approach (113). Internally applied joint kinetics were calculated via inverse dynamics, normalized to body mass, (115) and expressed in the joint coordinate system. Positive and negative joint angles and joint moments were defined using the right hand rule (i.e. knee flexion and knee abduction angle would be negative).

Initial contact knee abduction and flexion angle, initial contact foot progression angle, and peak knee internal adduction and extension moments were identified for each trial of baseline, acquisition, retention and transfer trials for each participant. Means and standard deviations for dependent were calculated for each participant. Group means and standard deviations were computed for the five trials of baseline, last five of acquisition, and the five of retention and transfer trials to create four blocks of time across testing points of analysis. A repeated measures (2 x 4) ANOVA with planned contrasts was used to compare the control and VC groups across the time. In the event of a significant main effect, baseline was compared to the acquisition, retention, and transfer blocks. In the event of a significant interaction, a paired samples t-test was done to compare baseline to acquisition, retention, and transfer within each group. An independent samples t-test was also performed to compare between groups within
each testing block. Significance for all variables was determined with an alpha set at \( p \leq 0.05 \). All statistical analyses were performed using SPSS (v25.0, SPSS Inc., IL, USA). Cohen’s \( d \) was computed to assess the effect size of the mean difference.

**Results**

There was an interaction for IC FPA between groups over time (\( p = 0.003 \), Table 2). Specifically, the VC group demonstrated a 21° increase in IC FPA from baseline to acquisition (\( p = 0.001, d = 2.91 \)) and a 14.2° increase from baseline to retention (\( p = 0.002, d = 2.23 \)). Furthermore, the VC group was significantly different from the Control group in IC FPA at acquisition (\( p = 0.001, d = 2.51 \)) and retention blocks (\( p = 0.007, d = 1.73 \)). An interaction for IC knee abduction angle was also determined between groups over time (\( p = 0.029 \)). Specifically, the VC group demonstrated a 5.9° increase in IC knee abduction angle from baseline to acquisition (\( p = 0.012, d = 1.06 \)) and a 2.7° increase from baseline to retention (\( p = 0.015, d = 0.56 \)). The Control group showed no within group differences across time.

For IC knee flexion angle, there was no significant interaction (\( p = 0.940 \)) but a significant main effect for time was found for both groups (\( p = 0.041 \)). Both the Control and VC groups significantly increased their IC knee flexion angle from baseline to acquisition (\( p = 0.005, d = 0.79 \)). No significant differences were found between or within groups nor interactions for peak knee adduction moment (\( p = 0.105 \)) and peak knee extensor moment (\( p = 0.254 \)). Figures 2 and 3 display the trends of each kinematic and kinetic variable between groups and across time.

**Discussion**

The aim of this study was to examine how introducing a verbal instruction cue effects the success of practicing and repeating proper foot placement (i.e. external foot rotation) during a dynamic landing movement. A secondary purpose was to further determine if external foot
rotation was effective in reducing known ACL biomechanical risk factors such as, knee abduction angle, knee flexion angle, and internal knee adduction moment. Our first hypothesis that the verbal instruction cue given to participants would increase FPA during practice (acquisition) and retention of a dynamic landing movement was supported. Additionally, our second hypothesis was partially supported, in that, the external foot rotation achieved did promote the reduction of known ACL risk factors initial contact knee flexion angle and abduction angle during acquisition and retention (12-16, 29). While no differences or changes were detected for knee joint kinetics when receiving the verbal instruction cue, initial contact knee joint angles significantly changed from baseline to the end of acquisition and from baseline to retention which demonstrated a level of effectiveness in reducing known ACL injury risk factors during landing. Moreover, the VC group demonstrated significantly increased IC FPA values at acquisition and retention blocks as compared to the Control group. However, when comparing our results from baseline to the transfer test, initial contact FPA, knee flexion, and knee abduction angles all were not significantly different. This suggests that the verbal instruction cue that was given during practice did not translate to different dynamic landing tasks as predicted (35-38). That being said, additional practice (increased number of acquisition trials) could be a potential aspect of future research that is considered. Does the additional practice result in increased retention of the modification to different landing tasks? Or does it result in different kinematic and kinetics at the knee joint?

