A Thesis

entitled

The Effect of a Video Feedback-Supplemented ACL Injury Prevention Program on Lower Extremity Biomechanics During a Cutting Task

by

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

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An Abstract of

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Biomechanics during cutting and landing tasks are thought to contribute to the increased risk of non-contact ACL injuries in females. Neuromuscular training preventions, with the inclusion of augmented feedback, have been successful in decreasing high-risk biomechanics in controlled laboratory settings; however it remains unclear if the use of augmented feedback in a clinical setting will demonstrate similar changes. Therefore, the objective of this investigation was to determine if the addition of video tape augmented feedback to an ACL injury prevention program would improve lower extremity biomechanics during a cutting task. We hypothesized that participants in the feedback group would demonstrate knee abduction and hip adduction angles, knee abduction and hip adduction angles, and peak vertical ground reaction force (vGRF), and would also demonstrate an increase in external hip and knee flexion moments as well as hip abduction and knee adduction moments during a cutting task when compared to a control group.

Sixteen female intercollegiate soccer players at the University of Toledo were recruited for this study. However, two participants were not included because they were no longer on the University of Toledo soccer team, while another sustained a previous injury that kept her from being able to participate. Sixteen female participants were recruited for this study and randomized into one of two groups; feedback or control, but due to drop outs, thirteen were
included in the final analysis (FB: n=6, 1.66 ± 0.03 m; 58.11 kg; 19.5 ± 0.83 yrs) (C: n=7, 1.66 ± 0.04 m; 63.16 ± 3.82 kg; 19.125 ± 0.83 yrs). Both groups completed a 9-week ACL injury prevention program two times per week. During the prevention program, all participants were recorded performing a squat jump task in both the frontal and sagittal planes during each week’s session. The feedback group later performed self analysis feedback followed by expert feedback given on their previously recorded squat jumps once per week whereas the control group was not provided any feedback on the task. Separate 2x2 analyses of variance with repeated measures on time were used to examine the differences for each kinetic and kinematic outcome measure. Post hoc t-tests were performed in the presence of a significant interaction. There were no significant differences between pre-post testing, or when comparing feedback and control groups for any of the biomechanical outcome measures. Although previous research has identified improvements in biomechanics following an ACL injury prevention program that utilized feedback as a modality, our modifications to the prevention program may have decreased its effectiveness. Furthermore, the use of video augmented feedback has previously been provided in real-time; therefore, the one to three day delay of feedback may have decreased the benefit of this feedback technique. In conclusion, video feedback given during a modified SportsMetrics prevention program may not augment changes in hip and knee biomechanics during a cutting task in collegiate female athletes.
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List of Abbreviations

ACL ................. Anterior Cruciate Ligament
ASIS .................. Anterior Superior Iliac Spine

BMI .................. Body Mass Index
LCL .................. Lateral Collateral Ligament

MCL .................. Medial Collateral Ligament
MTS .................. Musculotendinous Stiffness

OA .................. Osteoarthritis
PCL .................. Posterior Cruciate Ligament
PEP .................. Prevent Injury and Enhance Performance

SPSS ................. Statistical Package for the Social Sciences

vGRF .................. Vertical Ground Reaction Forces
Chapter 1

Introduction

Anterior cruciate ligament (ACL) tears occur in collegiate athletes upwards of 2,000 times annually in the United States. This high number of injuries, multiplied by the $17,000 cost per ACL reconstruction surgery, can cost the health care system over $30 million annually. An investigation by Ardent et al. concluded that females at the college level who actively participated in soccer or basketball had a 4 to 6 times greater risk of sustaining an ACL injury when compared to male athletes participating in the same sports. In addition, each year 1 in every 100,000 females who sustain an ACL injury, will sustain a re-injury; a higher risk than that of males.

Previous literature has suggested that certain landing biomechanics can potentially increase the risk of ACL injuries. Specifically, an investigation by McNair et al., demonstrated a positive correlation between increased peak vertical ground reaction forces (vGRFs) and increased tibial acceleration when landing from a jump. Increased tibial acceleration places a larger demand on the dynamic and static stabilizers, such as the knee joint musculature and ACL, respectively, to limit anterior translation of the tibia, potentially increasing ACL injury risk. Furthermore, an investigation by Mandelbaum and Silvers revealed that female participants tend to land with decreased knee flexion angles when compared to males during functional tasks such as running, side-pivoting, and cross-pivoting. Improper landing mechanics at the knee and hip can potentially become injurious to the ACL. Landing with a decreased knee flexion angle can lead to a larger amount of energy being absorbed at the knee when compared to a knee in flexion; thereby increasing knee extension torque and, subsequently, stress placed on the ACL.
Furthermore, decreased hip flexion angles and increased knee abduction angles, when combined with increased external rotation of the tibia and increased internal rotation angle of the femur, may become injurious to the ACL. During landing or cutting, as vGRF increases, the external knee extensor moments may also increase, which in turn increases anterior tibial shear force on the knee, stressing the ACL. The combination of these mechanics, decreased knee flexion and hip flexion, and increased knee abduction and vGRF create a reaction of forces up the kinetic chain that stress the ACL which could lead to its rupture. Research has illustrated that these biomechanical abnormalities can be improved. Given the high prevalence of ACL injuries and the large financial costs that these injuries place on the healthcare system, the development of effective injury prevention programs that improve biomechanics is imperative.

There has been a recent influx of lower extremity injury prevention programs specifically concentrating on ACL injury prevention. These prevention strategies frequently aim to improve strength, flexibility, and neuromuscular control. However, strength training protocols, as a single modality, have been shown to be an ineffective means by which to alter jump-landing biomechanics. Studies instructing individuals to land with proper biomechanics, though, have shown promising results in the reduction of knee injuries among female athletes. Collectively, these results suggest that while strength and balance training may together create an effective program, the education of the athlete in proper mechanics is invaluable.

Feedback is defined as informational cues on an individuals performance of a task and is a modality that has been studied and used effectively to correct faulty biomechanics in landing techniques in order to decrease the risk of lower extremity injuries. Previous studies have used check-lists and graded criteria evaluated by investigators to assess specific biomechanics during a variety of tasks. This is considered expert provided feedback, wherein the researchers
give a participant direct verbal and visual feedback on a specific task. Researchers like Herman et al. have also experimented with self-analysis feedback, where a participant, after being briefly educated in correct landing kinetics and kinematics, would grade herself on a provided check sheet on the aspects that she personally believed that she was able to accomplish. This method educated participants in proper landing techniques in hopes of reducing acute and chronic lower extremity injuries. Specifically, visual feedback has been implemented in investigations attempting to manipulate or alter mechanics within participants. Visual feedback is an important component of a prevention program because it allows the participant to better understand how he or she compares biomechanically to an ideal model. This type of feedback can be given in real time or recorded for further analysis. Therefore, the inclusion of video feedback during a clinically applicable prevention program may produce long-term improvements in landing biomechanics.

One form of visual feedback is feedback provided by video analysis. The use of videotape feedback has been used by coaches to review an athlete’s performance and allow the coaches to give specific feedback on tasks. Onate et al. conducted an investigation testing this use of videotape feedback in hopes of altering lower extremity motion patterns. Participants were placed into one of three feedback groups along with a control group: expert feedback only, self feedback only, or a combination of expert and self-reported feedback. These authors discovered that regardless of feedback group placement, all participants saw a significantly decreased vGRF following the injury prevention program. However, it was also reported that those individuals in the expert feedback only group did not show significant changes in knee flexion angles when compared to the control group. Therefore, it may be important to note that while videotape feedback has been shown to be successful, it should be given as either self-reported feedback or
a combination of self and expert reported feedback for clinically meaningful improvements in lower extremity biomechanics.\textsuperscript{24}

1.1 Statement of the Problem

It is suggested that certain landing biomechanics, such as decreased hip and knee flexion angles and increased knee abduction moments, contribute to the increased risk of non-contact ACL injuries in females. Injury prevention programs to reduce these risks have been established and implemented to decrease the incidence of injury. Unfortunately, in spite of the purported success of these programs, the incidence of ACL injuries has not decreased. Therefore, additional research is needed to determine the optimal strategy to improve landing biomechanics and thereby decrease the occurrence and reoccurrence of ACL injuries. The addition of feedback to biomechanical retraining preventions has been shown to be beneficial in injury prevention.\textsuperscript{22} Further research needs to be conducted to determine if feedback provided in a more clinically applicable manner, such as videotape feedback, would elicit similar results.

