A Thesis

entitled

Learned Biomechanics Through Feedback: Investigating the Transferability of a Jump Landing Task to a Cutting Task

by

Laura Young, ATC

Submitted to the Graduate Faculty as partial fulfillment of the requirements for the Master of Science Degree in Exercise Science

________________________________________
Dr. Pietrosimone, Committee Chair

________________________________________
Dr. Gribble, Committee Member

________________________________________
Dr. Pfile, Committee Member

________________________________________
Dr. Patricia R. Komuniecki, Dean
College of Graduate Studies

The University of Toledo

May 2013
An Abstract of

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There is a critical need to develop cost and time-effective prophylactic interventions to decrease the risk of anterior cruciate ligament (ACL) injury. Currently, jump-landing feedback interventions have demonstrated the ability to alter movements that increase the risk of ACL injury during landing. Unfortunately, it remains unknown if jump-landing interventions, which demonstrate the ability to alter movements during a jump-landing task, can alter similar movements in a different task, such as a cutting maneuver. The specific aims of this randomized control trial was to determine the effects of a jump landing feedback intervention on 1) the kinetics and 2) the kinematics performed during an anticipated cutting maneuver and a jump-landing task compared to a control group. Our central hypothesis was that biomechanical alterations known to occur during a jump-landing task, following a jump landing feedback intervention, will also be altered during a cutting maneuver. We used separate repeated measures ANOVAs to evaluate differences in kinetics and kinematics between feedback and control groups overtime. The results of this study revealed a significant decrease in peak vertical ground reaction force (VGRF) in the feedback group during the jump landing task but not the
cutting task. Neither group improved knee flexion angles during the jump landing task, while the feedback group became more extended at the knee joint compared to the control during the cutting task. Both groups demonstrated an improvement in hip flexion over time in the jump landing task, but not the cutting task. Lastly, neither group demonstrated a change in knee abduction angles during either of the tasks. The findings of the study do not entirely support our hypotheses, but we would expect to find more differences with more participants added to the sample size. While the results were not what we expected, they have provided us with insight into the limitations of a feedback intervention and in order to improve future prevention programs, it is imperative to understand the limitations of the feedback intervention.
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Chapter 1

Introduction

Upwards of 250,000 anterior cruciate ligament (ACL) ruptures occur in the United States each year, with many of these injuries occurring in young athletes between the ages of 15 to 25.\(^1\) ACL reconstruction is typically performed with an approximate cost of $17,000 per surgery\(^2\) and with approximately 100,000 reconstructions performed annually,\(^3\) the enormous economical strain this injury places on the United States health care system is clear. Additionally ACL reconstructed patients are at an increased risk of developing knee osteoarthritis.\(^4\) Due to the high medical costs associated with this injury, ACL tears have become a national and global concern with substantial research focused on prevention of these injuries.

The mechanism of ACL injury has not been clearly established as the injury appears to be multifactorial in nature. However, ACL injury is most commonly seen with a change of direction or deceleration, examples of these include performing a cutting maneuver, landing from a jump, and pivoting with the knee near full extension.\(^5\) In sport specific movements that increase the likelihood of non-contact ACL injury, many different risk factors have been implicated in ACL injury. Risk factors can be grouped into two different schemes. The first divides risk factors into extrinsic factors, which are
those outside of the body, and intrinsic factors, or those from within the body.\textsuperscript{6} The other classification scheme divides risk factors into environmental, anatomical, hormonal, and neuromuscular.\textsuperscript{1} Some of these risk factors can be modified, while others, such as anatomical risk factors, cannot. Much research has been focused on neuromuscular and biomechanical factors due to the fact that both have been found to be modifiable.\textsuperscript{7-11}

Females are at a six times increased risk of ACL injury when compared to their male counterparts\textsuperscript{12} and this may be attributed to females’ landing patterns. Compared to their male counterparts, females have been shown to land with decreased knee flexion, increased knee valgus, greater vertical ground reaction forces (VGRF) and greater external knee abduction moments.\textsuperscript{13,14} Females exhibiting these landing patterns have been found to be at increased risk of ACL injury.\textsuperscript{15} Many different prevention programs have been implemented in an attempt to prevent these injuries. Successful prevention programs have focused on strength, endurance training and neuromuscular control.\textsuperscript{9} Prevention programs range from six weeks to as long as 41 weeks and have varying degrees of cost associated with them.\textsuperscript{9} Although some prevention programs have had success with reducing ACL injuries,\textsuperscript{1,9} the time, materials and staffing needed, may limit the ability to implement these programs in certain settings.

