AN ABSTRACT OF THE THESIS OF

James M. Weilbrenner for the degree of Honors Baccalaureate of Science in Exercise and Sport Science (Honors Associate) presented on June 2, 2014. Title: The Influence of External Focus of Attention Feedback on ACL Injury Related Landing Biomechanics.

Abstract approved:

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Abstract Body

Title: The Influence of External Focus of Attention Feedback on ACL Injury Related Landing Biomechanics **Purpose:** To investigate whether a one-time dose of external feedback would result in immediate changes in landing biomechanics related to ACL injury risk and if any changes are retained after 48 hours. **Methods:** We used a nine camera motion capture system (Vicon, Inc.) using a standard retro-reflective marker set (25 static, 21 dynamic) to capture lower limb kinematics of 16 healthy female and 15 healthy male subjects during a double leg jump landing task. Kinematic data was then combined with force place data to calculate the three-dimensional loads at the knee joint using standard inverse dynamics. Following Baseline measurement of landing biomechanics, participants were assigned to either a Control or a Feedback group and were assessed immediately following the intervention (Intervention) and 48 hours later (Retention). **Results:** We identified a significant main effect for Group ($F_{1,\,29}$= 5.469, $P = 0.026$) for knee flexion angle at initial contact, but found no significant Time or Group*Time interaction effects ($P > 0.05$). Participants in the Feedback group exhibited significantly greater knee flexion at initial contact than Control participants across all testing conditions. With respect to frontal plane kinematics, there were no significant main effects for Time or Group, and no significant Group*Time interaction effect for frontal plane knee angle at initial contact ($P > 0.05$) No significant Time, Group, or Group*Time interaction effects were identified for peak knee extension moment ($P > 0.05$). There was a significant main effect for Time ($F_{2, 58}= 4.398$, $P = 0.017$) for peak anterior tibial shear force, but no significant main effect for Group or Group*Time interaction effect were identified ($P > 0.05$). Peak anterior tibial shear force was approximately 9% greater at Retention than at Baseline), but no differences were identified between Baseline and Intervention or Intervention and Retention. Finally, no significant main effects for Time or Group, and no significant Group*Time interaction were identified for peak knee varus moment ($P > 0.05$).

Conclusion: A one-time dose of externally focused feedback without practice did not change landing biomechanics related to ACL injury risk. It may be that feedback-related movement changes require the inclusion of agility or strengthening components, or a provision that individuals are allotted with time to practice the task.

Key Words: ACL, Jump Landing, External Feedback, Landing Mechanics

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The Influence of External Focus of Attention Feedback on ACL Injury Related Landing Biomechanics

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I understand that my project will become part of the permanent collection of Oregon State University, University Honors College. My signature below authorizes release of my project to any reader upon request.

James M. Weilbrenner, Author

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Dedication

Thank you to my parents. Without you I would literally not be here. Thank you for providing me with the opportunity to succeed and the support through all of my accomplishments.

Thank you to my support system here in Corvallis, especially my long-time girlfriend, roommates, baseball family and OSU family. Without you providing encouragement and balance in my life I would not be where I am today.

Thank you,

James

The Influence of External Focus of Attention Feedback on ACL Injury Related Landing Biomechanics

CHAPTER 1

Introduction

1.1 Introduction

Anterior cruciate ligament (ACL) tears are a common physical activity-related injury that result in significant personal and healthcare system costs (Mather, Koenig, Kocher, & Dall, 2013). In the short term, ACL tears result in decreased physical activity, poor quality of life, and decreased knee function (Frobell, Roos, Roos, Ranstam, & Lohmander, 2010). In the long term, ACL tears result in increased risk of osteoarthritis and large medical costs (Frobell et al., 2010). It is estimated that 28% of ACL rupture patients develop osteoarthritis within 10-20 years of the injury (Claes, Hermie, Verdonk, Bellemans, & Verdonk, 2012). Using an annual incidence of 200,000 ACL reconstructions, Mather et al. (2013) estimated the healthcare burden due to early onset osteoarthritis following an ACL injury to be \$2.78 - \$4.24 billion annually. Another long-term effect of ACL ruptures is the fear of return to sport. Lentz et al. (2011) reported that about 49% of subjects chose not to return to sport due to lack of confidence or fear of re-injury following an ACL injury event. For individuals that do return to sporting activity, they remain at greater risk for another ACL injury than individuals who have not been previously injured (Paterno et al., 2012). Given these tremendous personal and societal ramifications, it is apparent that there exists a continuing need to better understand and prevent ACL injury.

The majority of ACL tears are not caused by contact with another individual (Spindler & Wright, 2008; Etnoyer, Cortes, Ringleb, Van Lunen, & Onate, 2013). Rather, approximately 67% of ACL injuries in males and 90% of ACL injuries in females result from non-contact mechanisms (Spindler and Wright, 2008), with most non-contact injuries reportedly occurring during unipedal jump landings (Withrow, Huston, Wojtys, & Ashton-Miller, 2006). Non-contact injuries are defined as those that involve ground-reaction force and segmental inertia but no other external contact forces (Withrow et al., 2006). Some activities that involve this motion of injury include: basketball, soccer, and football (Bere et al., 2011; Krosshaug et al., 2006; Scranton et al., 1997). The non-contact ACL injuries from those sports involved a landing and cutting motion, with the knee moving in multiple planes (frontal and sagittal).