1.2 Statement of the Purpose

The purpose of this investigation was to examine if the addition of recorded videotape feedback to an already established ACL injury prevention program would augment changes on biomechanics of collegiate female athletes during a cutting task. Specifically, this investigation examined the influence of feedback on peak vGRFs and hip and knee sagittal and frontal plane biomechanics during a cutting task.

1.3 Significance of the Investigation
Previous studies have consistently demonstrated that females have a higher non-contact ACL injury rate than males, specifically in soccer, volleyball, and basketball.\textsuperscript{10,29} Along with the alarming incidence of non-contact ACL injuries in females, the cost and chronic disabilities associated with ACL injury make this an increasing concern among health care professionals.\textsuperscript{33} Prevention of these injuries through a videotape feedback-based program may be an effective way of decreasing the incidence of ACL injuries and, in turn, decreasing the financial and physical burden on the athletes, their families, and the health care system. This investigation addressed if videotape feedback, when added to an established ACL injury prevention program, was effective in manipulating landing biomechanics. The outcomes of this investigation could be fundamental in creating augmented feedback ACL injury prevention programs to successfully reduce the incidence of non-contact ACL injuries.

1.4 Specific Aim

Aim 1: To determine if the addition of videotape feedback to an already established ACL injury prevention program would improve lower extremity biomechanics, including knee and hip flexion angles, knee and hip extension moments, knee abduction angle and moment, hip adduction moment, and peak vGRF during a cutting task, compared to control participants completing the ACL injury prevention program, without receiving the supplemental videotape feedback prevention.

Hypothesis 1.1: Participants in the feedback group would demonstrate decreased peak vGRF, increased external hip and knee flexion moments, and increased hip abduction and knee adduction moments during a cutting task when compared with the control group following the 9 week ACL injury prevention program.
Hypothesis 1.2: Participants in the feedback group would demonstrate increased hip and knee flexion angles and decreased hip adduction and knee abduction angles during a cutting task when compared to the control group following the 9 week ACL injury prevention program.

1.5 Limitations

This investigation was implemented to determine if videotape feedback could be integrated with an already established ACL injury prevention program. One possible limitation of this investigation was its small sample size. Participants were recruited from a single women’s collegiate soccer team, which limited the total number of possible participants. The squat jump was selected as the task in which to give feedback because it was the one task that did not change throughout the duration of the ACL prevention program. Therefore, this task in which the video feedback was provided may not have been the most optimal task to elicit errors and encourage improvements in biomechanical landing patterns. However, it may have been difficult to judge changes over time when analyzing a task that altered over the 9-weeks. Individualized learning was not implemented, nor were the participants reminded to use the knowledge from the expert feedback sessions in the following prevention sessions or at the post-test. We had hoped that the participants’ learned knowledge from the feedback sessions would transfer to the cutting task, making this ACL injury prevention program clinically applicable to assist in altering biomechanics on the field. There was also a lack of blinding in this study due to the fact that it was necessary for the researchers to provide expert feedback directly to each participant in the feedback group.

1.6 Operational Definitions:

ACL: Anterior Cruciate Ligament
vGRF: Vertical Ground Reaction Forces

OA: Osteoarthritis

LCL: Lateral Collateral Ligament

MCL: Medial Collateral Ligament

PCL: Posterior Cruciate Ligament

BMI: Body Mass Index

PEP: Prevent Injury and Enhance Performance

MTS: Musculotendinous Stiffness

ASIS: Anterior Superior Iliac Spine

SPSS: Statistical Package for the Social Sciences
Chapter 2

The purpose of this literature review was to detail the: 1) incidence rates associated with ACL injuries; 2) relevant lower extremity anatomy; 3) etiology and risk factors associated with ACL injuries; and 4) current injury prevention strategies.

ACL injuries most often occur with a non-contact mechanism when the athlete is performing a quick deceleration and change of direction or cutting maneuver, pivoting when the knee is in extension, or when landing. As many as 80% of ACL injuries are from non-contact forces like the landing phases of a stop-jump task. These injuries occur most often in young athletes between the ages of 15 and 25 years. Many studies have found that women have a four to six times higher rate of ACL injuries in basketball, soccer and volleyball, than that of males. Factors that may explain this sex disparity in injury rates include: changes in muscle activation, the increased rate of fatigue, and biomechanical differences such as increased anterior tibial translation when landing from a jump or during a cutting task. Although this traumatic injury is most commonly seen in younger athletes, and has typically at least a six-month turn around, the affects can linger for years beyond the initial injury. These affects can include physical and psychological consequences in both the short and long term and can range from knee pain to developing early onset knee osteoarthritis (OA). Individuals with a history of an ACL tear are seven times more likely to develop moderate clinical OA and have over a 100 times greater chance of developing radiographically diagnosed OA when compared to individuals who have not experienced an ACL tear.

2.1 Anterior Cruciate Ligament Injury Incidence
ACL ruptures occur in 1 out of 3,000 people per year in the general population in the United States, with 2,000 of these injuries occurring specifically in collegiate sports.\textsuperscript{2-4} There are upwards of 250,000 ACL ruptures occurring per year in the United States\textsuperscript{20} resulting in approximately 100,000 reconstructions.\textsuperscript{42} At $17,000 per surgery\textsuperscript{5}, this immense cost, occurrence rate, and potential long term health issues make ACL injuries a health care concern. In addition to the monetary cost, there are other functional concerns of ACL injuries. An athlete with a history of knee injuries during adolescence is three times more likely to develop knee OA by the age of 65 years old, than an athlete without a knee injury history.\textsuperscript{43}

2.2 Anatomy

The tibiofemoral joint is the principal joint at the knee complex. Its proximal component consists of the femur which has convex femoral condyles, while the distal component of the tibia has a concave superior surface at the tibial plateau. The tibiofemoral joint is a hinge joint with two degrees of freedom due to the menisci between the articular surfaces. Knee flexion and extension with an anterior and posterior glide of the tibial plateau makes up one degree of freedom, with the other being tibial rotation, which occurs only in a flexed position. The knee joint is most stable in full knee extension, or the closed-packed position.\textsuperscript{44}

Four ligaments support the tibiofemoral joint: the lateral collateral ligament (LCL), medial collateral ligament (MCL), anterior cruciate ligament (ACL), and posterior cruciate ligament (PCL). The ACL and PCL provide rotational stability, prevent the knee from going into hyperextension, while the MCL and LCL prevent knee abduction and adduction. The ACL serves to resist anterior translation of the tibia on the femur, internal rotation of the tibia on the femur, external rotation of the tibia on the femur, and hyperextension of the tibiofemoral joint.\textsuperscript{44} The ACL originates from the anteromedial intercondylar eminence of the tibia, travels
posteriorly, and inserts on the medial wall of the lateral femoral condyle. The LCL originates on the lateral femoral epicondyle and inserts on the proximal aspect of the fibular head. This assists its resistance against internal and external tibial rotation. The MCL, the primary medial stabilizer of the knee, acts to protect the knee against valgus forces. This ligament originates from the medial femoral condyle and attaches on the medial tibial plateau. The PCL, the primary posterior stabilizer of the knee, originates on the posterior aspect of the tibia and attaches to the lateral portion of the medial condyle of the femur. Injuries to these ligaments increase laxity in the knee, which increases the risk of damaging the menisci.

The medial and lateral menisci of the knee are fibrocartilaginous structures that serve to deepen the articulation of the knee to increase load transmission, improve lubrication, provide shock absorption, and increase passive joint stability. They attach to the depressions between the condyles of the tibia. The medial meniscus resembles the letter C, while the lateral meniscus, the smaller and more mobile of the two is more of a closed circle.