Another modality that has previously been shown to have the ability to make immediate changes in landing biomechanics is feedback.\textsuperscript{10,11,16,17} Feedback methods can be divided into feedback by an expert, self-initiated feedback and a combination of the two. The self-initiated and combination feedback have proved to be most effective in changing knee kinematics and kinetics in ways that reduce peak ground reaction forces, as well as increasing knee flexion angles and decreasing anterior tibial shear forces.
during a jump landing task. These feedback interventions have been performed in a laboratory setting, with only one specific task being analyzed throughout the study. However, athletics are very unpredictable and fast paced so it is imperative to reflect these situations when implementing prevention programs. One step to making prevention programs more sport specific is determining whether feedback can be effective during a transfer task. A transfer task is when a participant uses their knowledge gained during one task and applies what they have learned to a new task. The use of transfer tasks are imperative to examining the long-term effects of an intervention, generalizing feedback intervention programs to ACL injury prevention and to answer the question of whether or not the effects of feedback can be transferred from one task to another.

1.1 Statement of the Problem

As a modality, feedback has been investigated on its ability used to correct improper landing techniques in an attempt to decrease the risk for future injury. Although this modality has been shown to improve kinematics and kinetics during jump landing tasks in a controlled, laboratory setting, athletes utilize various movement strategies when participating in live sport competition. Currently it remains unknown if successfully manipulating landing biomechanics through feedback interventions during one potential mechanism of injury, such as a jump landing, will induce changes in another potential mechanism of injury, such as cutting. More research into this area will determine if alterations made to landing biomechanics have the possibility to be transferred from a laboratory setting to a more clinical setting such as a game or practice situation.

1.2 Statement of the Purpose
The purpose of this study was to determine the effects of feedback provided during jump landing on peak vertical ground reaction forces (VGRF), hip flexion angle, knee flexion angle and knee abduction angle during a jump landing task after a 4 week feedback intervention program. Furthermore, this study aimed to determine if feedback that is used to evoke biomechanical alterations during a jump landing task will transfer over and cause similar alterations during a cutting task.

1.3 Significance of the Study

The cost of ACL injuries is a great burden on the healthcare system. These injuries can have debilitating long term consequences such as a reduced quality of life and the development of osteoarthritis (OA). Prevention, through feedback, is a cost effective means of treating this injury and decreasing the economic and physical burden it causes. This study will address the important question of whether or not successfully manipulating landing biomechanics through feedback will also induce changes in other ACL injurious mechanisms, such as a cutting task. Answering this question will be fundamental in optimizing ACL intervention programs and ultimately preventing ACL injury.

1.4 Research Hypothesis

1. Peak vertical ground reaction forces will be reduced during jump landing task and the cutting task after the 4 week feedback intervention.

2. There will be an increase in hip flexion angles collected at peak vertical ground reaction forces during the jump landing task and the cutting task after the 4 week feedback intervention.
3. There will be an increase in knee flexion angles collected at peak vertical ground reaction forces during the jump landing task and the cutting task after the 4 week feedback intervention.

4. There will be a decrease in knee abduction angles collected at peak vertical ground reaction forces during the jump landing task and the cutting task after the 4 week feedback intervention.

1.5 Limitations

A limitation to this study was the inability to recruit our desired number of participants. We determined that we needed a minimum of nine participants in each group to detect the presence of statistically significant differences; however, we oversampled by about 50%, so our desired number of participants included 14 participants for each group, or 28 total participants. We were only able to include a total of 16 participants. After one drop-out and one incomplete data set, we ended up with 9 participants in the feedback group and 5 participants in the control group.
Chapter 2

Literature Review

2.1 Introduction

Anterior cruciate ligament injuries (ACL) are becoming an increasingly common injury in today’s society. Each year approximately 80,000 to 250,000 ACL injuries occur with many of these injuries happening to young athletes.\(^1\) ACL rupture is most commonly seen with a change of direction or cutting maneuver combined with deceleration, landing from a jump, and pivoting with the knee near full extension.\(^5\) These non-contact mechanisms have been observed as the most common mechanism of ACL injuries, especially in female athletes.\(^{20}\) This may be why female athletes are at a six times greater risk for non-contact ACL injury compared to males.\(^{12}\) The effects of an ACL injury range from short-term, physical and psychological effects, to long-term early onset knee osteoarthritis years after the initial injury.\(^4\) ACL injuries have a substantial impact on the injured athlete, as well as the entire general population. Each ACL reconstruction surgery costs approximately $17,000\(^3\) and with about 100,000 surgeries performed each year,\(^2\) the financial burden on the healthcare system is enormous. In addition to the millions of dollars spent on reconstruction surgery only, the costs for associated rehabilitation and follow up care make this injury an important concern to the
general public since it has major implications on the entire healthcare system. With such an impact on the healthcare system, this injury and its negative effects have become a growing public concern, which has prompted the implementation of prevention programs to help reduce ACL injury risk. These prevention programs include many different components including: strength, endurance, plyometric, balance and neuromuscular training. Many of these prevention programs have also included different types of feedback, such as feedback provided by experts, self-analysis feedback, or a combination of the two. These programs have been shown to be effective in changing knee biomechanics, which is imperative when trying to prevent athletes from placing themselves in injurious situations. It currently remains unknown if successfully manipulating changes in landing biomechanics through feedback interventions have the ability to induce changes in other movements. This study will be examining a transfer task. The concept of a transfer task is to have participant use information gained from feedback given in the original task to complete a new task. The purpose of this project is to examine the effects of a feedback intervention on peak vertical ground reaction forces (VGRF), hip and knee flexion angles and knee abduction angles during a jump landing task and the ability of the biomechanical changes to transfer to another similar athletic task, such as a planned cutting task.