The verbal instruction group experienced significant changes for initial contact FPA during testing. A significant increase in FPA from baseline to acquisition and a significant increase in FPA from baseline to retention, which shows that landing technique modifications were observed for the verbal instruction group and not in the control group as predicted.
However, the landing technique modification was not retained in a different dynamic landing
task. Additionally, the decreased knee abduction angle experienced verbal instruction group at
acquisition and retention, only, demonstrated that the kinematic change was only present when
verbal instruction cue was provided or when the task was the same.

Previous literature has demonstrated that verbal instructions are effective in promoting
changes, increased skill acquisition or improvements (35-38), while also reducing the risk for
lower extremity injury. One study investigated how the use of verbal instructions influence the
learning of a new movement during a landing task, specifically assessing biomechanical risk
factors and the retention and transfer of the movement skills that were taught (40). Welling et al
(40) found that within group comparisons resulted in a 1-week improved landing technique
score during retention testing. The results of the current study further support the previous results
of increased landing technique retention. The verbal instruction group had a significantly
increased FPA of -23.8 ± 9.3° at the end of acquisition and at retention, -17 ± 8.7°, as compared
to a baseline FPA of -2.8 ± 2.4°. Thus, the results of this study further support previous literature
as to the efficacy of using verbal instructions as a method to promote the acquisition,
improvement, and retention of a new or modified skill/technique.

Tran et al. (29) previously demonstrated that an increase in toe-out FPA would lead not
only to a decrease in knee abduction angle, but the promotion of a knee adduction angle, which
was supported during this current study. Participants who received the verbal instruction cue
significantly changed their frontal plane knee angle from -0.2° at baseline to 6.1° at the end of
acquisition and 2.9° at retention. This further supports that notion that modification of the
ankle/foot plays a key role in initial contact knee kinematics, and more research is necessary as
to how the ankle effects joint responses and possible injuries up the lower extremity kinetic
Moreover, FPA modifications have been shown to produce a significant increase in initial contact knee flexion angle (105), which this current study also found from baseline to the end of acquisition, -16.2° ± 5.1 to -20.4° ± 4.6. That said, the same significant change in initial contact knee flexion angle was found for the control group, -16.6° ± 4.1 to -19.3° ± 4.0, which could be attributed to performing 40 drop-landings and the need to reduce cumulative loads imposed on the knee over time (13, 21). This suggests that further research is required to determine which verbal instruction cues are more effective than others in reducing known ACL risk factors and for which specific movements.

Previous research (7, 9, 12) has established that landing is considered a high risk movement for injury, while Padua et al. (28) also found that poor landing technique further increases the risk for lower extremity injuries—specifically to the ACL and ankle instability. Modification to FPA during landing movements have been found to reduce risk factors for ACL injury in the knee and hip such as, initial contact knee flexion angle, knee abduction angle, internal peak knee adduction moment, and peak hip extension moment (28, 29, 75, 82). This current study demonstrated a significant decrease in knee kinematic ACL injury risk factors when verbal instruction was given and during retention testing. Additionally, while not significant, it should be noted that peak knee adduction and peak knee extension moments all decreased from baseline to acquisition, retention, and transfer. Therefore, the results of this current study support previous literature on the benefits of a toe-out FPA modification and the reduction in known ACL injury risk factors when the desired FPA is achieved.

There are certain limitations that should be considered from this study. Firstly, all participants performed a drop-landing movement during baseline, acquisition, and retention which may not reflect that type of landing movements and heights experienced in sport or other
dynamic situations. Secondly, all participants wore a laboratory provided shoe during testing, whereas, shoe types and build vary based on movement or surface specificity. Finally, it should be noted that while there was a minimum threshold for being recreationally active to participate, certain participants were currently involved with division one athletics or intramural teams while others may have only met the minimum requirements. This may effect how certain participants react over time to a verbal instruction or joint responses to dynamic movements.

**Conclusion**

Our findings suggest that the use of a verbal instruction cue was effective in promoting the success of practice and retention of a desired FPA landing technique modification. Additionally, the external foot rotation that was achieved demonstrated a reduction in known ACL risk factors such as, initial contact knee abduction and knee flexion angles in the presence of verbal instruction. However, as the task or type of dynamic landing movement changed, the specific verbal instruction cue employed in this study lost effectiveness in retaining any kinematic or kinetic changes as seen during practice of the drop-landing movement. Future research is needed to determine operative verbal instruction cues in not only promoting landing technique modifications during practice of a landing task; but, also promoting those modifications when the dynamic environment is different than that of practice.
References


31. Hewett TE, Torg JS, Boden BP. Video Analysis of Trunk and Knee Motion During Non-Contact Anterior Cruciate Ligament Injury in Female Athletes: Lateral Trunk and Knee


Appendices
Appendix A. Participant Demographics.