With respect to knee biomechanics during landing, it has been shown that both frontal plane and sagittal plane factors are likely involved in ACL loading. Initial contact and peak knee abduction (valgus) angles have been shown to be primary predictors of ACL injury (Hewett, 2005). Knee abduction angles were also shown to be significantly different prospectively between an injured ACL group and a non-injured group, both at peak displacement during landing and at initial contact (Hewett, 2005). External knee abduction moments are also proposed to contribute to lower extremity dynamic valgus and knee joint loading (Hewett et al., 2005; Lephart et al., 2002; Roos, et al., 1995).

In the sagittal plane, DeMorat et al., (2004) reported that at knee flexion angles of less than 30 degrees, the addition of a quadriceps load significantly increases mean ACL force. During a jump landing, an eccentric quadriceps contraction must be used to resist knee flexion motion and slow the downward momentum of the body (Withrow et al., 2005). The change in ACL strain is highly correlated with the change in quadriceps force and the change in knee flexion from the impact force (Withrow et al., 2005). Anterior tibial translation, which the ACL resists, also increases as the force applied by the quadriceps increases (Myers, Torry, & Shelbourne, 2012) with greater anterior tibial shear force likely indicative of increased demand on the anterior cruciate ligament (Withrow et al., 2005). As a result, lesser knee flexion at initial contact and greater internal knee extension moment and anterior tibial shear force are considered unfavorable with respect to ACL injury risk.

External focus feedback directs the attention of the participant to objects or goals in the environment, while internal focus feedback directs the attention to the movement the body is performing or the action itself (Emanuel, Jarus, & Bart, 2008). External focus feedback has been shown to have an advantage in skill acquisition for various movements over internal focus in adults (Emanuel et al., 2008;Wulf, 2002). However, the isolated effect of external feedback on landing mechanics related to ACL injury is not clear. Oñate et al., (2005) and Herman et al., (2009) have shown that augmented feedback (using videotape) of both self-jumping and expert jumping resulted in increased peak knee flexion and reduced peak vertical ground reaction forces during a landing task. However, these methods of feedback are time-intensive and do not isolate external vs. internal feedback. (Prapavessis and McNair, 1999) provided a form of internal feedback by asking participants to focus on the sound that they made when contacting the ground during jump landings. Compared to pre-feedback landings, no changes in ground reaction forces were identified after participants were instructed to land as quietly as possible (internal focus). Given the previously identified benefits of external feedback on skill acquisition, it is plausible that an externally focused feedback intervention could result in changes in landing biomechanics related to ACL injury that are not seen using an internal focus. However, to our knowledge, the use of isolated external-focus feedback to change landing biomechanics during jump-landings has not been evaluated. Therefore, the purpose of this study was to investigate whether a one-time dose of external feedback would result in immediate changes in landing biomechanics related to ACL injury risk and if any changes are retained after 48 hours.

1.2 Research Question

Research Question: Does a one-time dose of externally directed feedback immediately cause changes to the five following biomechanical factors related to ACL injury during a double leg jump landing and are any changes retained after 48 hours?

A. Anterior tibial shear force
B. Internal knee extension moment
C. Internal knee varus moment
D. Peak knee valgus angle

E. Knee valgus angle at initial contact

F. Knee flexion angle at initial contact

Research Hypothesis: We hypothesized that participants in the external feedback group would show more favorable results in these five biomechanical measures immediately following the intervention and would retain those favorable results at the 48-hour retention test?

1.3 Operational Definitions

Initial ground contact (IGC): The beginning of the landing period was defined as the instant when the vertical component of the ground reaction force exceeded 10 Newtons.

Dominant limb: The limb used to kick a ball for maximal distance.

Double leg jump landing: Subjects stood atop a 0.30 m tall box positioned 50% of their height away from a force plate. They then jumped forward and down toward the plate and landed with each foot centered on a force place before immediately jumping up for maximum height.

1.4 Assumptions

The following assumptions were made:

1. Participants performed all testing protocols to the best of their ability and with maximum effort.

2. Participants were honest regarding their prior history with respect to the inclusion/exclusion criteria.

3. The biomechanical data collected during these experiments was reliable and valid for all participants.

1.5 Delimitations

The following delimitations were made for this thesis project.

1. All participants were between the ages of 18-30 at the time of testing.

2. All kinematic and kinetic data were sampled using the same motion analysis system and force plates.

4. All participants had no history of ACL injury, lower extremity surgery, neurological disorder, or lower extremity injury that restricted activity for more than 3 days within the 6 months preceding data collection.

5. All participants were physically active as defined by participation in at least 30 minutes of activity a minimum of three days per week.

CHAPTER 2

Literature Review

2.1 ACL Tears

Anterior cruciate ligament (ACL) sprains are a common injury in the United States with over 200,000 reported ACL injuries each year (Mather et al., 2013). In the short term, ACL ruptures lead to decreased physical activity and unsatisfactory knee function (Frobell et al., 2010). In the long-term, ACL ruptures lead to an increased risk of osteoarthritis (Frobell et al., 2010). There are two primary treatments for recovering from an ACL tear: non-surgical rehabilitation and surgical reconstruction. In 1996, there were over 346,000 total knee surgeries with 127,000 of those involving division of ligament, joint capsule, or cartilage (Owings and Kozak, 1998). The cost of ACL reconstruction directly to the patient was at least $11,900, making ACL reconstruction the reason for over $1 billion of United States health care costs in 1999 (Paxton et al., 2010). In 2000, it was estimated that over 175,000 ACL reconstructions were performed in the United States, with the total cost to be around $2 billion (Spindler and Wright, 2008). More recently, it is estimated that there are over 200,000 ACL tears in the U.S. each year with an estimated cost of $2-4 billion in reconstruction and rehabilitation costs alone (Mather et al., 2013;Frobell et al., 2010). While these cost estimates continue to increase annually, it is likely that they still underestimate the total financial burden on the US healthcare system as not all ACL injuries are diagnosed (Spindler and Wright, 2008).