2.2 Epidemiology

Knee injuries, especially ACL ruptures, are becoming increasingly common in the world of sports. Annually, approximately 250,000 people sustain ACL injuries. One study found females to have a three to four times greater risk of sustaining an ACL rupture compared to their male counterparts. During a four year surveillance of
National Collegiate Athletic Association injuries, women’s basketball and women’s soccer had the highest percentage of knee injuries with 15.9%,\textsuperscript{22,23} followed by women’s volleyball with 14.1%\textsuperscript{24} and women’s lacrosse with 14.0%\textsuperscript{25}. In comparison, men’s sports saw a percentage of knee injuries ranging from 3.7% to 13.5%.\textsuperscript{26-28} The only men’s sport that saw a higher percentage than a female sport was football, with 17.8%,\textsuperscript{29} which is most likely due to the contact nature of the sport. Overall, almost all sports ranked knee injuries as the second most frequent injury during games, behind ankle ligament sprains, with women’s sports and the more dynamic sports, like basketball and soccer, seeing increased percentages.\textsuperscript{12,22-28,30}

ACL injury and associated disability go far beyond the short-term, immediate effects. Immediate pain and disability are obvious effects, but psychological effects, like long term depression, and emotional disturbances,\textsuperscript{31} have been seen soon after injury and surgery. When an injured athlete is not able to participate in their sport, they may feel disconnected from their team and feel as though they can no longer make a meaningful contribution. All of these psychological issues can have negative effects on the injured athlete’s mental health. In addition to short term effects, long terms effects, like the early development of osteoarthritis, are very common. By the age of 65 people who have suffered an ACL injury are at a threefold increased risk of developing knee osteoarthritis (OA).\textsuperscript{4} A study investigating the incidence of knee OA in females who sustained an ACL injury twelve years prior, functional limitations and pain, assessed using questionnaires, as well as evidence of radiographic knee osteoarthritis, were examined.\textsuperscript{4} Seventy-five percent of the patients reported symptoms in their knee that affected their quality of life and 51% had evidence of radiographic knee OA when examined by weight-bearing knee
radiography. Not only do ACL ruptures affect the injured athlete, but they have a tremendous impact on society and our health care system. One ACL reconstruction surgery costs approximately $17,000 and annually, it is estimated that approximately 100,000 reconstruction surgeries are performed. With 100,000 surgeries being performed at a cost of $17,000 dollars each, the estimated cost per year is over $17 million dollars.

2.3 Risk Factors

Many different risk factors have been implicated in non-contact ACL injuries. Much focus and attention have gone into identifying risk factors for non-contact ACL injuries, however, not one risk factor has been implicated in all ACL injuries and this area still needs more research to define clear conclusions regarding the various risk factors. Non-contact ACL risk factors can be grouped into environmental risk factors, anatomical risk factors, hormonal risk factors and neuromuscular risk factors. Environmental risk factors include weather conditions, the type of surface, the type of footwear and its interaction with the playing surface and protective equipment. Non-contact ACL injuries tend to occur during dry conditions, when the ground is harder which may increase the shoe-surface traction. Anatomical risk factors include the greater Q angle in females, increased knee valgus angle upon landing in females compared to males, body mass index, width of the femoral notch and ACL size and properties. The fluctuation of sex-specific hormones has been investigated in terms of its’ effect on the properties of the ligament and how those fluctuations may influence ACL injury risk, however no clear consensus has been established. The last category of risk factors, neuromuscular risk factors, includes altered movement patterns, altered
muscle activation patterns, and inadequate muscle stiffness.\textsuperscript{1} Previous literature support the findings that females have consistently shown different lower extremity mechanics with varying athletic tasks.\textsuperscript{32} For example, females have been shown to land with small knee flexion angles during a jump landing task.\textsuperscript{33} It has been hypothesized that when females land in a more erect position with less knee flexion, it creates a larger knee extensor load, which results in greater energy absorbed at the knee instead of the hip and could help to explain the gender bias seen with non-contact ACL injuries.\textsuperscript{34} In addition to landing with less knee flexion, females have also consistently landed with decreased hip flexion, increased knee valgus, increased internal rotation of the hip and increased external rotation of the tibia.\textsuperscript{1,35-37} The ACL plays a role in rotary stability of the knee and when an athlete lands with increased hip internal rotation combined with increased external rotation of the tibia, there will be stress placed directly on the ACL, as the two bones are moving in opposite directions. Another important factor to examine is knee valgus because landing in a position with increased knee valgus has been viewed as hazardous to the ACL during biomechanical studies.\textsuperscript{35,38}