Table 1. Participant demographics: mean ± STD.

<table>
<thead>
<tr>
<th>Group</th>
<th>Age (years)</th>
<th>Mass (kg)</th>
<th>Height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>23.1 ±2.85</td>
<td>61.3 ±12.13</td>
<td>1.68 ±9.51</td>
</tr>
<tr>
<td>Verbal Instruction</td>
<td>26.1 ±4.01</td>
<td>62.7 ±6.74</td>
<td>1.64 ±5.99</td>
</tr>
</tbody>
</table>
### Appendix B. Chapter 4 Tables.

Table 2. Kinematic and Kinetic repeated measures ANOVA results: mean ± STD.

<table>
<thead>
<tr>
<th>Table 2 Kinematic and Kinetic repeated measures ANOVA results: mean ± STD.</th>
<th>Baseline</th>
<th>Acquisition</th>
<th>Retention</th>
<th>Transfer</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>VC</td>
<td>Control</td>
<td>VC</td>
<td>Control</td>
</tr>
<tr>
<td><strong>IC Foot Progression Angle (˚)</strong>&lt;sup&gt;§,1,2&lt;/sup&gt;</td>
<td>-4.9 ±4.3</td>
<td>-2.8 ±2.4</td>
<td>-5.2 ±4.94</td>
<td>-23.8 ±9.2</td>
<td>-5.9 ±2.5</td>
</tr>
<tr>
<td><strong>IC Knee Flexion Angle (˚)</strong>&lt;sup&gt;*,a&lt;/sup&gt;</td>
<td>-16.6 ±4.1</td>
<td>-16.2 ±5.1</td>
<td>-19.3 ±4.0</td>
<td>-20.4 ±4.6</td>
<td>-15.9 ±7.4</td>
</tr>
<tr>
<td><strong>IC Knee Abduction Angle (˚)</strong>&lt;sup&gt;§,1,2&lt;/sup&gt;</td>
<td>-0.2 ±2.8</td>
<td>0.2 ±3.9</td>
<td>0.4 ±2.8</td>
<td>6.1 ±6.8</td>
<td>0.4 ±2.5</td>
</tr>
<tr>
<td><strong>Peak Knee Adduction Moment (Nm/Kg°)</strong></td>
<td>0.13 ±0.15</td>
<td>0.25 ±0.29</td>
<td>0.10 ±0.18</td>
<td>0.07 ±0.19</td>
<td>0.16 ±0.14</td>
</tr>
<tr>
<td><strong>Peak Knee Extension Moment (Nm/Kg°)</strong></td>
<td>2.35 ±0.44</td>
<td>2.59 ±0.55</td>
<td>2.37 ±0.44</td>
<td>2.43 ±0.59</td>
<td>2.34 ±0.44</td>
</tr>
</tbody>
</table>

<sup>§</sup> significant group × time interaction  
<sup>*</sup> significant main effect of time  
<sup>†</sup> significant main effect of group  
<sup>a</sup> difference between baseline and acquisition  
<sup>1</sup> difference between baseline and acquisition for VC  
<sup>2</sup> difference between baseline and retention for VC  
<sup>3</sup> difference between baseline to transfer for VC
Figure 1. Marker Locations anatomical markers, cluster markers, and joint axes of rotation. Anatomical markers are used to define joint centers and cluster markers used to track segment movement during data collection. Anatomical markers (yellow) were removed prior to data collection.
Figure 2. Kinematic Performance Curves
* Significant difference between groups at block. † Significant difference within VC group from baseline. ‡ Significant difference within Control group from baseline.
Figure 3. Kinetic Performance Curves
Appendix D. Informed Consent

Informed Consent

Effects of Verbal Instructions on Learning Safe Landing Technique and Reducing ACL Injury

INTRODUCTION
You are invited to participate in a research study conducted in the University of Tennessee Biomechanics Lab (HPER 136). The purpose of this study is to determine the effects of verbal instructions on learning and retaining safe landing technique in order to reduce ACL injuries.