It has been estimated that the average lifetime cost to society for a person undergoing ACL reconstruction is approximately $38,121 (Mather et al., 2013). Should that individual choose a conservative rehabilitation approach instead of surgery, the lifetime cost to society has been estimated to be $88,538 (Mather et al., 2013). The cost to society is defined as the cost of missed work, treatment, and other factors other than the surgery itself (Mather et al., 2013). The lifetime cost of ACL tears in the United States is estimated to be $7.6 billion annually when treated with ACL reconstruction, and $17.7 billion dollars when treated with conservative rehabilitation (Mather et al., 2013). The cost to treat ACL injuries over the lifetime of a patient is substantial, and resources need to be directed to producing programs for injury prevention (Mather et al., 2013). The increasing estimations of ACL costs are partially correlated with the increase of female participation in jumping and cutting sports since the passing of Title IX.

Since 1972, when Title IX was passed, female participation in sports has increased over 9-times, roughly doubling every ten years from 300,000 to 2.8 million (Hewett, 2005). Females are at four to six times greater risk for an ACL injury than males in pivoting and jumping sports such as basketball and volleyball (Hewett, 2005). In that same span of time, male participation has increased less than three percent, from 3.7 million to 3.8 million (Hewett, 2005). Roughly 38,000 ACL injuries annually occur in girls and women's athletics in the United States (Hewett, 2005). These injuries amount to $646 million annually in treatment of female ACL injuries alone (Hewett, 2005).

The majority of ACL tears result from non-contact mechanisms of injury (Spindler and Wright, 2008;Etnoyer et al., 2013). Almost 67% of ACL injuries in males and 90% of ACL injuries in females were non-contact (Spindler and Wright, 2008). Non-contact injuries are defined as those that involve foot ground-reaction force and segmental inertia but no other external contact forces (Withrow et al., 2005). Non-contact injuries are most likely to occur on a unipedal jump landing (Withrow et al., 2005). Individuals with a history of ACL injuries are at more risk for a future ACL injury than non-injured individuals (Paterno et al., 2012; Shelbourne, Gray, & Haro, 2009).

Anterior cruciate ligament tears do not usually occur without other tissue damage. Only 37.3% of all ACL reconstruction surgeries performed in New York State from 1997 to 2006 were solely to repair the ACL (Lyman, 2009). According to Spindler and Wright (2008) an isolated ACL injury only happens less than 10% of the time. Along with the ACL injury, an associated meniscus injury occurs 60%-75% of the time, subchondral bone injuries occur 80% of the time, articular cartilage injuries occur up to 46% of the time, and complete collateral ligament tears occur 5 to 24% of the time (Spindler and Wright, 2008). Patients with no meniscal tears have a 0% to 13% risk of developing osteoarthritis while patients with meniscal tears face a 21% to 48% risk (Mather et al., 2013;Oiestad, Engebretsen, Storheim, & Risberg, 2009). Recent studies have shown that the medial meniscus functions as an important secondary stabilizer to anterior tibial translation in diminished ACL knees (Claes et al., 2013). Meanwhile, the lateral meniscus acts as a secondary restraint to axial and rotary loads, which, when injured, allows instability and an increase in shearing forces being applied at the meniscus (Claes et al., 2013). This shearing can cause further meniscal damage, tears, and pain. There have been higher rates of reported meniscal injuries, up to 33% more, following ACL rehabilitation programs over those that completed an ACL reconstruction (Claes et al., 2013) The higher rates indicate that ACL reconstruction possibly leads to a better quality recovery of the knee joint, which reduces incidences of further knee joint injuries. Since osteoarthritis is strongly linked to meniscal tears along with the ACL injury, the importance in studying ACL forces to alleviate stress on menisci could lead to reduced osteoarthritis in patients. ACL injuries carry both the short-term effects of surgery, rehab, and loss of athletic identity, and the long-term effects of osteoarthritis and joint laxity (Etnoyer et al., 2013).

It is estimated that osteoarthritis develops in 50% of patients with ACL ruptures within 10-20 years of the injury (Spindler and Wright, 2008). A study by Claes et al. (2013) constructed a meta-analysis of osteoarthritis incidence following ACL reconstruction and found that the number is close to 28%. However, this study also pointed out that a menisecctomy should be considered an important risk factor for developing osteoarthritis after ACL reconstruction, due to the 42% of patients shown to have developed osteoarthritis compared to 19% of patients that retained full meniscal status. Since most of these injuries occur to young athletes while participating in sports, this means that osteoarthritic development occurs when they are still young.

Another side effect of an ACL injury is the fear to return to the sport in which the athlete sustained the injury. In a study by Lentz et al. (2011), out of the 97 subjects studied that had ACL reconstruction, 49% cited not returning to sport due to fear of re-injury or lack of confidence. These same athletes also reported lower knee function and lower quality of life post-injury than those athletes that did return to sport. The non-return to sport athletes that cited fear as a reason not to return to sport also have a higher pain-related fear of re-injury yet similar function and quality of life grades as other the rest of the non-return to sport athletes (Lentz et al., 2011).