\textbf{2.4 Prevention}

Much research has been done investigating how to reduce ACL injury risk. Through this research, various prevention programs have been implemented in an attempt to reduce the incidence of ACL injury. Previous prevention programs have been successful when proper strength, endurance and neuromuscular training have been emphasized.\textsuperscript{2,19} Strength and endurance training of the core and lower extremity has been shown to promote kinesthetic awareness and encourage better lower extremity rotational and angular control, \textsuperscript{2} while neuromuscular training can decrease landing forces and knee
adduction and abduction moments. There are a myriad of different prevention programs that have been proven to be successful, but all focus on different aspects and use a vast array of methods to achieve their results. Therefore, it is unclear which aspect of a prevention program may be the most critical in improving landing biomechanics and reducing the risk of non-contact ACL injury. Another consideration of prevention programs to look at is the time and materials needed to implement a successful program. A meta-analysis by Hewett et al. examined the effects of different prevention programs and found that successful programs ranged from 6 weeks to 41 weeks. Training sessions lasted from 10 minutes in length up to 75 minutes in length and on average 3 sessions were held per week during the length of the programs. In addition to the vast amount of time spent executing these prevention programs, costs also must be examined. Costs, including equipment and labor, typically fell under $100 per participant, but some programs saw costs as high as $375 for each athlete. As it is easy to see these types of prevention programs are very costly and require much time to be completed. Another tool that could be used in prevention programs that requires much less time and equipment is the use of feedback.

2.5 Feedback Interventions

Feedback is one method that is currently being studied, in order to help improve lower extremity biomechanics during functional tasks. Types of feedback methods include feedback given by experts, self-analysis feedback and a combination of the two. Expert provided feedback is when the participant receives instruction or views an expert model performing a task with proper landing mechanics, whereas self-analysis feedback
is when the participant views their own trials of the jump landing task. Combination feedback is any combination of expert and self-analysis feedback.

A study by Onate, et al. investigated the effects of three different modes of feedback on knee biomechanics during a jump-landing task. These different modes of feedback were effective in reducing peak ground reaction forces, as well as increasing knee flexion angles and decreasing anterior tibial shear forces; although, the self-initiated and combination feedback proved to be more effective than the expert only feedback. The self-initiated and combination feedback groups had significantly larger decreases in peak VGRF and had greater increases in knee flexion angles compared to the expert only group.

To understand how the effects of feedback can change landing biomechanics, it is essential to understand how the person learns the desired movements. Motor learning is broken down into explicit and implicit motor learning. Explicit motor learning refers to acquiring motor skills with an internal focus and specific knowledge about the performance of the skill, while implicit motor learning refers to the acquisition of a motor skill without the current acquisition of explicit knowledge about the performance of a skill. Implicit learning may produce more stable solutions under stress, anxiety-provoking conditions and fatigued states, which are all things an athlete will experience during a game setting. Augmented feedback, which is external feedback provided to the participant and what we will be using in this project can be used to improve kinetics and kinematics during jump landing and falls under the implicit motor learning category.

2.6 Transfer Task
Previous research has shown feedback to be effective in changing knee biomechanics and reducing ground reaction forces during a jump-landing task. Some of the most common mechanisms for ACL injury are planting and cutting, straight-knee landing, and a one-step stop with the knee in hyperextension. In order to improve ACL injury prevention programs it must be understood if the biomechanical changes made during one task have the ability to transfer to another task.

A transfer task is when a participant uses their gained knowledge during an original task and applies what they have learned to a new task. In this study, a plant and cut task will be used as the transfer task. We will investigate if feedback given during an initial jump landing task can transfer over and have positive adaptations during a plant and cut task. One previous study examined the effects of real-time feedback on knee abduction moments during a double-leg and single-leg jump landing. They found that knee abduction moments were able to be transferred from the original task, a double-leg jump landing, to a single-leg jump landing. Although these results are promising there is still a lack of research involving transfer tasks. In order to help fill this void, this project will explore if feedback is an effective prevention modality that can be transferred from a laboratory setting into a more dynamic athletic setting on the field or court. Although the use of a transfer task is rarely seen in biomechanical studies, they are imperative to understand the transferability of biomechanical changes made with feedback given during one task and applied to another task. Determining if the biomechanical adaptations can be seen during a transfer test will help to determine the most effective method to delivering feedback interventions.
Chapter 3

Methods

3.1 Experimental Design

This study was a randomized controlled trial. A block randomization was used to place participants into one of two groups: a feedback intervention group and a control group. An opaque envelope was used to conceal group assignment until the examiner opened the envelope immediately prior to the intervention. Outcome measures included peak VGRF, hip flexion angle, knee flexion angle and knee abduction angle, which were collected at two time points: baseline, and following a 4-week intervention.