The musculature of the tibiofemoral joint includes the groups of muscles of the quadriceps and the hamstrings. Anteriorly, the quadriceps muscle group is made up of the vastus medialis, the rectus femoris, the vastus intermedius, and the vastus lateralis muscles. The vastus muscles are responsible for knee extension, while the rectus femoris muscle is responsible for knee extension and hip flexion. Each of these muscles has a common insertion on the tibial tuberosity. Posteriorly, the hamstring muscle group is made up of the semitendinosus, semimembranosus, and biceps femoris muscles. Together, the hamstrings act to flex the knee and extend the hip. The semitendinosus and semimembranosus muscles additionally contribute to knee and hip internal tibial rotation, while the biceps femoris externally rotates the hip and knee joints. Due to the fact that the functions are redundant, the semimembranosus muscle is often
used as a graft source during ACL reconstruction surgeries. Other muscles acting on the tibiofemoral joint are the gracilis, popliteus, and sartorius muscles. The gracilis’ function is to flex the knee, internally rotate the tibia, and adduct the hip. The popliteus has functions in the open and closed chain. In the open chain, or in a non weight bearing position, it works to internally rotate the tibia and flex the knee. In the closed chain, or in a weight bearing position, the popliteus works to externally rotate the femur and to flex the knee. Lastly, the sartorius muscle acts in knee flexion, internal tibial rotation, hip flexion hip abduction, and hip external rotation.44

2.3 Etiology and Risk Factors of Anterior Cruciate Ligament Injury

Although injuries to the ACL can be a result of direct contact with another player or object to the knee or lower extremity, approximately 80% of ACL injuries are caused by non-contact forces.34,35 Non-contact ACL injuries may be the result of faulty biomechanics, landing incorrectly from a jump, attempting a cutting maneuver, or simply decelerating too quickly. One of the most common mechanisms of injury for sustaining an ACL injury occurs when an individual forcefully rotates his or her knee while the foot remains stationary or planted, which places tensile forces on the knee and can cause a rupture of the ACL.44 Another common mechanism of injury is decreased hip and knee flexion during cutting or landing which prevents the individual from properly absorbing the force placed on the body upon impact. This can increase their peak vGRF which would increase knee loading and therefore increase the risk of injuring or tearing the ACL.5,26

An investigation by Smith et al.45 examined anatomic and neuromuscular risk factors for ACL injuries from the current peer-reviewed literature in 2012. Only prognostic studies and prospective cohort study designs were included in the review. A total of 50 articles were
included with 30 specifically focusing on anatomical and neuromuscular factors of ACL injuries. The research team concluded that there were several risk factors associated with an increased probability of an athlete sustaining an ACL injury including a smaller intercondylar femoral notch size, depth of concavity of the medial tibial plateau, and an increased slope within the tibial plateaus and anterior and posterior knee laxity. These factors may, in combination with one another, further increase the risk of sustaining an ACL injury.

Risk factors for non-contact ACL injuries can be either non-modifiable, or modifiable. Non-modifiable are factors that cannot be changed; such as width of the athlete’s femoral notch in relation to the size of their ACL, and higher Q angles in females. The width of an athlete’s pelvis in relation to their knee determines the size of their Q angle. Also, the size of the athlete’s intercondylar notch, which is the space in which the ACL moves, could be a determining factor in injury predisposition. Women often times have a more narrow intercondylar notch than that of males, and therefore allowing for a more limited movement of the ACL.

Potentially modifiable risk factors include extremity biomechanics and neuromuscular risk factors that can differ between genders. Research has hypothesized that female athletes who land in an erect position with decreased knee flexion angles, could create an increased knee extensor load that could lead to a larger amount of energy absorbed at the knee instead of being dispersed at the hip. Furthermore, decreased hip flexion angles with increased knee abduction angles, combined with an increased external rotation of the tibia and increased internal rotation angle at the hip are more commonly seen in females and may be determining factors in why ACL injuries occur most often in females. Environmental risk factors may also play a role, including field or surface conditions, type of footwear in relation to the surface, protective
equipment, and weather conditions.\textsuperscript{20} Research has suggested that a combination of these factors could increase risk for ACL injury.\textsuperscript{20}

2.4. Prevention of Anterior Cruciate Ligament Injuries

There have been many studies dedicated to discovering ways in which to prevent ACL injuries. Much research has concentrated on various prevention programs implemented into daily practice of sports teams in an attempt to pinpoint a protocol that could effectively reduce the incidence of ACL injuries. In the investigation by Noyes \textit{et al.}\textsuperscript{50}, researchers looked to determine if ACL injury prevention programs had a positive influence on injury rates as well as athletic performance in female athletes. Of these programs, two significantly reduced the incidence of ACL injury rates and improved athletic performance tests: Sportsmetrics and the Prevent Injury and Enhance Performance program (PEP).\textsuperscript{50} Along with decreasing injury rates, the Sportsmetrics program significantly increased abdominal and lower extremity strength, vertical jump height, speed and agility, while the PEP program significantly improved only knee flexion strength.\textsuperscript{50} Although these programs have shown positive results in the reduction of ACL injury risk, it is important to look further into the time and cost that each program would need. Depending on the clinical site, available funds or the amount of time allotted to the prevention may vary. A prevention program that would fit in with a division 1 athletics team may not be the same for a high school team with a smaller budget and only one athletic trainer on staff. Prevention programs should be specific to the team’s interests and keep time and potential costs in mind.

One investigation by Cronin \textit{et al.}\textsuperscript{21} demonstrated a reduction in peak vGRF in collegiate volleyball players following a one-time augmented feedback prevention. However, available literature is hampered by these preventions that contain multiple modalities, and as a result,
researchers lack understanding regarding which included modalities caused the observed changes. Research has shown that non-contact ACL injuries can be reduced 20-80% by completing regular neuromuscular training with a focus on manipulating learned movement patterns, muscle strength, balance and proprioception. Research suggests that altered lower extremity biomechanics via prevention programs, using a combination of balance, plyometrics and strength training may be able to decrease the incidence of ACL injuries in female athletes. Research focusing on the effects of motor learning and strategy instruction to alter mechanics have effectively demonstrated the ability to improve landing kinematic and kinetic components of the lower extremity, and therefore reducing the risk of injury to the ACL.

ACL injury prevention programs implement a myriad of different techniques to reduce the risk of sustaining an injury. An investigation by Kristianslund et al. observed that decreased knee abduction loads could be achieved in female handball players. In this investigation, three cutting tasks were performed and analyzed; measuring knee joint kinetics. Due to the differences in technique within the participants, the researchers concluded that decreased knee abduction loads could be achieved if the participant completing the cutting task performs narrow cuts with a low knee valgus and toe landing. Therefore, just by completing a task differently, the injurious biomechanics can be decreased. Blackburn et al. suggest that isometric training may be one important factor in an ACL injury prevention program, it is likely that other components are needed to augment greater significant changes. One article concluded that the ideal ACL injury prevention program would begin six weeks prior to the start of the athletic season, and be at least 20 minutes in length. This review of the literature has concluded that while certain aspects of an ACL injury prevention program may be beneficial, other components have not
proven to augment statistical changes. Therefore, further research is needed to create a prevention program to decrease the risk of ACL injuries.

Different forms of feedback could be used separately, or in combination with one another to achieve the desired biomechanical changes. Augmented feedback is feedback which is received from a participants surroundings; auditory or visual stimuli. Expert provided feedback is that which is given by an expert model to the participant. He or she is given direct instructions or is able to view examples from the researcher on the correct ways to perform a specific task, which could include proper landing mechanics during a jump-landing, or cutting task. Self-analysis feedback is where the participant watches recorded sessions of his or her own trials of a specific task. These videos can be slowed or stopped to allow the athlete view important sections of the tasks, such as initial contact of a jump landing. Typically, a self-analysis is used in conjunction with expert provided feedback to cover different aspects of learning.

An investigation by Prapavessis et al. compared augmented feedback and sensory feedback in which was more effective in reducing peak vGRF. The 91 children participants were randomly assigned into the two groups and only received one type of feedback for the entirety of the prevention. All of the participants were instructed to jump from a box and to land as softly as possible on a force plate. Both the pre and post prevention peak vGRFs were recorded. The augmented feedback group was instructed to focus on their hip and knee joint motion along with their forefoot landing technique. Participants in the sensory feedback group were instructed to use their experience with the previous jump to land even more softly in subsequent landings. The investigation concluded that the sensory feedback group did not significantly reduce the
peak vGRFs from the pre-testing scores, while the participants in the augmented feedback group significantly reduced their peak vGRFs from their pre-testing scores.25

Stroube et al.63 completed a investigation on the effects of task-specific augmented feedback on modifying deficits during a tuck-jump exercise in 2013. The ACL injury prevention program was completed over an 8-week duration and included a pre-test and post-test analysis of the participants. During each of the three sessions per week, the participants were videotaped while completing the tuck-jump task and while running on a treadmill. These tapes were then used to provide the participants with augmented feedback. Stroube et al.63 found that there were significantly greater improvements in valgus moments, landing noise, landing width, and jump timing consistency in the feedback group when compared to the control group at the post testing session.63 Findings such as these indicate that providing specific feedback to athletes on jumping tasks may reduce certain risk factors that are associated with ACL injuries.