2.2 Biomechanical Factors

There are structural risk factors that can make an individual predisposed to ACL injury. Smaller ACLs by cross-sectional area and volume were found in ACL-injured patients compared to the non-injured controls (Chaudhari, Zelman, Flanigan, Kaeding, & Nagaraja, 2009). Greater lateral-posterior tibial plateau slopes and reduced condylar depth of the medial plateau were shown to be indicators of ACL injury (Everhart, Flanigan, Simon, & Chaudhari, 2010; Hashemi, Chandrashekar, Mansouri, & et al., 2010; Khan, Seon, & Song, 2011; Stijak, Herzog, & Schai, 2008). Increased knee joint laxity, which is correlated with higher risk landing strategies is more often observed in females (Scerpella, Stayer, & Makhuli, 2005; Uhorchak et al., 2003). Increased tibiofemoral angles and quadriceps angles which are common in more physically mature females, were also shown to be potential indicators of predisposition to ACL injury (Hertel, Dorfman, & Braham, 2004; Nguyen & Shultz, 2007). However, as these factors are generally non-modifiable, there has been a significant amount of research dedicated to identifying high risk landing mechanics that might be amenable to change via intervention programs.

With respect to knee biomechanics during landing, it has been shown that both frontal plane and sagittal plane factors are likely involved in ACL loading. Initial contact and peak knee abduction (valgus) angles have been shown to be primary predictors of ACL tears (Hewett, 2005). Knee abduction angles were also shown to be significantly different prospectively between an injured ACL group and a non-injured group, both at peak displacement during landing and at initial contact (Hewett, 2005). In uninjured athletes initial contact during landing from a vertical drop, the average knee abduction angle of uninjured females was 3.4 degrees, while in ACL injured athletes it was shown to be an average of 5 degrees (Hewett, 2005). Also, the results from the knee abduction angles at the peak angle during the interval from initial contact to the time of peak knee flexion during landing show that the uninjured athletes only had an abduction angle of 1.4 degrees compared to 9.0 degrees for the ACL injured athletes (Hewett, 2005). External knee abduction moments are also known to contribute to lower extremity dynamic valgus and knee joint loading; and were shown to have a sensitivity of 78% and a specificity of 73% for predicting ACL injury status (Hewett et al., 2005).

In the sagittal plane, DeMorat et al, (2004) reported that at knee flexion angles of less than 30 degrees, the addition of a quadriceps load significantly increases mean ACL force. During a jump landing, an eccentric quadriceps contraction must be used to resist knee flexion motion and slow the downward momentum of the body (Withrow et al., 2006). These lengthening forces can be over 140% of the isometric forces of the quadriceps (Withrow et al., 2006). Using a cadaveric model, Withrow et al. demonstrated that stimulating the quadriceps when a knee is flexed at less than 60 degrees results in an increase in quadriceps force that directly increases ACL strain (Withrow et al., 2006). The change in ACL strain is highly correlated with the change in quadriceps force and the change in knee flexion from the impact force (Withrow et al., 2006). Anterior tibial translation, which the ACL resists, also increases as the force applied by the quadriceps increases (Shultz et al., 2012). The greater the anterior shear force on the jump landing, the greater the demand on the anterior cruciate ligament (Withrow et al., 2006). Increasing the quadriceps force can cause anterior tibial translations of over 20mm, which can cause ACL rupture (DeMorat et al., 2004). Therefore, it is proposed that ACL strain due to sagittal plane loading is greatest when there are large quadriceps forces (indicated biomechanically by increased internal knee extension moment and anterior tibial shear force), while the knee is positioned in a relatively less flexed position. As a result, lesser knee flexion at initial contact and greater internal knee extension moment and anterior tibial shear force are considered unfavorable with respect to ACL injury risk.

2.3 Use of Feedback

External focus instruction is that which directs the attention of the individual to objects or goals in the environment (Emanuel et al., 2008). Internal focus of instruction directs the attention of the individual to the movement the body is performing or the action itself (Emanuel et al., 2008). External focus has been shown to have an advantage in skill acquisition over internal focus in adults (Emanuel et al., 2008;Wulf, McConnel, Gartner, & Schwarz, 2002). Also, the more feedback given to participants, the more successful they will be in sport skill acquisition (Wulf et al., 2002). In a study performed by Wulf et al. (2002) participants were divided into four groups, novice and advanced and treated with either an internal or external focus. They found that while all participants increased their scores over the three-day trial, the retention test on day three showed that performers who received external focus feedback had clearly higher scores than those with internal focus feedback, in both the novice and advanced groups. Improved scores indicate that using external feedback could theoretically improve landing form, which could decrease the potential of ACL injuries, and that these changes might be retained for a longer period of time than with an internal focus approach.