3.2 Participants

Sixteen, female participants were recruited from the University of Toledo community to be included in this study. All participants were physically active for at least 3 times per week for at least 30 minutes each session. Those with a history of lower extremity fracture or surgery, chronic ankle instability, defined as scoring <90% on the Foot and Ankle Ability Measure, or those who have sustained major knee or hip ligamentous injury were excluded from this study. To be included in the study, participants exhibited excessive valgus during a screening and if excessive knee valgus was not present during the initial screening, the participant was excluded from this study.
In order to assess knee valgus, participants were placed on a 30 cm box that was positioned a horizontal distance equal to 50% of their height behind the force plates. The participants were instructed to jump off of the box and onto the force plates and as they landed on the ground, immediately rebound for maximum height. Valgus was visually assessed as the participant was jumping by an experienced investigator and inclusion or exclusion was determined after three jumps. If the investigator felt that knee valgus was present, they were included into the study and if knee valgus was not present, they were dismissed from the study. All participants provided written informed consent approved by the institutional review board at the University of Toledo prior to performing any of the proposed experiments.

3.3 Instrumentation

The following instrumentation was used to execute this study:

1) Passive marker motion capture system with 12 Eagle digital cameras (Motion Analysis Corporation, Santa Rosa, CA) for the kinematic analysis.

2) AMTI OR6-5 Force plates (Advanced Motion Technology, Inc., Watertown, MA) integrated with the motion capture cameras through National Instruments NI USB-6218 A/D converter (32-inputs, 16-bit, 250kS/s Isolated Multifunction I/O) (National Instruments, Austin, TX).

3) Cortex 3.6.0.1312 motion capture/processing software (Motion Analysis Corporation).

4) Visual 3D Basic RT (C-Motion, Inc., Germantown, MD) for post-processing data analysis.

3.4 Testing Procedures
After determining knee valgus was present using the LESS protocol all participants filled out a Godin Leisure-Time Exercise Questionnaire, a sport participation questionnaire, the Foot and Ankle Ability Measure, and an injury history questionnaire. These were completed in order to ensure all participants meet the inclusions criteria. Reflective markers were then attached to the participant with double-sided tape for collection of the kinematic outcomes. Forty-one reflective markers were placed on the following bilateral landmarks: acromioclavicular joint; anterior superior iliac spine; posterior superior iliac spine; iliac crest; greater trochanter; distal thigh; medial and lateral femoral condyles; patella proximal, lateral and distal shank; medial and lateral malleoli; great toe; second toe; on right inferior angle of the scapula and the sternum (Figures 1 and 2). A static trial was performed initially in order to align the participant with the global laboratory coordinate system, followed by a dynamic trial. Both trials were recorded using a 3-dimensional, 12-camera system (Digital Eagle System, Motion Analysis Corporation, Santa Rosa, CA) and processed with Cortex software (Motion Analysis Corporation). Following calibration, four medial markers were removed.

Figure 1. Anterior view of marker set

Figure 2. Posterior view of marker set
The participants then performed a jump landing task off of a 30 cm box by jumping forward off the box, landing on the force plates and sticking the landing. The distance between the box and the force plate was standardized to half of the height of each participant (Figure 3). Practice trials were permitted to allow the participants to familiarize themselves with the task. Once the participant felt comfortable with the task, five trials with adequate data were collected for processing. After the jump landing task, participants performed the transfer task in the form of a cut. The participants took a four step approach run, planted with their right foot on the force plate and then performed a cut at a 60 degree angle to the left of the force plate (Figure 4). A path was provided to the participants using orange cones to guide them in the direction of the cut. After the cutting maneuver, the participants sprinted a short distance. Participants were provided practice trials until the both the participant and the investigator were comfortable with the ability of the participant to properly perform the movement. Timing gates were placed at the beginning and end of the sprint and the velocity was calculated. Participants performed the cut at a velocity between 3m/s and 4 m/s to be counted as a successful trial. Five cutting trials with adequate data were collected for processing.

Figure 3. Participant with markers jumping off of a 30 cm box onto the force plate
Figure 4. Participant with markers making a 60° cut off of their right foot after a four step approach

Following the baseline testing, group allocation was revealed. Participants in the feedback group were shown a brief PowerPoint presentation which had both writing and pictures explaining how to properly land from a jump. The list included: 1) landing with both feet at the same time, 2) landing in a neutral valgus/varus position, 3) landing with feet shoulder width apart, 4) landing on your toes, rocking back to your heels, 5) landing in increased bending in your knees and hips, and 6) landing softly. The participants then performed six sets of six jumps off of a 30 cm box, sticking the landing. After each set of jumps, the participant received individualized feedback explaining which items from the PowerPoint they were to focus on for the next set of jumps. In addition to the individualized feedback, participants also performed a self-analysis where they indicated which of the six characteristics they thought they correctly executed for each set. Participants in the control group were shown a PowerPoint presentation covering general nutrition, while sitting quietly for 10 minutes in place of the jumps and feedback. Ten minutes was used based on previous research in our lab that found this to be the average time it takes to complete the feedback intervention.
All participants in the feedback group returned to the laboratory three times per week for four weeks to complete the feedback intervention. During these intervention sessions, the investigator provided feedback on specific landing errors, similar to that performed during the original intervention session. The same PowerPoint presentation with the six instructions was used prior to each intervention. At the end of the four week feedback intervention outcome measures were collected during the jump landing task, as well as the cutting transfer task. Participants in the control group were tested at the same time points as the feedback group without completing the intervention sessions.