Another feedback prevention conducted by Herman et al.22 tested the effects of feedback with and without the addition of a strength-training component on lower extremity biomechanics.22 Upon enrolling in the 9-week prevention program, the participants were randomly assigned to either a strength training and feedback prevention, or a non-strength trained group that only received feedback. Both groups were tested before and after the completion of the prevention. During this 9-week period, the control group would refrain from strength training. At the completion of the 9-week data collection session, the feedback group completed a video assisted feedback program based on “expert plus self.”24 The participants would watch a video of themselves completing two trials of the stop jump task in the frontal plane, followed by two trials of an expert model completing the stop jump task. The participants were given a self-evaluation sheet to complete based on the techniques used by the expert model.
These feedback sessions were held once per week for three weeks during the prevention.\textsuperscript{22} One main finding of this investigation was that the 9-week strength-training program, with a video feedback component, increased the capacity for alterations in hip and knee kinematics and kinetics during a stop-jump task.\textsuperscript{22}
Chapter 3

3.1 Experimental Design

This randomized controlled pilot investigation took place in both the Musculoskeletal Health and Movement Sciences Laboratory and Savage Hall on the University of Toledo main campus. Participants were randomly assigned into one of two groups: a videotape feedback group or a control group. Group assignment randomization occurred by means of an online randomization tool and was given to the investigators performing the testing in a sealed envelope. The envelope was sealed until eligibility criteria were met and the participant completed baseline testing.

3.2 Participants

Sixteen female intercollegiate soccer players at the University of Toledo participants were recruited for this study and randomized into one of two groups: feedback or control (feedback[FB]: n=6, height 1.66 ± 0.03 m; mass 58.11 kg; age 19.5 ± 0.83 yrs)(control[C]: n=7, height 1.66 ± 0.04 m; mass 63.16 ± 3.82 kg; age 19.125 ± 0.83 yrs). Due to the pilot nature of this investigation, this research examined both healthy and previously injured populations. An individual was included in the investigation if she: 1) was a female soccer player at the University of Toledo; 2) had a body mass index (BMI) ≤35 kg/m²; and 3) was cleared for participation by a physician at the time of the investigation. Participants were excluded only if they were not cleared for participation at the time of pre-testing. Only females were recruited because they are at an increased risk of sustaining ACL injuries than males. To justify our estimated enrollment, a sample size estimate was completed. Based on a similar study that was
conducted on healthy, recreationally active college-aged females, it was estimated that 34 participants (17 per group) were needed to achieve an approximately 15° difference in knee flexion angle between groups following the injury prevention program (alpha = 0.05, power = 0.8). Unfortunately, the University of Toledo women’s soccer team only had a roster of 16 athletes. To rule out differences in upper and lower extremity intensive sports, athletic season, and position, other female Division I athletes at the University of Toledo were not enrolled in the injury prevention program. 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 Testing Procedures

Prior to testing, participants had their age, height, body mass, and injury history assessed by the investigators. Next, participants were asked to complete a biomechanical assessment of a cutting task. This same biomechanical assessment was also completed at follow-up testing.

Figure 1: Upper extremity marker placement
The biomechanical assessment consisted of a dynamic cutting task. Thirty-seven retro-reflective markers were placed on each participant at specified anatomical landmarks bilaterally: acromioclavicular joints; anterior superior iliac spines (ASIS); posterior superior iliac spines; iliac crests; greater trochanters; medial and lateral femoral condyles; lateral and distal shank; tibial tuberosities; medial and lateral malleoli; second metatarsal head; calcanei; navicular; great toe; and base of the fifth metatarsal. Additional markers were placed on right inferior angle of the scapula, manubrium of the sternum, and the seventh cervical vertebra (Figures 1 and 2). These markers were used to record the participant’s kinematics using a 12-camera motion capture system (Motion Analysis Corporation, Santa Rosa, CA, USA) sampling at 200Hz and its associated Cortex software version 5. Prior to the dynamic trials, a static trial was performed with the participant standing in a neutral position and from which a 3D kinematic model with 6 degrees of freedom per joint was created. During the dynamic trial the participants performed an
anticipated cutting task. Participants completed a four step approach run, landed with their dominant foot in the center of the force platform (2000Hz sampling rate; OR 6-7, Advanced Medical Technologies, Inc., Watertown, MA, USA), cut at a 45° angle in the opposing direction of their dominant limb, and sprinted several more steps (Figure 3). Dominant limb was defined as the limb with which the participant would kick a ball. Trials were completed at a velocity of 3.2-3.7 m/s. The cutting trajectory was marked on the ground with cones. Practice trials were conducted to ensure the participant’s understanding of the task and ability to properly perform the movement. Five successful trials were collected. A trial was considered successful if the participant landed with her foot in the center of the force platform and if her speed was between 3.2 and 3.7 m/s.

Figure 3: Participant completing biomechanical assessment: Cutting Task

3.4 Anterior Cruciate Ligament Injury Prevention Program

Over a 9-week period, participants in both the feedback and control groups completed an ACL injury prevention program twice per week. This program was a modified version of the SportsMetrics program, which includes a dynamic warm up, and strength, flexibility, agility, and
plyometric training. The program was modified to specifically address potential risk factors in female soccer players. This prevention was completed in place of the team’s warm up.

Although there were strength and flexibility components implemented into the ACL injury prevention program, they were performed as a part of the athletes’ lifting program, which was supervised by the strength and conditioning staff at the University of Toledo and, therefore, not a part of this investigation. During the plyometric exercises, quality was emphasized over quantity so that participants could concentrate on proper form to reduce knee injury risk. Over the course of the 9-week program, the exercises and tasks became increasingly more challenging. Examples of the progressions of exercises include: increased time required to complete tasks and moving from double leg to single leg exercises (Appendix C). Participants were educated on proper technique by the team’s athletic trainer and paired with another participant for the duration of the prevention program. They were given standardized cues to assist in providing feedback regarding proper task performance to their partners during each task. The certified athletic trainer assigned to the team supervised all exercises.

Videotape Feedback

All participants, both in the feedback and control groups, were videotaped using two Sony video cameras placed 1.5 meters away from the participants in both the sagittal and frontal planes during the squat jump portion of the ACL injury prevention program. The participants came two at a time to the videotaping area to be recorded while performing the squat jump task. The squat jump task was chosen because the task remained the same over the 9-week injury prevention program, thus allowing for feedback to be delivered during the same task for the duration of the investigation. The participants in the feedback group met with the investigators at their convenience to receive feedback on their recorded squat jump performance. These
recordings consisted of the squat jumps that were performed at the ACL injury prevention session prior to the feedback session.

Prior to each feedback session, the researchers viewed the recorded squat jump trials from each feedback participant and documented landing errors on the expert assessed sheet shown in Appendix D. Recorded trials were viewed on an iPad in the CoachMyVideo app (Figure 4). This free app allowed the researchers to view trials at full speed as well as 50% of regular speed, zoom in and out, and estimate knee joint angle during landing to aid in landing error detection and visualization.

Each trial was seen once at regular speed and once at 50% of regular speed in both the sagittal and frontal planes. Although the duration of the squat jump increased over time, the researchers only assessed five of each feedback participants’ squat jumps. The first three squat jumps were not analyzed, while the following five were assessed and recorded on the expert feedback sheet. Before the start of this prevention, researchers practiced evaluating the same trials together until there was an agreement on errors; therefore, keeping scoring consistent.

When the participants arrived individually for the feedback sessions, they viewed their squat jumps from the previous injury prevention program day. While watching their recorded squat jumps, the participants were given a self-analysis checklist to complete consisting of the same landing errors for which the researcher was looking (Appendix D). Similar to the expert assessed viewings, the participants watched each trial once at regular speed and once at 50% of regular speed in both the sagittal and frontal planes. This allowed the participant time to mark her check sheet and evaluate her biomechanics to see what she believed needed to be improved.
After the participants completely filled out the self-analysis checklist, the researchers would then provided them with the expert feedback that was previously recorded, pausing the video and highlighting each error within the trials. The researchers also paused the video at peak knee flexion to allow further analysis into the participant’s landing biomechanics. Following the expert feedback, the participant was instructed to use the information provided to attempt to correct future errors when performing the squat jump during the next ACL injury prevention session.

3.5 Biomechanical Data Analysis

Biomechanical data were processed in Visual 3D using a standard inverse dynamics analysis. Joint rotations were calculated using a Cardan rotation sequence based on the 3D marker trajectories captured during each trial and expressed relative to the participant’s static (neutral) position. All kinetic and kinematic data were filtered using a fourth-order, zero-lag Butterworth filter with a 12 Hz cut-off frequency. Data were extracted at the peak of the first 25% of the stance phase, defined as initial contact to toe off, of each participant’s dominant limb. This point was chosen because ACL injuries commonly occur within the first 25% of landing. Initial contact was defined as the instant the peak vGRF exceeded 10N, while toe off was the instant that the peak vGRF fell below 10N. Joint moment data were normalized to participant body mass and height (Nm/kg*m), while peak vGRF data were normalized to body mass (N/kg). All biomechanical data extracted were averaged across trials and submitted to statistical analysis.
3.6 Statistical Analysis

Independent variables included time (pre-prevention and post-prevention) and group (video feedback and control). The dependent variables of this investigation included hip and knee sagittal and frontal plane angles and moments and peak vGRF during the anticipated cutting task: knee flexion angle, knee extension moment, knee abduction angle, knee abduction moment, hip flexion angle, hip adduction angle, hip extension moment, hip adduction moment, and peak vGRF.