The learning benefits that external focus has over internal focus of attention has been shown to be true for a variety of tasks, such as tennis serves, golf swings, and balance activities (Wulf, McNevin, & Shea, 2001) When concentrating on the movement itself, performers seem to intervene in the control process, which leads to reduced performance and retention (Wulf et al, 2002). Notably, external focus instructions improved the performance of experienced athletes relative to internal focus and control conditions (Wulf, 2013). The success of external focus can be attributed to the individual’s use of automatic motor control processes that attend to the movement’s effect rather than the movement of the action itself (Wulf et al, 2002). Therefore, top-down processing interferes with the coordination of the movement. This thought was also given merit by Prapavessis and McNair (1999) who showed that augmented verbal feedback could significantly reduce ground reaction forces when landing from a jump versus just having the athlete change how they land based on how they felt the previous jump.

2.3A Amount of Feedback

In a study by Weeks and Kordus (1998), feedback was given to participants either after every trial or after every third trial. The feedback given was internally focused and described the movement that the body would go through in order to accomplish a soccer throw-in. The participants in the group that only received internally focused feedback after every third attempt was shown to have significantly better movement form than the group that received internally focused feedback after every attempt (Weeks and Kordus, 1998).

2.3B Efficient Muscle Use

One study of muscular activity using electromyography (EMG), oxygen consumption, and heart rate has shown external focus feedback to be more successful than internal focus. Wulf (2013) examined muscular activity during a biceps curl. It was shown that integrated EMG activity decreased in the biceps brachii and triceps brachii when the participants were cued to focus on the barbell versus to focus on their arms. This suggests that less extraneous electrical stimuli was sent from the brain, allowing the muscle to function efficiently to produce the same force. Co-contractions of agonist and antagonist muscle groups, when paired with an internal focus, were found by Lohse et al. (2011) and led to a less efficient cooperation between muscle groups. When external focus reduces the muscular activity relative to internal focus, it has been shown to provide more accurate force production and the possibility of greater maximal force production (Wulf, 2013). More accurate force production could allow for proper landing techniques that could reduce the risk for ACL injury.

2.3C Maximum Force Production

Maximal force production requires ideal overlap of actin and myosin, activation of agonist and antagonist muscle, as well as ideal motor unit recruitment. Imperfect timing, unnecessary co-contractions, and improper direction of forces can all lead to less than maximal force output (Wulf, 2013). Maximum jump height was increased with external versus internal focus for adults (Wulf et al., 2010).

2.3D Reduce Fatigue

In a study by Lohse and Sherwood (2011), it was found that depending on internal or external focus, the participants could stay in a wall-sit position longer. The participants were given: internal focus, external-associative focus, or external-dissociative focus instructions during the trials (Lohse and Sherwood, 2011). It was found that both external focus trials were able to last longer in the wall-sit, therefore a seeming reduction in fatigue occurred. It was also noted that the group which had external-associative feedback lasted longer on their second-trial than their first trial, indicating improved stamina when all other groups lasted a shorter amount of time on the second trial (Lohse and Sherwood, 2011). This finding implies that when an athlete is fatigued it may be advantageous to implement external-associative focus to reduce effects of fatigue (Lohse and Sherwood, 2011). As the athlete fatigues, she is more likely to lose proper muscle control and therefore more susceptible to injury. Reduced effects of fatigue can lead to proper ACL landing form.

The other measure of fatigue used was a rating of perceived exertion (RPE) scale, which indicates how fatigued the participants felt they were. In the results of the study, it was shown that RPE was lower in the external focus groups (Lohse and Sherwood, 2011). The lower RPE scores indicate the internal sensations of fatigue may be decreased by distractions from the environment (Lohse and Sherwood, 2011).

2.3E Feedback and Landing Mechanics

As described above, external feedback has shown advantages over internal feedback in skill acquisition for various movements. However, the isolated effect of external feedback on landing mechanics related to ACL injury is not clear. Oñate et al. (2005) and Herman et al. (2009) have shown that augmented feedback (using videotape) of both self-jumping and expert jumping resulted in increased peak knee flexion and reduced peak vertical ground reaction forces during a landing task. However, these methods of feedback are time-intensive and do not isolate external vs. internal feedback. Prapavessis and McNair (1999) provided a form of internal feedback by asking participants to focus on the sound that they made when contacting the ground during jump landings. Compared to pre-feedback landings, no changes in ground reaction forces were identified after participants were instructed to land as quietly as possible (internal focus). Given the previously identified benefits of external feedback on skill acquisition, it is plausible that an externally focused feedback intervention could result in changes in landing biomechanics related to ACL injury that are not seen using an internal focus. However, to our knowledge, the use of isolated external-focus feedback to change landing biomechanics during jump-landings has not been evaluated.

2.4 Summary

Anterior cruciate ligament injuries cause over $4 billion in costs to the United States every year. The injuries not only cost money, but also time with up to a yearlong recovery period. They cause short-term pain due to surgery and rehabilitation as well as long-term problems with osteoarthritis. The fear of return to sport for the individual also adds a psychological cost to this process. These injuries have been shown to have biological risk factors that can increase the risk of injury. Those biological factors, as well as high-risk movement patterns, should be studied to provide ways to reduce injuries. Feedback has been shown to reduce unwanted movements, with external feedback being more successful in reducing that than internal feedback. The purpose of this study is to see if a one-time dose of external feedback can reduce biomechanical factors that lead to ACL injury both immediately after intervention and be retained after 48 hours.