3.5 Data Analysis

The independent variables in this study include group and time. The two groups were: 1) the feedback intervention group and 2) the control group. The two time points include: 1) baseline, 2) four weeks post-intervention. The dependent variables include: 1) knee flexion angle, 2) hip flexion angle, 3) knee abduction angle and 4) peak vertical ground reaction force. All kinematic variables were collected at peak VGRF. Peak vertical ground reaction forces were calculated for each trial and normalized to the mass of each participant (N/kg). Processed data was exported to Excel and the averages of the first three usable trials were extracted for further statistical analysis. The alpha level was set at \( p \leq 0.05 \) a priori for all inferential statistics and SPSS 17.0 (SPSS, Inc., Chicago, IL) statistical software was used to evaluate all statistics. Eight separate, 2 x 2 ANOVAs with repeated measures on time were used to evaluate differences between groups for all outcome measures. Outcomes for the jump landing and cutting tasks were analyzed separately. In the presence of statistical significance, dependent and independent t-tests were used to evaluate within and between group differences, respectively.
Chapter 4

Results

4.1 Participant Demographics

Participant demographics of age, height, mass and exercise activity levels are presented in Table 1. There were no statistically significant differences found between the groups for any of the demographics.

<table>
<thead>
<tr>
<th>Table 4.1. Participant Demographics</th>
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<tr>
<td>Height (m)</td>
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<td>Mass (kg)</td>
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<td>Godin Leisure-Time Exercise Questionnaire</td>
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4.2 Peak Vertical Ground Reaction Forces

There was a significant group by time interaction for peak vertical ground reaction forces (VGRF) during the jump landing task, \( F_{1,12} = 14.56, \) \( p=0.002, \) \( 1-\beta=0.938; \) Table 2). The feedback intervention group had a significant reduction in VGRF when comparing the post-test to the baseline \( (t_{8}=7.40, \) \( p<0.000), \) while the control group did not change between the baseline and posttest \( (t_{4}=0.53, \) \( p=0.622). \) There was no difference between groups before the feedback intervention \( (t_{12}=0.018, \) \( p=0.986), \) or after the feedback intervention \( (t_{12}=-2.05, \) \( p=0.063; \) Table 2). There was no significant main effect for time \( (F_{12}=0.049, \) \( p=0.326, \) \( 1-\beta=0.157), \) group \( (F_{1,12}=0.547, \) \( p=.474, \) \( 1-\beta=.105) \) or
interaction (F_{1,12}=0.095, p=0.764, 1-\beta=0.059 Table 3), between groups over time for VGRF during the cutting task.

4.3 Knee Flexion

There were no main effects for time (F_{1,12}=9.298, p=0.010, 1-\beta=0.799) or group (F_{1,12}=0.670, p=0.429, 1-\beta=0.117) and no interaction, (F_{1,12}=2.731, p=0.124, 1-\beta=0.331; Table 2) for knee flexion during jump landing. During the cutting task, there was a significant time by group interaction (F_{1,12}=8.89, p=0.011, 1-\beta=0.782; Table 3). The feedback intervention group had a significant decrease in knee flexion when comparing the post-test to the baseline (t_8=-3.2526, p=0.012), while the control group did not change between the two time points (t_4=1.50, p=0.0207). There was no difference between groups before the intervention (t_{12}=-1.16, p=.268), or after the intervention (t_{12}=1.143, p=0.275; Table 3).

4.4 Hip Flexion

There was a significant main effect for time (F_{1,12}=37.527, p<0.000, 1-\beta=1.0; Table 2), indicating that both of the groups increased their hip flexion during jump landing after the 4 week intervention period. There was no significant interaction, (F_{1,12}=0.677, p=0.427, 1-\beta=0.118; Table 2). There were no main effects for time (F_{1,12}=1.298, p=0.277, 1-\beta=0.183) or group (F_{1,12}=0.104, p=0.753, 1-\beta=0.060) and no interaction, (F_{1,12}=2.25, p=.159, 1-\beta=.282; Table 3), for hip flexion between the two groups during the cutting task.