ELIGIBILITY
To participate in this study, you must be a female between the ages of 18 and 35 and be currently recreationally active. We define recreationally active as being physically active at least 3 days per week for a minimum of 40 minutes each session, and one session must include dynamic lower extremity movements, such as jumping or landing. You must NOT have: undergone surgery for a lower extremity injury (e.g., ligament rupture, meniscus repair, bone fracture), have had an ACL injury, or suffered a lower extremity injury in the past six months.

INFORMATION ABOUT PARTICIPANTS’ INVOLVEMENT IN THE STUDY
You will come into the Biomechanics Lab for two sessions, which will last approximately 1.5 hours.

You will come into the Biomechanics Lab, where you will read the informed consent document and given time to ask any questions pertaining to the study. You will also complete the Lower Extremity Functional Scale to ensure that you are qualified to participate. A score of 71/80 or lower on the scale will exclude you from the study. You then will change into Spandex shorts and a generic t-shirt, which will be provided. Height and weight will be taken, followed by a 5-minute warmup jog and stretching of the lower extremities.

Anatomical and tracking markers will be placed on you, which will be used to track movement data throughout the session. You will be asked to complete 45 landings trials on Day 1 and receive a verbal instruction before each landing. On Day 2, you will perform 10 landing trials. For all landing tasks, you will drop from a box 40-cm off the ground. There is no success or failure criterion for a trial. The session will conclude once all trials are collected.

RISKS
Because a dynamic landing movement is being performed, there is a possibility of lower extremity injury. You will be required to warmup with a 5-minute jog and stretching of the lower extremity to ensure their muscles are ready for this dynamic movement. The speed at which this movement will be performed will be slower than a game-like situation, ensuring that you will have control of their body throughout the landing. Practice runs will be before data collection begins until the participant feels comfortable with the route they are to take.
BENEFITS
There will be no direct benefits to you. The data collected from your participation will help provide a better understanding of how verbal instructions during landing effect ACL risk factors. The data collected may also provide athletes, coaches, and researchers a better insight into how to improve cutting tasks to reduce the risk of ACL injuries occurring.

CONFIDENTIALITY
The information collected in this study will be kept confidential. You will be identified by a given number. Data will be stored securely, both in a password-protected computer desktop and in a locked drawer in the Biomechanics lab. Information will be available only to persons conducting the study unless participants specifically give permission in writing to do otherwise. No reference will be made in oral or written reports which could link you to the study.

CONTACT INFORMATION
If you have questions at any time about the study or the procedures, (or you experience adverse effects because of participating in this study,) you may contact the researcher, Alec Genter, at agenter@vols.utk.edu or (865) 974-2091 (office number), or Dr. Joshua Weinhandl at jweinhan@utk.edu. If you have questions about your rights as a participant, you may contact the University of Tennessee IRB Compliance Officer at utkirb@utk.edu or (865) 974-7697.

PARTICIPATION
Your participation in this study is voluntary; you may decline to participate without penalty. If you decide to participate, you may withdraw from the study at any time without penalty and without loss of benefits to which you are otherwise entitled. If you withdraw from the study before data collection is completed your data will be permanently deleted from our system, and any forms with identification information will be shredded.

CONSENT
I have read the above information. I have received a copy of this form. I agree to participate in this study.

Participant's Name (printed) ______________________________________________

Participant's Signature ___________________________ Date __________
Appendix E. Lower Extremity Functional Scale

Lower Extremity Functional Scale

We are interested in knowing whether or not you are having any difficulty at all with the activities listed below. Please provide an honest answer for each activity.

**KEY**

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Extreme difficulty or unable to perform activity</td>
</tr>
<tr>
<td>1</td>
<td>Quite a bit of difficulty</td>
</tr>
<tr>
<td>2</td>
<td>Moderate difficulty</td>
</tr>
<tr>
<td>3</td>
<td>A little bit of difficulty</td>
</tr>
<tr>
<td>4</td>
<td>No difficulty</td>
</tr>
</tbody>
</table>

Today, _do you_ or _would you_ have any difficulty at all with:

<table>
<thead>
<tr>
<th>Activity</th>
<th>Extreme</th>
<th>Quite a bit</th>
<th>Moderate</th>
<th>Minimal</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Any of your usual work, housework or school activities</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Your usual hobbies, recreational or sporting activities</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Getting into or out of the bath</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Walking between rooms</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Putting on your shoes or socks</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Squatting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Lifting an object, like a bag of groceries from the floor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Activity</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>---</td>
<td>-------------------------------------------------------------------------</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>8</td>
<td>Performing light activities around your home</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>9</td>
<td>Performing heavy activities around your home</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>10</td>
<td>Getting into or out of a car</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>11</td>
<td>Walking 2 blocks</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>12</td>
<td>Walking a mile</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>13</td>
<td>Going up or down 10 stairs (about 1 flight)</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>14</td>
<td>Standing for 1 hour</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>15</td>
<td>Sitting for 1 hour</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>16</td>
<td>Running on even ground</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>17</td>
<td>Running on uneven ground</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>18</td>
<td>Making sharp turns while running fast</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>19</td>
<td>Hopping</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>20</td>
<td>Rolling over in bed</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>
November 20, 2018

Joshua Weinhandl,
UTK - Coll of Education, Hlth, & Human - Kinesiology Recreation & Sport Studies

Re: UTK IRB-18-04817-XP
Study Title: HOW VERBAL INSTRUCTIONS AFFECT THE SUCCESS IN LEARNING A NEW LANDING TECHNIQUE AND REDUCING RISK FACTORS FOR ACL INJURY

Dear Joshua Weinhandl:

The UTK Institutional Review Board (IRB) reviewed your application for the above referenced project. It determined that your application is eligible for expedited review under 45 CFR 46.110(b)(1), categories (4), (6) and (7). The IRB has reviewed these materials and determined that they do comply with proper consideration for the rights and welfare of human subjects and the regulatory requirements for the protection of human subjects.

Therefore, this letter constitutes full approval by the IRB of your application (version 1.1) as submitted, including:
- Informed Consent_Verbal_Instruction_Landing Technique - Version 1.1
- Recruitment Flyer_Verb Instruc Safe Land - Version 1.0
- Recruitment Email_Verbal Instruction_SafeLanding - Version 1.0
- Screening Questions - Version 1.0
- LEFS document - Version 1.0

The above listed documents have been dated and stamped IRB approved. Approval of this study will be valid from 11/20/2018 to 11/19/2019.

In the event that subjects are to be recruited using solicitation materials, such as brochures, posters, web-based advertisements, etc., these materials must receive prior approval of the IRB. Any revisions in the approved application must also be submitted to and approved by the IRB prior to implementation. In addition, you are responsible for reporting any unanticipated serious adverse events or other problems involving risks to subjects or others in the manner required by the local IRB policy.

Finally, re-approval of your project is required by the IRB in accord with the conditions specified above. You may not continue the research study beyond the time or other limits specified unless you obtain prior written approval of the IRB.
Appendix G. Individual Results

Table 3. Individual participant demographics.

<table>
<thead>
<tr>
<th>SUBJECT</th>
<th>AGE (yrs)</th>
<th>HEIGHT (m)</th>
<th>MASS (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>26</td>
<td>1.71</td>
<td>80.1</td>
</tr>
<tr>
<td>2</td>
<td>23</td>
<td>1.60</td>
<td>70.7</td>
</tr>
<tr>
<td>3</td>
<td>23</td>
<td>1.55</td>
<td>47.9</td>
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<tr>
<td>4</td>
<td>20</td>
<td>1.66</td>
<td>59.9</td>
</tr>
<tr>
<td>5</td>
<td>21</td>
<td>1.62</td>
<td>60.4</td>
</tr>
<tr>
<td>6</td>
<td>27</td>
<td>1.70</td>
<td>57.5</td>
</tr>
<tr>
<td>7</td>
<td>28</td>
<td>1.69</td>
<td>57.4</td>
</tr>
<tr>
<td>8</td>
<td>27</td>
<td>1.61</td>
<td>68.5</td>
</tr>
<tr>
<td>9</td>
<td>22</td>
<td>1.68</td>
<td>50.1</td>
</tr>
<tr>
<td>10</td>
<td>27</td>
<td>1.73</td>
<td>68.3</td>
</tr>
<tr>
<td>11</td>
<td>20</td>
<td>1.66</td>
<td>57.8</td>
</tr>
<tr>
<td>12</td>
<td>26</td>
<td>1.56</td>
<td>52.3</td>
</tr>
<tr>
<td>13</td>
<td>22</td>
<td>1.86</td>
<td>75.3</td>
</tr>
<tr>
<td>14</td>
<td>33</td>
<td>1.67</td>
<td>61.9</td>
</tr>
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</table>
Table 4. Individual Initial Contact and Peak Knee Kinematics: mean ± STD