Separate 2x2 ANCOVAs with repeated measures on time were used to examine the differences between groups and over time for each kinetic and kinematic outcome measure along with the functional performance tests. Because there were differences in body mass between groups at baseline testing, these ANCOVAs were run with body mass as a covariate. T-tests were performed in the presence of significant interactions. Statistical Package for the Social Sciences (SPSS, Version 21) was used to perform all statistical analyses. Alpha was set a priori to 0.05.
Chapter 4

Results

Of the original 16 participants, 15 were able to complete the pre-testing session, while 13 completed the post-testing session. One participant had a pre-existing injury that prevented her from completing the cutting task in the pre-test and post-test time points. The other two participants who did not complete the post-testing session were no longer part of the women’s soccer team at the University of Toledo at the time of the post-test and, therefore, were not tested. Two of the participants indicated a history of a knee injury. Both of these participants had sustained an ACL tear prior to the prevention and were completing rehabilitation with the team’s athletic trainer. Due to these injuries, the athletes were not cleared at the time biomechanical testing of the cutting task.

There was a significant difference observed between groups for mass at baseline \( t = -2.38, P = 0.032 \) (Table 4). The control group had a significantly greater mass at baseline when compared to the feedback group; therefore, mass was used as a covariate in the statistical analysis.

4.1 Knee and Hip Kinematics

There were no significant differences between groups over time for knee flexion angle \( (F_{1,11} = 0.64, P = 0.44; FB \text{ pre/post } = -43.45 \pm 4.6, -41.79 \pm 3.9; C \text{ pre/post } = -43.87 \pm 4.0, -39.51 \pm 7.2) \), or for knee abduction angle \( (F_{1,11} = 0.09, P = 0.78; Table 5; FB \text{ pre/post } = -2.68 \pm 3.9, -1.39 \pm 3.1; C \text{ pre/post } = -2.36 \pm 4.1, -1.24 \pm 3.1) \).
The data demonstrated that there were also no significant differences between groups over time for hip flexion angle \((F_{1,11}=1.78, P=0.21)\) (FB pre/post = 31.27 ± 6.9, 29.77 ± 5.5; C pre/post = 22.11 ± 16.6, 24.06 ± 8.7), or for hip adduction angle \((F_{1,11}=0.014, P=0.91;\) Table 5).

Furthermore there were no significant group by time interactions for knee flexion angle \((F_{1,11}=1.25, P=0.29)\), knee abduction angle \((F_{1,11}=0.00, P=0.97;\) Table 5), hip flexion angle \((F_{1,11}=0.05, P=0.828)\), or hip adduction angle \((F_{1,11}=0.264, P=0.619;\) Table 5).

4.2 Knee and Hip Kinetics

There were no significant differences between groups over time knee flexion moment \((F_{1,11}=0.06, P=0.82)\) (FB pre/post = -0.36 ± 0.09, -0.35 ± 0.07; C = pre/post = -0.34 ± 0.15, -0.34 ± 0.13) or for knee abduction moment \((F_{1,11}=0.10, P=0.76;\) Table 6) (FB pre/post = -0.76 ± 0.31, -0.82 ± 0.27; C = pre/post = -0.71 ± 0.27, -0.70 ± 0.28), hip flexion moment \((F_{1,11}=0.59, P=0.46)\) (FB pre/post = -0.21 ± 0.13, -0.17 ± 0.35; C pre/post = -0.22 ± 0.39, -0.17 ± 0.32) or hip adduction moment \((F_{1,11}=0.02, P=0.89;\) Table 6) (FB pre/post = -0.12 ± 0.25, -0.14 ± 0.12, C pre/post = -0.05 ± 0.21, -0.03 ± 0.12).

Furthermore the data demonstrated no significant differences between groups over time knee flexion moment \((F_{1,11}=1.19, P=0.30)\), or knee abduction moment \((F_{1,11}=0.30, P=0.60;\) Table 6) hip flexion moment \((F_{1,11}=0.185, P=0.676)\), or for hip adduction moment \((F_{1,11}=0.414, P=0.534;\) Table 6).

4.3 Peak Vertical Ground Reaction Force

There was no significant differences between groups over time for dominant limb vGRF \((F_{1,11}=0.10, P=0.76;\) Table 6) (FB pre/post = 1.59 ± 0.26, 1.73 ± 0.18; C pre/post = 1.70 ± 0.23,
1.58 ± 0.23). There was no significant group by time interaction for dominant limb peak vGRF (F\(_{1,11}\) = 2.95, P=0.12; Table 6).

<table>
<thead>
<tr>
<th>Table 1: Participant Demographics</th>
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<td></td>
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<tr>
<td>Height (m)</td>
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<td>Mass (kg)</td>
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<td>Age (y)</td>
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* Indicates statistical significance (P<0.05)

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<thead>
<tr>
<th>Table 2: Cutting Task Pre/Post Means and Standard Deviations: Kinematics</th>
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<td>Knee angle (°)</td>
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<td>Flexion (-)</td>
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<td>Abduction (-)</td>
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<td>Hip angle (°)</td>
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<tr>
<td>Flexion (+)</td>
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<td>Abduction (-)</td>
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Table 3: Cutting Task Pre and Post Means and Standard Deviations: Kinetics

<table>
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<tr>
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<th>Feedback Group</th>
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<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
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<tr>
<td>Knee moments (Nm/kg*m)</td>
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<tr>
<td>Extension/Flexion</td>
<td>-0.36 ± 0.09</td>
<td>-0.35 ± 0.07</td>
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<tr>
<td>Adduction/Abduction</td>
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<td>-0.82 ± 0.27</td>
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<td>Hip moments (Nm/kg*m)</td>
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<tr>
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<tr>
<td>Adduction/Abduction</td>
<td>-0.12 ± 0.25</td>
<td>-0.14 ± 0.12</td>
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<tr>
<td>Peak vGRF (N/kg)</td>
<td>1.59 ± 0.26</td>
<td>1.73 ± 0.18</td>
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* First motion represents a positive number
Chapter 5

Discussion

The aim of this investigation was to determine if the addition of video feedback to an established ACL injury prevention program would improve lower extremity biomechanics during a cutting task when compared to individuals performing the same injury prevention program who did not receive video feedback.

Overall, there were no significant differences between groups over time for any of the knee and hip kinematic and kinetic outcome variables assessed during the cutting task, which was contrary to our hypothesis. Though not statistically significant, both groups demonstrated a decrease in knee and hip flexion angles at the post-test. This is not what we would want to see in terms of reducing ACL injury risk. The data that was collected from this investigation was similar to those seen in other studies. Onate et al.\textsuperscript{24,56} studied college aged recreational athletes in 2001 and 2005. When comparing the data from this investigation to that of Onate et al., one would see that the vGRFs in this study were lower than that of previous investigations.\textsuperscript{24,56} However, Cronin et al.\textsuperscript{21} also published vGRFs from female volleyball players that had similar results to this investigation. Therefore, one could deduce that the participants involved with this study did not have vGRF that were abnormal for this population and that would not predispose them to an ACL injury from their soley vGRFs. Females who tend to land from a jump with a more extended knee position create an increased knee extensor load, which could potentially lead to a larger amount of energy absorbed at the knee.\textsuperscript{1} When landing with increased knee flexion, the energy would instead be dispersed at the hip.\textsuperscript{1} Decreased hip and knee flexion prevents proper absorption of forces which can increase peak vGRF and can therefore increase knee
loading and the risk of sustaining an ACL injury\textsuperscript{5,26}. A potential explanation for the lack of statistical significance in hip and knee kinetics and kinematics between groups over time is that the athletes may not have understood that we intended them to use the information they were given during video feedback, to make changes during the cutting task when tested in the lab. Future research should consider explicitly asking participants to use the feedback they were provided during their individual sessions to alter mechanics during the cutting task at the post-testing session.