4.5 Knee Abduction
During the jump landing task, there was no significant interaction ($F_{1,12}=0.108$, $p=0.748$, $1-\beta=0.61$; Table 2). During the cutting task there was no significant interaction ($F_{1,12}=0.059$, $p=.811$, $1-\beta=.056$; Table 3).

Table 4.2. Changes in Kinetics and Kinematics During Jump Landing Task, Mean ± SD

<table>
<thead>
<tr>
<th>Jump Landing</th>
<th>Feedback</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>Post</td>
</tr>
<tr>
<td>VGRF (N/m)</td>
<td>1.88±0.46</td>
<td>1.35±0.47*</td>
</tr>
<tr>
<td>Knee Abduction (degrees)</td>
<td>-1.70±4.19</td>
<td>1.43±3.80</td>
</tr>
<tr>
<td>Knee Flexion (degrees)</td>
<td>-46.46±6.77</td>
<td>-59.03±12.49</td>
</tr>
<tr>
<td>Hip Flexion (degrees)</td>
<td>31.16±9.92</td>
<td>43.55±14.32#</td>
</tr>
</tbody>
</table>

* The feedback intervention group saw a significant reduction in VGRF after the feedback intervention ($F_{1,12}=14.56$, $p=0.002$, $1-\beta=0.93$)
# Both groups saw a significant reduction in hip flexion comparing the post-test to the baseline ($F_{1,12}=37.527$, $p<0.000$, $1-\beta=1.0$)

Table 4.3. Changes in Kinetics and Kinematics During the Cutting Task, Mean ± SD

<table>
<thead>
<tr>
<th>Cut</th>
<th>Feedback</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>Post</td>
</tr>
<tr>
<td>VGRF (N/m)</td>
<td>2.06±0.22</td>
<td>1.97±0.18</td>
</tr>
<tr>
<td>Knee Abduction (degrees)</td>
<td>-4.43±4.14</td>
<td>-2.57±3.50</td>
</tr>
<tr>
<td>Knee Flexion (degrees)</td>
<td>-48.94±3.99</td>
<td>-43.55±4.99^</td>
</tr>
<tr>
<td>Hip Flexion (degrees)</td>
<td>38.00±9.96</td>
<td>37.04±10.13</td>
</tr>
</tbody>
</table>

^The feedback intervention group saw a significant decrease in knee flexion after the feedback intervention, ($F_{1,12}=8.89$, $p=0.011$, $1-\beta=0.782$).
Chapter 5

Discussion

We found a decrease in peak VGRF following a four-week feedback intervention in the jump landing task, but not in the cutting task. Additionally, the feedback intervention was not found to be effective in increasing knee flexion in either the jump landing or cutting tasks. Contrary to our hypothesis, the feedback group actually decreased their knee flexion angles during the cutting task. There was no significant difference in knee abduction angle between the feedback and the control groups in either of the tasks. Hip flexion angles increased post intervention in the feedback intervention group, as well as in the control group in the jump landing task, while there were no significant differences found between the two groups during the cutting task.

Our main significant finding was that the feedback intervention group decreased peak VGRF during the jump landing task. Participants were given feedback to “land as softly as possible” during the 4 week feedback intervention jumps. This feedback, coupled with the repeated practice of the task throughout the 4 weeks is most likely why the feedback intervention group decreased their peak vertical ground reaction forces and the control group did not. Our findings agree with previous literature which investigated the immediate effects of a feedback intervention during a jump landing task.10,11,42 The
results of these studies have shown a significant improvement in peak VGRF in the feedback intervention groups compared to the control groups.\textsuperscript{10,11,42} A recent systematic review investigated the effect of different types of feedback on peak VGRF.\textsuperscript{43} The results of this review support the use of feedback because there was a homogenous negative effect, meaning that the feedback reduced peak VGRF.\textsuperscript{43} Landing with increased peak VGRF has been implicated as an injury mechanism for many lower extremity injuries.\textsuperscript{44} One study also found that there was a positive correlation between increased peak vertical ground reaction forces and anterior tibial translation.\textsuperscript{45} The main function of the ACL is to limit anterior translation of the tibia. If individuals are landing with higher VGRF, this may increase anterior translation of the tibia, placing greater stress on the ACL and increasing the likelihood of potential rupture.

We did not find a subsequent decrease in peak VGRF during the cutting task as we hypothesized. The intent of a transfer task, such as the cutting task in this study, is to investigate if a participant can use the knowledge gained during an original task and apply it to a new task.\textsuperscript{17} It is important to examine a transfer task, in order to discover the limits of the feedback intervention. Determining if this feedback intervention has the ability to transfer from one task to another will help to determine the most effective method of delivering feedback. The lack of decreases in peak VGRF during the cutting task can be attributed to the fact that the only time the participants performed the cutting task was during the testing sessions and the participants were not able to practice what they learned during the feedback sessions while performing the cutting task. Our results demonstrated a decrease in peak VGRF during the same task in which the participants were trained with the feedback intervention. That same decrease was not observed during
the multiplanar cutting task. This may attest to the inability of feedback to transfer to other more dynamic tasks.