CHAPTER 3

Methods

3.1 Subjects

Thirty-one individuals (16 females, 15 males) voluntarily participated in this investigation after reading and signing an Institutional Review Board approved consent form. Criteria for participant inclusion in the study were: 1) 18-30 years of age, 2) healthy and physically active as defined by participation in at least 30 minutes of physical activity at a minimum of three times per week, 3) no history of ACL injury, lower extremity surgery, or neurological disorder, and 4) no lower extremity injury within the six months preceding data collection. Following enrollment, participants were assigned to either a Feedback (8 females, 7 males, [Mean (SD); age: 21.3, (2.6) years; height: 1.70, (0.11) m; mass: 70.0, (12.1) kg]) or Control (8 females, 8 males, [Mean (SD); age: 21.0, (1.8) years; height: 1.70, (0.09) m; mass: 70.1, (10.7) kg]) group in a counterbalanced order.

3.2 Subject Preparation and Experimental Procedures

Subjects completed the testing protocol during two sessions separated by approximately 48 hours. The height and mass of each subject were recorded prior to data collection on the first day and later used for biomechanical model generation and standardization of the dependent variables. Prior to both sessions, participants completed a warm-up at a selected pace, and were outfitted with a retro-reflective marker set, (25 static, 21 dynamic) placed bilaterally on the acromion process, anterior superior iliac spine, greater trochanter, anterior thigh, medial and lateral femoral epicondyles, anterior shank, medial and lateral malleoli, and the sacrum. Also, markers were placed bilaterally on the shoes over the approximate locations of the calcaneus, and the 1st and 5th metatarsal heads. Nine motion capture cameras (Vicon, Inc., Centennial, CO, USA) were used to record participant kinematics during double leg jump landings following a static subject calibration trial. The double-leg jump landings were performed from a 30 cm high box that was set a distance equal to 50% of the subject's height away from the edge of a two force plates (Type 4060-08, Bertec Corporation, Columbus, OH, USA). Subjects were instructed to jump down and forward towards the force plate, contact the ground with both feet at the same time with their feet landing in the middle of each force plate, and then immediately jump up for maximum height using both legs. Landing biomechanics were recorded for 5 landing trials in each of three conditions: pre- (Baseline) and post (Intervention) intervention conditions during the first testing session and a Retention condition during the second testing session. During the Baseline condition, both Control and Feedback group participants were instructed to jump as high as possible while performing the task. Prior to the Intervention condition trials, all participants were instructed to continue to jump as high as possible while performing the task. However, the Feedback group was also asked to focus on landing as "light as a feather" during the task. Instructions for the all participants in the Retention condition were identical to those during the Baseline condition. Subjects performed at least 3 practice trials prior to the first series of double-leg jump landings on each day (i.e., Baseline and Retention). Rest breaks of 30 seconds between each of the five, successful testing trials in each condition were provided to lessen any potential effects of fatigue. Trials were judged to be successful if subjects jumped from the box and landed with both feet at the same time and in the correct position

3.3 Data Sampling and Reduction

The kinematic and force plate data were sampled at 120 and 1560 Hz, respectively, using (Vicon, Inc., Centennial, CO, USA). Raw three-dimensional kinematic coordinates and kinetic data were imported into The Motion Monitor motion analysis software for model generation (Innovative Sports Training, Chicago, IL, USA). Ankle and knee joint centers were defined as the midpoint of the medial and lateral malleolus and the medial and lateral femoral epicondyle markers, respectively. The hip joint center was predicted using external landmarks as described by (Bell, Brand, & Pedersen, 1989). The local coordinate systems of the shank, thigh, and sacrum were defined with the positive x-axis directed anteriorly, positive y-axis directed to the left, and the positive z-axis directed superiorly. Kinematic and force plate data were lowpass filtered at 10 Hz using a 4th order zero-phase lag Butterworth digital filter. Kinematic data was time-synchronized to kinetic data, and re-sampled at 1560 Hz. Joint angular positions were calculated based on a right hand convention using Euler angles in a Y (flexion/extension), X (adduction/ abduction), Z (internal/external rotation) rotation sequence with motion defined about the knee as the shank relative to the thigh. Intersegmental forces and moments of force were calculated within The MotionMonitor using the methods described by Gagnon and Gagnon, (1992). Custom computer software

(LabVIEW, National Instruments, Austin, TX) was used to identify dominant limb peak internal knee extension and varus moments and anterior tibial shear force during the 100 ms immediately after initial ground contact. This same software was used to also identify sagittal and frontal plane knee angles at initial contact and the peak knee valgus angle between initial contact and peak knee flexion during each trial. Leg dominance was determined by asking participants which leg they would use to kick a soccer ball for distance. Mean values for each dependent variable were calculated over the 5 trials for each task in each of the three conditions. Anterior tibial shear force was normalized to participant body weight, while internal knee extension and varus moments were normalized to the product of subject height and weight.

3.4 Statistical Analyses

Separate 2 (Group: Feedback vs. Control) x 3 (Time: Baseline, Intervention, Retention) repeated-measures ANOVAs were used to evaluate the influence of external feedback on the five biomechanical outcome measures. In ANOVA models where the data violated the assumption of sphericity, the Greenhouse-Geisser correction was applied. Following significant ANOVA models, planned pairwise comparisons were completed using *t*-tests with a Bonferroni correction. All analyses were performed using commercially available software (SPSS 21.0, SPSS Inc., Chicago, IL, USA) with statistical significance established *a priori* as $\alpha \leq 0.05$.