Knee abduction angle decreased from pre to post-testing in both groups; however, this change was less than two degrees. The clinical significance of such a small change may not be very meaningful. In a study by Etnoyer \textit{et al.}\textsuperscript{24}, physically active women with no history of ACL injury were recruited and instructed to perform a box jump. The data by Etnoyer demonstrated a decreased knee flexion angle, similar knee abduction angle, increased hip flexion angle, and increased hip abduction angle when compared to the data from this investigation\textsuperscript{24}. In terms of non-contact ACL injuries, we do not know what magnitude of knee abduction that is harmful or beneficial. We would expect to see a decrease in knee abduction angle following the video feedback program. Research has shown that knee abduction loads predict ACL injury risk with high sensitivity and specificity\textsuperscript{68}. These abduction angles could increase tension on the ligaments of the knee that can lead to injury\textsuperscript{68}. Hip adduction angle increased in the feedback group, however, this change was also minimal and the clinical significance should be questioned. The control group hip adduction angle remained unchanged following the prevention.

There were no significant changes in any of the recorded kinematic data. Because we did not see significant changes in the angles or vGrF, it would make sense that the moments would also remain unchanged. These results were contrary to our hypothesis that we would observe a
decrease in peak vGRF following the video feedback prevention. One explanation as to why these results were not statistically significant is that we did not give specific feedback concerning ground reaction forces during the individualized feedback sessions. This was a difficult variable to provide feedback for because we were unable to record the sound of the participants landing during the squat jump task. Participants were reminded to try land as softly as possible when performing the squat jump task, but there was no external feedback that we could provide. Reduced ground reaction force may reduce stress on the ACL and reduce risk of injury. Previous investigations have demonstrated a positive correlation between increased vGRF and increased tibial acceleration during landing. Furthermore, when there is an increase to tibial acceleration, the dynamic and static stabilizers work harder to limit tibial translation, which could potentially increase ACL injury risk. Reducing the forces placed on the lower extremities could decrease tension on the ACL.

There are several potential explanations for the lack of statistical significance observed with this investigation. One explanation could be the caliber of participants included in this investigation. The participants selected for this research were all Division I women’s soccer athletes at the University of Toledo. Due to their high level of skill and experience at the Division I level, they may not be able to demonstrate significant changes from baseline. A study completed by Smith et al. concluded that Division I and Division III collegiate female athletes demonstrated different sagittal-plane mechanics when analyzed completing a drop vertical jump. This investigation discovered that the participants in the Division I athletics group demonstrated decreased knee flexion range of motion and greater peak external knee flexion moment when compared with those individuals in the Division III athletics group. Since there were differences found in the performance of individuals in collegiate athletics, one could assume that
there would also be significant differences when comparing the participants tested in this study to the general population.

The SportsMetrics program has been successful in decreasing injury rates, significantly increasing abdominal and lower extremity strength, vertical jump height, speed, and agility.\textsuperscript{50} The modified version that was used for this investigation may not have been as sufficient in augmenting lower extremity biomechanics as the unaltered SportsMetrics program. The SportsMetrics prevention program consist of a dynamic warm up, sport specific agility drills, plyometrics and jump training, high intensity strength training, sport specific cardio workouts, and flexibility training. Due to the emphasis of this investigation being on video feedback of movement patterns and considering that the athletes were already participating in a strength training program, this study only emphasized the jump training components of the SportsMetrics program. However, it seems that participating in the entire program is necessary to realize biomechanical adaptations. Future studies may be necessary to determine if the addition of videotape feedback to the unmodified SportsMetrics program augments biomechanical alterations during activity.

5.1 Limitations

When using skin markers to evaluate movement through motion capture, there was a risk of error due to the skin movement and marker placement over time. To help combat this limitation, the participants were instructed to wear tightly fitted clothing during the pre- and post-test data collections and the same examiner placed the markers at each data collection session. The reliability of the methods in this investigation within and between researchers using skin markers has been tested previously.\textsuperscript{71} Error due to re-application of markers has been estimated to be 3.8° for angles and 0.03 Nm/kg*\textring{} for moments.\textsuperscript{72}
Participants received feedback on only the squat jump task. The jump itself was described and demonstrated as performing a squat, jumping in the air to maximum height with knees tucked into chest, and landing in the squat position in the same location. This task is part of the modified SportsMetrics program and was the only task that did not change throughout the duration of the 9-week program. During the squat jump task participants were instructed to complete as many correct squat jumps as they could within 20 seconds for the first three weeks of the prevention, within 25 seconds for the next three weeks, and within 30 seconds through the end of the prevention program. They were also informed that the quality of each squat jump was more important than the total number of squat jumps performed and therefore it can be assumed that this did not affect the outcomes of the investigations.

The participants who were given feedback may not have seen changes biomechanically because of the number of corrections that needed to be made at each session. Having to concentrate on landing with their feet shoulder width apart, knees in a neutral position, in increased hip and knee flexion, and landing softly could have overwhelmed the participants. This change may have been seen in the kinetics and kinematics individually if the feedback was more specific, rather than over the squat jump as a whole. However, the same instructions were given at each feedback session and therefore the participants were familiar with these modifications. If another task was chosen, it may have shown more variability in terms of errors, which would have allowed for more feedback to be given and potentially larger biomechanical changes observed. The reason the squat jump was chosen as the task in which feedback was delivered was because all of the other tasks progressed throughout the ACL injury prevention program. The duration of the ACL injury prevention program itself may be another limitation to this investigation. The modified SportsMetrics program was a 9-week program; however, the
participants were only videotaped and given feedback from the fourth through the ninth week, for a total of six weeks. Providing feedback throughout the entirety of the 9-week program may have augmented biomechanical changes observed over time or between the feedback and control groups. Optimal length of time to deliver feedback is unknown. However, biomechanical changes, such as knee and hip flexion angles and reductions in peak vGRF, have been observed during four week duration studies.  

Participants were scheduled to receive feedback on their landing biomechanics once per week. The participants completed the ACL injury prevention program which was scheduled for every Monday, and Friday with feedback sessions scheduled in between prevention sessions at the availability of the participants. It is possible that had a shorter duration of time elapsed between the ACL injury prevention and feedback sessions, the results of this study could have been different. Feedback was provided on six different landing errors. Attempting to correct all of these kinetics and kinematics at once may have been overwhelming for the participants. The Performance Coach Training program implemented a coaching feedback model. Within this model it discusses how to give different forms of feedback most effectively and when. The article discusses that it is most effective to give an athlete negative feedback immediately after a task, and all forms of feedback in a direct and specific manner. This immediate feedback may have proved to be beneficial to the participants, however, because the squat jump task was performed and recorded during the women’s soccer practise, it would not have been possible to take the time necessary to give the immediate feedback.

We did not directly track the participants learning throughout the prevention. Higher levels of motor learning may have occurred throughout the six weeks of feedback, but it may have been more effective had the feedback sessions been tailored to fit varying learning styles of
the participants. Verbal feedback that would produce changes in one participant may not produce similar changes in another participant. One way to accommodate different styles of learning could be to give participants real time feedback. Giving the participants feedback during the task could help in their understanding of how to physically correct their landing biomechanics instead of solely comprehending the changes that needed to be made. It is possible that the participants understood the instructions, but were physically unable to reenact these changes in the short time frame of this study.

In this investigation, we did not communicate with the participants the intent of the feedback or instruct them to use the learned feedback during the post-test. The participants may not have completely understood that the feedback was implemented to augment changes in the post testing session, which may have had an effect on the results. We may have not observed a change in the cutting task due to the fact that the participants were not directly instructed to use the feedback they learned during the squat jump task on the cutting task. This information was not divulged to the participants because the researchers wanted to see if the learned biomechanics from the video feedback sessions would transfer to another task.

Exercise outside of the prevention was not recorded or regulated. However, all the participants in this investigation were members on the same women’s soccer team. Therefore, it can be assumed that they participated in similar practice lengths and intensities. Weight lifting and conditioning between different skill levels and positions may have differed between participants, but we did not believe that exercise influenced the results of our investigation. Although practices for all members of a sports team could not be standardized, it may be important for future research to document the intensity and frequency of all practices, conditioning days, and weight lifting that occurred separately from the prevention program. It is
important to acknowledge and learn from the limitations of this investigation in order to improve future investigations.

5.2 Future Research

Video feedback was not successful in altering biomechanics when given the day or days after completing a task.\textsuperscript{74,75} Future research should strive to create and implement a prevention program that can be used in daily practices, with multiple students or athletes at once, reducing time and financial costs. This would be beneficial to athletes and coaches as it would improve biomechanical performance while decreasing injury risk. This investigation has highlighted the importance of using real time or immediate feedback.

Future research may also find that to augmenting changes on biomechanics it may be beneficial perform the biomechanical assessments on the same task in which the feedback is being provided. We had hoped that the information learned from the squat jump would transfer to the cutting task. Future investigators should research task transference and ways for it to maintain long term outcomes. The time frame in which we collected the data from the cutting task was days after the final feedback session. It may have been beneficial to the participants to receive feedback directly before completing the post testing assessment.