Previous literature has shown similar results as the current study; however, specific feedback to reduce ground reaction forces was not given. Beaulieu, et al. examined knee abduction angles, as well as peak VGRF, and found the effect of the training program on knee abduction angles was able to be transferred from a double-leg landing to a single-leg landing. Our results are promising; however, we acknowledge that this lack of change during the transfer task may also be attributed to the small sample size and low power of this study. It was noted throughout our testing sessions that it took participants more practice trials to correctly perform the cutting task compared to the jump landing task. The cutting task is more of a quick, dynamic and multiplanar task compared to the jump landing task and requires the participant to focus on numerous items in order to execute it properly. Not all of our participants have participated in the same sports and for the same length of time, so the cutting task may have been more of a novel task for some of the participants. Perhaps more practice might be needed in order to see the same changes that were observed with the jump landing task.

There were no significant differences in knee flexion angles between the two groups during the jump landing task. The amount of participants included may have influenced our results and we expect with a larger sample size differences in knee flexion angles during the jump landing task will be detected. Contrary to our hypothesis, the feedback intervention group demonstrated a more extended knee position during the cutting task compared to the control group. This finding may suggest that feedback initiated adaptations may be observed during a cutting task but not in the task that was
performed during the feedback intervention. The decrease in knee flexion angles in the feedback intervention group may be in part due to the small sample size of this study and low power. Our small sample size greatly reduced our ability to detect differences between the two groups. There were no differences observed in knee abduction angles between groups during the jump landing task and the cutting task. Although both groups were able to decrease their knee abduction angles during the cutting task, there were no significant differences and this might be attributed to the fact that there is a lot less total motion in the frontal plane compared to other kinematic outcomes. Also, knee abduction is a lot harder for participants, who are unfamiliar with biomechanics, to visualize; therefore, it may be harder for them to know how to make changes to decrease their knee abduction.

Another main finding was the increase in hip flexion angles from the baseline testing session to the 4-week post-test regardless of group assignment during the jump landing task. Increasing hip flexion during landing is important because decreased flexion has been attributed to landing in a more erect position, causing the knee joint to have to dissipate larger forces. It has been hypothesized that landing in a more upright, erect position with decreased hip flexion creates a larger extensor load at the knee joint. A larger knee extensor load means that more forces are absorbed at the knee joint instead of at the hip, potentially placing more force on the ACL. Both the feedback intervention group and the control group demonstrated a significant increase in hip flexion from the baseline measurements to post intervention for the jump landing task. Although both groups showed an increase in hip flexion during the jump landing task, there were no significant differences between the two groups. It was expected to see an
increase in hip flexion in the feedback group; however, the control group may have also improved during the post-test because it was their second session performing these and the previous experience might have been enough practice to help them improve. When examining hip flexion during the cutting task, there were no significant differences between the control group and the feedback group. Again, with such a small sample size, we may have been limited in our ability to detect differences but with a larger sample size, we expect to see significant differences between the groups.
Chapter 6

Limitations

The major limitation to this study is the very small sample size. At this time, only one-third of the total number of expected participants have completed the study. Having a larger sample size would increase the power of the study and could drastically change the results. Although the intent of this study was to investigate the transferability of feedback from one task to another more dynamic task, this could be observed as a limitation. The cutting task was chosen as the transfer task because it has been implicated as a potential injurious position for ACL ruptures. Perhaps using a different task as the transfer task would yield different results. Another limitation could be the length of this study. There is currently a lack of research examining the long term effects of a feedback intervention, so there was no previous research to use as a guide for this study. Perhaps the four week intervention is not the optimal time period to produce changes in both tasks.

In the future, in order to see results that support our hypotheses, a larger sample size must be used. Increasing the power will increase the potential for seeing changes during both the jump landing task and the cutting transfer task. Future research should investigate the immediate effects of the feedback intervention on the cutting task. The
feedback intervention must first be established as having the ability to improve cutting biomechanics immediately before looking at the long-term effects of the intervention. Determining the immediate effects of the feedback intervention will provide insight into the future direction of these programs.
Chapter 7

Conclusion

In conclusion, we found that a four-week feedback intervention was successful in decreasing peak VGRF during a jump landing task. Although the feedback intervention group was able to improve their knee flexion angles during the jump landing task, we also observed similar results with the control group. There were no changes between the control and feedback group for peak VGRF forces during the cutting task; knee flexion during the jump landing task; hip flexion during the cutting task or knee abduction during either of the tasks. An unexpected finding of this study was that the feedback group decreased their knee flexion angles during the cutting task. Although these results may not support our hypothesis, we expect that adding participants to our sample size will drastically change our results. Although this was not what we expected to see, these results have provided us with insight into the limitations of a feedback intervention. It is imperative to understand the limitations of the feedback intervention, in order to improve future prevention programs.
References