CHAPTER 4

Results

4.1 Kinematics

We identified a significant main effect for group ($F_{1, 29}$= 5.469, *P* = 0.026) for knee flexion angle at initial contact, but found no significant time ($F_{2,58}$= 0.850, *P*= 0.433) or group*time interaction ($F_{2,58}$= 0.656, *P*= 0.523) effects (Table 1). Participants in the Feedback group exhibited significantly greater knee flexion at initial contact than Control participants across all testing conditions.

With respect to frontal plane kinematics, there were no significant main effects for time ($F_{1.365, 39.597}$= 0.655, *P* = 0.469) or group ($F_{1, 29}$= 0.102, *P* = 0.752), and no significant group*time ($F_{1.365, 39.597}$ = 1.237, *P* = 0.288) interaction effect for frontal plane knee angle at initial contact (Table 1). Similarly, no significant main effects for time ($F_{1.439, 41.742}$= 1.562, *P* = 0.223) and group ($F_{1, 29}$= 0.039, *P* = 0.844), or group*time ($F_{1.439, 41.742}$ = 0.166, *P* = 0.775) interaction effects for peak knee valgus angle were identified (Table 1).

Table 1. Means ± SDs for sagittal plane knee angle at initial contact (+flexion/-extension), frontal plane knee angle at initial contact (+varus/-valgus), and peak knee valgus angle (+varus/-valgus) at Baseline, Intervention, and Retention.

Sagittal Plane Knee Angle at IC (°)		**Baseline**	**Intervention**	**Retention**
	Control	13.49±5.49	14.28±6.05	14.53±6.29
	Feedback*	18.27±4.90	17.39±3.63	18.90±5.73

Frontal Plane Knee Angle at IC (°)		**Baseline**	**Intervention**	**Retention**
	Control	0.54±3.88	0.85±3.39	0.52±2.34
	Feedback	-0.061±3.90	0.069±4.13	0.74±3.52

Peak Knee Valgus Angle (°)		**Baseline**	**Intervention**	**Retention**
	Control	-3.12±6.31	-4.56±6.79	-3.66±6.42
	Feedback	-2.87±4.66	-3.75±4.51	-3.56±5.48

*While no Group differences in initial contact or peak frontal plane knee angle were identified, the Feedback group demonstrated greater knee flexion at initial contact than the control group across test conditions (Group main effect: P = 0.026).

4.2 Kinetics

No significant main effects for time ($F_{2, 58}$= 0.536, P = 0.588) and group ($F_{1, 29}$= 0.106, P = 0.747), or group*time interaction ($F_{2, 58}$ = 0.096, P = 0.908) were identified for peak knee extension moment (Table 2).

There was a significant main effect for time ($F_{2, 58}$= 4.398, P = 0.017) for peak anterior tibial shear force, but no significant main effect for group ($F_{1, 29}$= 0.986, P= 0.329) or group*time interaction ($F_{2, 58}$= 3.760, P= 0.029) effect was identified (Table 2). All participants across groups exhibited significantly greater peak anterior tibial shear force at Retention than at Baseline.

Finally, no significant main effects for time ($F_{1.232, 35.714}$= 0.112, P = 0.792) or group ($F_{1, 29}$= 0.102, P = 0.752), and no significant group*time ($F_{1.232, 35.714}$ = 0.104, P = 0.801) interaction effect were identified for peak knee varus moment (Table 2).

Table 2. Means ± SDs for peak internal knee extension (+flexion/-extension) and varus moments (+varus/-valgus), and peak anterior tibial shear force (+anterior/-posterior) at Baseline, Intervention, and Retention.

Peak Knee Extension Moment (x[BW*Ht]$^{-1}$)		**Baseline**	**Intervention**	**Retention**
	Control	-0.114±0.023	-0.114±0.026	-0.116±0.033
	Feedback	-0.111±0.018	-0.110±0.020	-0.115±0.015

Peak Knee Varus Moment (x[BW*Ht]$^{-1}$)		**Baseline**	**Intervention**	**Retention**
	Control	0.013±0.016	0.012±0.013	0.013±0.015
	Feedback	0.012±0.009	0.012±0.009	0.012±0.009

Peak Anterior Tibial Shear Force (x[BW]$^{-1}$)		**Baseline**	**Intervention**	**Retention***
	Control	0.669±0.200	0.657±0.244	0.713±0.247
	Feedback	0.561±0.111	0.656±0.124	0.634±0.130

*Peak anterior tibial shear force was approximately 9% greater at Retention than at Baseline (Time main effect: *P* = 0.017), but no differences were identified between Baseline and Intervention or Intervention and Retention.

CHAPTER 5

Discussion

5.1 Introduction

The primary finding of this investigation is that a one-time dose of externally focused feedback without practice did not change landing biomechanics related to ACL injury risk. It may be that in order to elicit movement changes during landing using feedback requires: 1) inclusion of agility or strengthening components as these are often used in conjunction with technique training in ACL injury prevention programs (Myer et al., 2013); or 2) providing individuals with time to practice the task so that they can "explore" the movement to identify the movement pattern that best enables them to "land light as a feather"(Myer et al., 2013).

5.2 Sagittal Plane Kinematics

The significantly greater knee flexion angle at initial contact exhibited by the Feedback group (Feedback = 18.27±4.90 vs. Control= 13.49±5.49) across conditions may indicate that the majority of participants in this group were already using a "safe" landing strategy, and therefore the feedback did not further "improve" their landing strategy. Greater knee flexion at initial contact during landing is generally considered a safer landing strategy as the ACL loading imparted by a standardized quadriceps contraction is reduced as knee flexion is increased (DeMorat et al., 2004; Markolf, O'Neill, Jackson, & McAllister, 2004; Withrow et al., 2006). As a result, participants in the Feedback group may have not responded to the feedback provided, as they were already using the type of landing strategy that the feedback was intended to induce.