<table>
<thead>
<tr>
<th>SUBJECT</th>
<th>GROUP</th>
<th>IC KNEE FLEXION ANGLE (°)</th>
<th>IC KNEE ABDUCTION ANGLE (°)</th>
<th>PEAK KNEE EXTENSION MOMENT (Nm/Kg⁻¹)</th>
<th>PEAK KNEE ADDUCTION MOMENT (Nm/Kg⁻¹)</th>
<th>IC FOOT PROGRESSION ANGLE (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S01</td>
<td>Control</td>
<td>-22.6 ±3.3</td>
<td>1.9 ±1.9</td>
<td>0.07 ±0.21</td>
<td>2.95 ±0.10</td>
<td>-8.2 ±2.4</td>
</tr>
<tr>
<td>S02</td>
<td>Verbal Instruction</td>
<td>-15.8 ±7.3</td>
<td>-3.2 ±3.1</td>
<td>0.33 ±0.15</td>
<td>2.64 ±0.29</td>
<td>-14.6 ±13.9</td>
</tr>
<tr>
<td>S03</td>
<td>Control</td>
<td>-11.2 ±1.0</td>
<td>-4.7 ±0.9</td>
<td>0.40 ±0.07</td>
<td>2.29 ±0.12</td>
<td>-2.6 ±4.1</td>
</tr>
<tr>
<td>S04</td>
<td>Verbal Instruction</td>
<td>-18.9 ±4.1</td>
<td>-1.7 ±1.1</td>
<td>0.27 ±0.30</td>
<td>3.41 ±0.10</td>
<td>-5.3 ±2.9</td>
</tr>
<tr>
<td>S05</td>
<td>Control</td>
<td>-18.9 ±2.4</td>
<td>0.6 ±1.6</td>
<td>0.21 ±0.11</td>
<td>2.63 ±0.22</td>
<td>-6.6 ±3.8</td>
</tr>
<tr>
<td>S06</td>
<td>Verbal Instruction</td>
<td>-10.3 ±2.3</td>
<td>4.2 ±2.7</td>
<td>0.11 ±0.20</td>
<td>2.90 ±0.19</td>
<td>-13.5 ±14.0</td>
</tr>
<tr>
<td>S07</td>
<td>Control</td>
<td>-16.0 ±4.5</td>
<td>1.7 ±1.7</td>
<td>0.07 ±0.05</td>
<td>2.40 ±0.06</td>
<td>-2.6 ±3.5</td>
</tr>
<tr>
<td>S08</td>
<td>Verbal Instruction</td>
<td>-16.3 ±0.2</td>
<td>-0.04 ±2.2</td>
<td>0.26 ±0.08</td>
<td>1.93 ±0.05</td>
<td>-11.9 ±9.7</td>
</tr>
<tr>
<td>S09</td>
<td>Control</td>
<td>-16.7 ±4.2</td>
<td>0.02 ±0.6</td>
<td>0.19 ±0.12</td>
<td>2.22 ±0.12</td>
<td>-5.4 ±1.3</td>
</tr>
<tr>
<td>S10</td>
<td>Verbal Instruction</td>
<td>-22.6 ±4.0</td>
<td>8.3 ±2.9</td>
<td>-0.14 ±0.05</td>
<td>2.10 ±0.14</td>
<td>-18.6 ±11.6</td>
</tr>
<tr>
<td>S11</td>
<td>Control</td>
<td>-18.7 ±3.1</td>
<td>1.1 ±0.9</td>
<td>0.06 ±0.07</td>
<td>1.84 ±0.13</td>
<td>-4.4 ±1.8</td>
</tr>
<tr>
<td>S12</td>
<td>Verbal Instruction</td>
<td>-17.4 ±3.9</td>
<td>9.9 ±6.5</td>
<td>0.24 ±0.27</td>
<td>2.06 ±0.45</td>
<td>-17.5 ±10.7</td>
</tr>
<tr>
<td>S13</td>
<td>Control</td>
<td>-14.1 ±7.4</td>
<td>1.1 ±1.1</td>
<td>0.13 ±0.13</td>
<td>2.23 ±0.28</td>
<td>-7.6 ±4.2</td>
</tr>
<tr>
<td>S14</td>
<td>Verbal Instruction</td>
<td>-19.1 ±4.5</td>
<td>-0.3 ±2.89</td>
<td>0.16 ±0.05</td>
<td>2.43 ±0.22</td>
<td>-6.6 ±8.9</td>
</tr>
</tbody>
</table>
### Appendix H: Statistics Tables