5.3 Conclusion

This investigation found that video feedback given with an already existing modified SportsMetrics prevention program does not augment changes in hip and knee biomechanics during a cutting task in collegiate female athletes. These results did not support our hypothesis that the feedback given would transfer from one task to another. This idea of task transference
should be further investigated in the future to give athletes an inexpensive and beneficial way to improve biomechanics and therefore reduce their risk of injury.
References


Appendix A

Institutional Review Board Consent Form #108549

ADULT RESEARCH SUBJECT INFORMATION AND CONSENT FORM
THE EFFECTS OF VIDEO FEEDBACK ON HIP AND KNEE BIOMECHANICS DURING ATHLETIC ACTIVITIES

Principal Investigator: Abbey Thomas, PhD, ATC
Other Staff (identified by role): Phillip Gribble, PhD, ATC (Co-investigator)
                                Hayley Ericksen, MS, ATC (Coordinator)
                                Jaclyn Grusy, ATC (Coordinator)
                                Kelsey Shearman, ATC (Coordinator)

Contact Phone number(s): (419)-530-4501

What you should know about this research study:

• We give you this consent/authorization form so that you may read about the purpose, risks, and benefits of this research study. All information in this form will be communicated to you verbally by the research staff as well.

• Routine clinical care is based upon the best-known treatment and is provided with the main goal of helping the individual patient. The main goal of research studies is to gain knowledge that may help future patients.

• We cannot promise that this research will benefit you. Just like routine care, this research can have side effects that can be serious or minor.

• You have the right to refuse to take part in this research, or agree to take part now and change your mind later.

• If you decide to take part in this research or not, or if you decide to take part now but change your mind later, your decision will not affect your routine care.

• Please review this form carefully. Ask any questions before you make a decision about whether or not you want to take part in this research. If you decide to take part in this research, you may ask any additional questions at any time.

• Your participation in this research is voluntary.

PURPOSE (WHY THIS RESEARCH IS BEING DONE)
You are being asked to take part in a research study of an exercise program to prevent anterior cruciate ligament (ACL) injuries in the knee. The purpose of the study is to learn more about the use of videotape feedback during exercise in changing hip and knee joint mechanics during athletic activities. This information will help researchers determine the best way to prevent ACL injuries. You were selected as someone who may want to take part in this study because you play a sport that is known for its risk of ACL injury. Up to 45 people from the University of Toledo will participate in this study.
NO TEXT THIS PAGE
DESCRIPTION OF THE RESEARCH PROCEDURES AND DURATION OF YOUR INVOLVEMENT

If you decide to take part in this study, you will be asked to report to the Musculoskeletal Health and Movement Sciences Laboratory in the Department of Kinesiology on 2 occasions, separated by 6 weeks. Each session will last up to 2 hours. You will also be asked to participate in an exercise program (3x/week for 6 weeks) emphasizing dynamic lower extremity movements that you commonly perform as part of your sport. These sessions will be lead by your team athletic trainer. Additionally, you may be randomly assigned to a feedback group, which will meet 1 day per week for 6 weeks.

Each laboratory session will include the following:
1) Biomechanical assessment
2) Functional assessment

Biomechanical Assessment
You will be asked to wear a series of reflective markers that will be placed on specific landmarks on your trunk and legs. These allow the researchers to record your movement. You will then be asked to perform a drop landing and cutting task. For the drop landing, you will stand on a 30cm box and drop down to the ground. Immediately upon landing, you will jump up as high as possible. You will also perform a cutting task by sprinting toward a particular spot on the floor and cutting to the opposite side before sprinting a few more steps. Up to 5 trials of each task will be performed for each leg. These tasks will take approximately 40 minutes to complete.

Functional Assessment
You will be asked to perform two functional tasks. The first is a single-leg hop. You will stand on one leg with your hands on your hips and jump forward as far as possible. The second task is a single-leg squat. You will stand on one leg with your hands on your hips and squat down to approximately 45. You will perform up to 3 trials of each task for each leg. These tasks will take approximately 20 minutes to complete.

Each exercise session will include the following:
1) Dynamic, plyometric exercises
2) Videotaping of exercises

Dynamic Exercises
These will be similar to what you perform during team weight lifting sessions. You will be asked to complete a series of double-limb and single-limb jumps. Some jumps will be for maximal height, others for maximal distance. Some tasks may require you to jump over small cones. These sessions will last approximately 20 minutes and will be incorporated into your team activities up to 3 days per week.

Videotaping
You will be videotaped during the performance of a squat jump task. Two video cameras will be used, once placed in front of your and one at your side. This video may be used to provide you feedback on your jumping mechanics. The researchers will mask any identifiable features, including your face, tattoos, and scars, from the video.

Feedback sessions will include:
1) Review of videotape recorded during exercise sessions

Review of Videotape
If you are randomized to the feedback group, you will meet with one of the researchers 1 day per week for 6 weeks. We will show you the video of you performing the squat jump and ask you to rate your performance based on a series of specific criteria. We will then review the video again and point out specific things for you to work on during your next exercise session. These meetings will take approximately 10 minutes.

**RISKS AND DISCOMFORTS YOU MAY EXPERIENCE IF YOU TAKE PART IN THIS RESEARCH**

**Potential Risks**
- Muscle soreness as a result of the dynamic exercises.

**Unlikely Risks**
- Loss of confidentiality.

The dynamic exercises are common for preventing ACL injuries. Your condition may not get better or may become worse while you are in this study. There are no known additional risks to pregnant women for participating in this study. There may be risks that are unknown to the investigators at this time.

**POSSIBLE BENEFIT TO YOU IF YOU DECIDE TO TAKE PART IN THIS RESEARCH**

Your chance of sustaining a knee injury may be reduced by participating in this study. However, we cannot and do not guarantee or promise that you will receive any benefits from this research.

**COST TO YOU FOR TAKING PART IN THIS STUDY**

There is no cost to you for taking part in this study.

**PAYMENT OR OTHER COMPENSATION TO YOU FOR TAKING PART IN THIS RESEARCH**

You will not receive financial compensation for participating in this study.

**ALTERNATIVE(S) TO TAKING PART IN THIS RESEARCH**

Your alternative to participating in this study is not to participate.

**CONFIDENTIALITY - (USE AND DISCLOSURE OF YOUR PROTECTED HEALTH INFORMATION)**

By agreeing to take part in this research study, you give to The University of Toledo (UT), the Principal Investigator and all personnel associated with this research study your permission to use or disclose health information that can be identified with you that we obtain in connection with this study. We will use this information to contact you and for the purpose of conducting the research study as described in the research consent/authorization form.

The information that we will use or disclose includes your knee injury history. We may use this information ourselves as part of the research study.
Under some circumstances, the Institutional Review Board, or the Research and Sponsored Programs of the University of Toledo may review your information for compliance audits. If you receive any payments for taking part in this study, your personal information and limited information about this study will be given to The University of Toledo’s accounts payable department as necessary to process payment to you. We may also disclose your protected health information when required by law, such as in response to judicial orders.

The University of Toledo is required by law to protect the privacy of your health information, and to use or disclose the information we obtain about you in connection with this research study only as authorized by you in this form. There is a possibility that the information we disclose may be re-disclosed by the persons we give it to, and no longer protected. However, we will encourage any person who receives your information from us to continue to protect and not re-disclose the information.

Your permission for us to use or disclose your protected health information as described in this section is voluntary. However, you will not be allowed to participate in the research study unless you give us your permission to use or disclose your protected health information by signing this document.

You have the right to revoke (cancel) the permission you have given to us to use or disclose your protected health information at any time by giving written notice to [list the name and address of the research study personnel that should receive the revocation]. However, a cancellation will not apply if we have acted with your permission, for example, information that already has been used or disclosed prior to the cancellation. Also, a cancellation will not prevent us from continuing to use and disclose information that was obtained prior to the cancellation as necessary to maintain the integrity of the research study.

Except as noted in the above paragraph, your permission for us to use and disclose your protected health information will stop at the end of the research study.

A more complete statement of University of Toledo’s Privacy Practices is set forth in its Joint Notice of Privacy Practices. If you have not already received this Notice, a member of the research team will provide this to you. If you have any further questions concerning privacy, you may contact the University of Toledo’s Privacy Officer at 419-383-6933.

A description of this clinical trial will be available on http://www.ClinicalTrials.gov, as required by U.S. Law. This Web site will not include information that can identify you. At most, the Web site will include a summary of the results. You can search this Web site at any time.