5.3 Frontal Plane Kinematics

We also failed to identify any changes in frontal plane knee kinematics (angle at initial contact and peak knee valgus angle) following the use of externally directed feedback. However, similar to knee flexion angle at initial contact, both groups exhibited mean knee valgus angles at initial contact (Control = 0.54°±3.88; Feedback= -0.061°±3.90) that were less than the knee valgus angles at initial contact of females who went on to suffer an ACL injury event (-5.0°) (Hewett et al., 2005). Conversely, the mean values for all of our subjects were similar to the frontal plane knee angle at initial contact of Hewett et al.'s uninjured participants (3.4°) . Similarly, the peak valgus angle for our groups at Baseline (Control=-3.12±6.31; Feedback= -2.87±4.66) was similar to the mean peak knee valgus angle of uninjured participants (-1.4 degrees) and less than that of participants who went on to suffer an ACL injury (-9.0 degrees)(Hewett et al. (2005). These results indicate that the majority of participants in the Feedback group seem to be "safer" landers to begin with, and thus are likely not as amenable to any changes that might be induced by the feedback. Future research should evaluate whether the feedback might affect the landing mechanics of "unsafe" landers who have room for improvement.

5.4 Sagittal Plane Kinetics

We failed to identify any significant group, time, or group*time interaction effects for peak knee extension moment. We had hoped that the Feedback group would exhibit a reduction in peak knee extension moment following the intervention as DeMorat et al. (2004) have shown that lesser quadriceps forces result in reduced ACL loading. The magnitude of knee extension moment that we found was similar to previous work using double leg landing tasks. Chappell et al., (2005) reported an average 0.0735XBW*HT, Blackburn et al. (2013) reported an average of -160.1±36.9 N*m, and (Butler et al., 2014) reported a 0.10±0.03XBW*HT.

With respect to peak anterior tibial shear force, all participants across groups exhibited significantly greater peak anterior tibial shear force at Retention than at Baseline. However, it is likely that the 0.058 $x[BW]^{-1}$ increase is not clinically significant and does not substantially increase ACL loading given that a force of more than 2000N is required to rupture the ACL (Noyes, Butler, Grood, Zernicke & Hefzy, 1984). For a 100kg (220lb) person, a 0.058 $x[BW]^{-1}$ increase results in an absolute increase of just 5.8N, which is only 0.29% of the 2000N force reportedly necessary to rupture an ACL. While the net anterior tibial shear force calculated using inverse dynamics is not directly indicative of the force on the ACL during landing, it has been shown to be related to actual ACL loading (Markolf, 2004) and is often used as a surrogate for inferring changes in ACL loading (Sell et al., 2007). Feedback techniques are used to try and reduce biomechanical factors related to ACL injury, including peak anterior tibial shear force, which was the goal of our experiment. However, augmented feedback, another way to reduce biomechanical factors related to ACL tears, has sometimes been shown, as in a study by Herman et al., (2009), to cause an increase in peak anterior tibial shear force. This is counter to our predicted reduction in peak anterior tibial shear force, which we believe is characteristic of a better landing (Withrow et al., 2005).

5.5 Frontal Plane Kinetics

Finally, there was no significant group, time, or group*time interaction effects for peak knee varus moment during landing. What we have found in previous research is that external knee abduction moments are known contributors to knee joint loading and are shown to have a sensitivity of 78% and specificity of 73% for predicting ACL injury (Hewett et al., 2005). The fact that the participants showed no change peak knee varus moment throughout the experiment limits our conclusions about external feedback. As alluded to before, the test may not have been difficult enough to actually elicit a change in landing mechanics of the double-leg jump-landing task or the feedback group may have already been using a "safe" landing technique.

5.6 Limitations

The primary limitation of our study is that we included healthy participants who may or may not have been at increased risk for ACL injury. Future research should re-investigate the influence of external focus of attention feedback using participants identified as less proficient landers who have greater potential to improve their landing biomechanics.

Our study also studied both males and females in this task, distributed to either the feedback or control group. With such small sample sizes and the known variation between males and females, with females having increased risk of ACL injuries, it would be beneficial to increase the sample size to evaluate whether sex serves to modify the effect of feedback on landing mechanics. We also did not have any injured individuals jump in this analysis and we did not have a screening process from “bad” landers. Singling out “bad” landers to run this test on could produce more conclusive results than this study shows.

5.7 Conclusions

A one-time dose of externally focused feedback without practice did not change landing biomechanics related to ACL injury risk. It may be that feedback-related movement changes require an inclusion of agility or strengthening components or a provision of individuals with time to practice the task. Kinematically, the only significant difference identified was sagittal plane knee flexion at initial contact with the Feedback group exhibiting greater knee flexion than the Control group across test conditions. Kinetically, the only difference identified was greater peak anterior tibial shear force in all participants at Retention compared to Baseline. However, the limited magnitude of this difference is likely not clinically relevant. We suggest that further research is required, using a larger sample of volunteers who demonstrate “high risk” landing strategies to determine whether or not isolated externally focused feedback is viable intervention to change landing biomechanics related to ACL injury.

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