#### H. 1 Initial Contact Foot Progression Angle ANOVA

**Tests of Within-Subjects Effects**

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
<th>Noncent. Parameter</th>
<th>Observed Power*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>1024.028</td>
<td>3</td>
<td>341.342</td>
<td>16.674</td>
<td>.000</td>
<td>.882</td>
<td>50.922</td>
<td>1.000</td>
</tr>
<tr>
<td>Greenhouse-Geisser</td>
<td>1024.028</td>
<td>2.332</td>
<td>439.201</td>
<td>16.674</td>
<td>.000</td>
<td>.882</td>
<td>36.877</td>
<td>1.000</td>
</tr>
<tr>
<td>Huynh-Feldt</td>
<td>1024.025</td>
<td>3.000</td>
<td>341.342</td>
<td>16.674</td>
<td>.000</td>
<td>.882</td>
<td>50.922</td>
<td>1.000</td>
</tr>
<tr>
<td>Lower-bound</td>
<td>1024.025</td>
<td>1.000</td>
<td>1024.826</td>
<td>16.674</td>
<td>.002</td>
<td>.882</td>
<td>16.874</td>
<td>.992</td>
</tr>
<tr>
<td>Time * Group</td>
<td>925.077</td>
<td>3</td>
<td>396.359</td>
<td>15.063</td>
<td>.000</td>
<td>.557</td>
<td>45.169</td>
<td>1.000</td>
</tr>
<tr>
<td>Greenhouse-Geisser</td>
<td>925.077</td>
<td>2.332</td>
<td>396.762</td>
<td>15.063</td>
<td>.000</td>
<td>.557</td>
<td>35.120</td>
<td>.999</td>
</tr>
<tr>
<td>Huynh-Feldt</td>
<td>925.077</td>
<td>3.000</td>
<td>396.359</td>
<td>15.063</td>
<td>.000</td>
<td>.557</td>
<td>45.169</td>
<td>1.000</td>
</tr>
<tr>
<td>Lower-bound</td>
<td>925.077</td>
<td>1.000</td>
<td>925.977</td>
<td>15.063</td>
<td>.002</td>
<td>.557</td>
<td>15.163</td>
<td>.945</td>
</tr>
</tbody>
</table>

*a. Computed using alpha = .05*

**Tests of Between-Subjects Effects**

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
<th>Noncent. Parameter</th>
<th>Observed Power*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>4463.214</td>
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<td>4463.214</td>
<td>72.777</td>
<td>.000</td>
<td>.858</td>
<td>72.777</td>
<td>1.000</td>
</tr>
<tr>
<td>Group</td>
<td>742.123</td>
<td>1</td>
<td>742.123</td>
<td>12.101</td>
<td>.005</td>
<td>.502</td>
<td>12.101</td>
<td>.891</td>
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<tr>
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<td>735.927</td>
<td>12</td>
<td>61.327</td>
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</table>

*a. Computed using alpha = .05*
### Independent Samples Test

<table>
<thead>
<tr>
<th></th>
<th>Levene’s Test for Equality of Variances</th>
<th>t-test for Equality of Means</th>
<th>95% Confidence Interval of the Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>Sig.</td>
<td>t</td>
</tr>
<tr>
<td>Baseline</td>
<td>2.497</td>
<td>.140</td>
<td>-1.096</td>
</tr>
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<td></td>
<td>Equal variances assumed</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Equal variances not assumed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acquisition</td>
<td>1.303</td>
<td>.276</td>
<td>4.706</td>
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<tr>
<td></td>
<td>Equal variances assumed</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Equal variances not assumed</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Equal variances assumed</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Equal variances not assumed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transfer</td>
<td>3.376</td>
<td>.091</td>
<td>.729</td>
</tr>
<tr>
<td></td>
<td>Equal variances assumed</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Equal variances not assumed</td>
<td></td>
<td></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>df</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pair 1</td>
<td>Baseline – Acquisition</td>
<td>21.05143</td>
<td>9.40340</td>
<td>3.55415</td>
<td>12.33474</td>
<td>29.74812</td>
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<tr>
<td>Pair 3</td>
<td>Baseline – Transfer</td>
<td>3.85429</td>
<td>4.52968</td>
<td>1.71206</td>
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H. 2 Initial Contact Knee Flexion Angle ANOVA

Tests of Within-Subjects Effects

<table>
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<th>Source</th>
<th>Type III Sum of Squares</th>
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<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
<th>Noncent. Parametr.</th>
<th>Observed Power*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>Sphericity Assumed</td>
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<td>49.953</td>
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<td>.041</td>
<td>.282</td>
<td>9.131</td>
<td>.868</td>
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<tr>
<td></td>
<td>Greenhouse-Geisser</td>
<td>2.515</td>
<td>58.689</td>
<td>3.044</td>
<td>.052</td>
<td>.282</td>
<td>7.665</td>
<td>.607</td>
</tr>
<tr>
<td></td>
<td>Hayn-Fold</td>
<td>3.000</td>
<td>46.953</td>
<td>3.044</td>
<td>.041</td>
<td>.282</td>
<td>9.131</td>
<td>.868</td>
</tr>
<tr>
<td></td>
<td>Lower-Bound</td>
<td>1.000</td>
<td>146.059</td>
<td>3.044</td>
<td>.107</td>
<td>.282</td>
<td>3.044</td>
<td>.362</td>
</tr>
<tr>
<td>Time * Group</td>
<td>Sphericity Assumed</td>
<td>6.429</td>
<td>3</td>
<td>2.143</td>
<td>.132</td>
<td>.440</td>
<td>.011</td>
<td>396</td>
</tr>
<tr>
<td></td>
<td>Greenhouse-Geisser</td>
<td>6.429</td>
<td>2.515</td>
<td>2.556</td>
<td>.132</td>
<td>.440</td>
<td>.011</td>
<td>396</td>
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<tr>
<td></td>
<td>Hayn-Fold</td>
<td>6.429</td>
<td>3.000</td>
<td>2.143</td>
<td>.132</td>
<td>.440</td>
<td>.011</td>
<td>396</td>
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<td>1.000</td>
<td>6.429</td>
<td>.132</td>
<td>.723</td>
<td>.011</td>
<td>132</td>
</tr>
</tbody>
</table>

Error(Time) | Sphericity Assumed | 583.727 | 36 | 16.215 |
|           | Greenhouse-Geisser      | 583.727 | 30.181 | 16.241 |
|           | Hayn-Fold               | 583.727 | 36.000 | 16.215 |
|           | Lower-Bound             | 583.727 | 12.000 | 16.241 |

a. Computed using alpha = .05

Tests of Between-Subjects Effects

<table>
<thead>
<tr>
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a. Computed using alpha = .05
### H. 3 Initial Contact Knee Abduction Angle ANOVA

#### Tests of Within-Subjects Effects

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a. Computed using alpha = .05

#### Tests of Between-Subjects Effects

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a. Computed using alpha = .05

#### Paired Samples Test

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<th>Sig. (2-tailed)</th>
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### Tests of Within-Subjects Effects

**Measure:** MEASURE 1

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### Tests of Between-Subjects Effects

**Measure:** MEASURE 1  
**Transformed Variable:** Average

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### Tests of Within-Subjects Effects

**Measure:** MEASURE_1

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| Error(time)     | Sphericity Assumed      | 1.602| 36         | .044 |       |
|                 | Greenhouse–Geisser      | 1.602| 20.517     | .078 |       |
|                 | Huynh–Feldt             | 1.602| 25.582     | .063 |       |
|                 | Lower–bound             | 1.602| 12.000     | .133 |       |

### Tests of Between-Subjects Effects

**Measure:** MEASURE_1

**Transformed Variable:** Average

<table>
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<tr>
<th>Source</th>
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Vita

Alec Genter was born and raised in Clarkston, Michigan in 1995 to Michael and Jennifer Genter. He is the older of two children, with a younger brother, Kyle. Alec graduated from Clarkston High School in 2013. He graduated from Alma College in the Spring of 2017 with a degree in Integrative Physiology and Health Sciences. After graduation, he completed a M.S. in Kinesiology with an emphasis in Biomechanics at the University of Tennessee, Knoxville in Spring 2019. Alec plans on pursuing a career related to human performance and clinical research in industry upon graduation.