IN THE EVENT OF A RESEARCH-RELATED INJURY
In the event of injury resulting from your taking part in this study, treatment can be obtained at a health care facility of your choice. You should understand that the costs of such treatment will be your responsibility. Financial compensation is not available through The University of Toledo or The University of Toledo Medical Center.

By signing this form you are not giving up any of your legal rights as a research subject. In the event of an injury, contact the principle investigator: Abbey Thomas, PhD, ATC at 419-530-4501.
VOLUNTARY PARTICIPATION
Taking part in this study is voluntary. You may refuse to participate or discontinue participation at any time without penalty or a loss of benefits to which you are otherwise entitled. If you decide not to participate or to discontinue participation, your decision will not affect your future relations with the University of Toledo or The University of Toledo Medical Center.

NEW FINDINGS
You will be notified of new information that might change your decision to be in this study if any becomes available.

OFFER TO ANSWER QUESTIONS
Before you sign this form, please ask any questions on any aspect of this study that is unclear to you. You may take as much time as necessary to think it over. If you have questions regarding the research at any time before, during or after the study, you may contact Abbey Thomas, PhD, ATC at 419-530-4501.

If you have questions beyond those answered by the research team or your rights as a research subject or research-related injuries, please feel free to contact the Chairperson of the University of Toledo Biomedical Institutional Review Board at 419-383-6796.

SIGNATURE SECTION (Please read carefully)
YOU ARE MAKING A DECISION WHETHER OR NOT TO PARTICIPATE IN THIS RESEARCH STUDY. YOUR SIGNATURE INDICATES THAT YOU HAVE READ THE INFORMATION PROVIDED ABOVE, YOU HAVE HAD ALL YOUR QUESTIONS ANSWERED, AND YOU HAVE DECIDED TO TAKE PART IN THIS RESEARCH.

BY SIGNING THIS DOCUMENT YOU AUTHORIZE US TO USE OR DISCLOSE YOUR PROTECTED HEALTH INFORMATION AS DESCRIBED IN THIS FORM.

The date you sign this document to enroll in this study, that is, today’s date, MUST fall between the dates indicated on the approval stamp affixed to the bottom of each page. These dates indicate that this form is valid when you enroll in the study but do not reflect how long you may participate in the study. Each page of this Consent/Authorization Form is stamped to indicate the form’s validity as approved by the UT Biomedical Institutional Review Board (IRB).

<table>
<thead>
<tr>
<th>Name of Subject (please print)</th>
<th>Signature of Subject or Person Authorized to Consent</th>
<th>Date</th>
<th>a.m.</th>
<th>Time p.m.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relationship to the Subject (Healthcare Power of Attorney authority or Legal Guardian)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name of Person Obtaining Consent (please print)</th>
<th>Signature of Person Obtaining Consent</th>
<th>Date</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Name of Witness to Consent Process (when required by ICH Guidelines)</th>
<th>Signature of Witness to Consent Process (when required by ICH Guidelines)</th>
<th>Date</th>
</tr>
</thead>
</table>

YOU WILL BE GIVEN A SIGNED COPY OF THIS FORM TO KEEP.
Appendix B

Knee Injury History Form
Age_________ Sex_________

Height _______  Mass________

Laboratory

Subject Number ____________________ Date _____________

University of Toledo

Please Circle (Yes or No) regarding your situation.

<table>
<thead>
<tr>
<th>Yes</th>
<th>No</th>
<th>Question</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Have you had an injury to either leg that has altered you function in the past 6 months?</td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
<td>Have you had a surgery to either leg (knee, ankle, hip) in the past six months (other than meniscectomy)?</td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
<td>Do you have any ruptured knee ligaments that have not been reconstructed?</td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
<td>Do you have any nerve injuries in your legs or lower back?</td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
<td>Do you have any known muscular abnormalities?</td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
<td>Do you have a heart condition that would stop you from exercising?</td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
<td>Do you currently have an infection over your thigh or in your knee?</td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
<td>Do you know of a hypersensitivity to electrical stimulation?</td>
</tr>
</tbody>
</table>

1. Which leg would you choose to kick a ball with?  R    L

2. Have you ever had a knee injury?
When (month / year): ____________________ Which leg?  R    L

Explain:________________________________________
_____________________________________________________________________

3. Have you ever had a knee Surgery?
When (month / year): ____________________ Which leg?  R    L

Explain:________________________________________

Was there subsequent meniscal injury?       Yes    No

If yes, was it repaired?       Yes    No    Unknown

If ACL Reconstruction, What graft type? __________________________________________

4. Did you participate in physical therapy or therapeutic exercise?
When did you start (month / year): ____________________

For How Long: ____________________

5. Have you ever had an injury/surgery to your ankle, hip or lower back?
When (month/year): ____________________

Explain:________________________________________

_____________________________________________________________________

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### Appendix C

**ACL Injury Prevention Program Progression Sheet**  
**Sportsmetrics Training Log**  
**Weeks #1 & 2**

#### Plyometric Training

<table>
<thead>
<tr>
<th>JUMP</th>
<th>Date</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall Jumps</td>
<td>20 sec</td>
<td>25 sec</td>
</tr>
<tr>
<td>Tuck Jumps</td>
<td>20 sec</td>
<td>25 sec</td>
</tr>
<tr>
<td>Squat Jumps</td>
<td>10 sec</td>
<td>15 sec</td>
</tr>
<tr>
<td>Barrier Jumps (S/S)</td>
<td>20 sec</td>
<td>25 sec</td>
</tr>
<tr>
<td>Barrier Jumps (F/B)</td>
<td>20 sec</td>
<td>25 sec</td>
</tr>
<tr>
<td>180° Jumps</td>
<td>20 sec</td>
<td>25 sec</td>
</tr>
<tr>
<td>Broad Jumps (stick 5 sec.)</td>
<td>5 reps</td>
<td>10 reps</td>
</tr>
<tr>
<td>Bounding in place</td>
<td>20 sec</td>
<td>25 sec</td>
</tr>
</tbody>
</table>

#### Strength Training

<table>
<thead>
<tr>
<th>EXERCISE</th>
<th>1 run</th>
<th>1 run</th>
<th>1 run</th>
<th>2 runs</th>
<th>2 runs</th>
<th>2 runs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral Step w/ band</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monster Walks w/ band (Forw/Back)</td>
<td>1 run each</td>
<td>1 run each</td>
<td>1 run each</td>
<td>2 runs</td>
<td>2 runs</td>
<td>2 runs</td>
</tr>
<tr>
<td>Heel/ Toe Walks</td>
<td>1 run each</td>
<td>1 run each</td>
<td>1 run each</td>
<td>2 runs each</td>
<td>2 runs each</td>
<td>2 runs each</td>
</tr>
<tr>
<td>Clamshells w/ band</td>
<td>15 each leg</td>
<td>15 each leg</td>
<td>15 each leg</td>
<td>20 each leg</td>
<td>20 each leg</td>
<td>20 each leg</td>
</tr>
<tr>
<td>Supine Hamstring Bridge</td>
<td>20 each leg</td>
<td>20 each leg</td>
<td>20 each leg</td>
<td>25 each leg</td>
<td>25 each leg</td>
<td>25 each leg</td>
</tr>
<tr>
<td>Single Leg Deadlift</td>
<td>15 each leg</td>
<td>15 each leg</td>
<td>15 each leg</td>
<td>20 each leg</td>
<td>20 each leg</td>
<td>20 each leg</td>
</tr>
<tr>
<td>Single Leg Balance</td>
<td>30 sec each</td>
<td>30 sec each</td>
<td>30 sec each</td>
<td>2x30 sec each</td>
<td>2x30 sec each</td>
<td>2x30 sec each</td>
</tr>
<tr>
<td>Single Leg Squat to Box</td>
<td>10 each leg</td>
<td>10 each leg</td>
<td>10 each leg</td>
<td>12 each leg</td>
<td>12 each leg</td>
<td>12 each leg</td>
</tr>
</tbody>
</table>
## Sportsmetrics Training Log

**Weeks # 3 & 4**

### Plyometric Training

<table>
<thead>
<tr>
<th>JUMP</th>
<th>Date</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall Jumps</td>
<td>25 sec</td>
<td>30 sec</td>
</tr>
<tr>
<td>Tuck Jumps</td>
<td>25 sec</td>
<td>30 sec</td>
</tr>
<tr>
<td>Jump, Jump, Jump Vertical</td>
<td>5 total</td>
<td>8 total</td>
</tr>
<tr>
<td>Squat Jumps</td>
<td>15 sec</td>
<td>20 sec</td>
</tr>
<tr>
<td>Single Leg Barrier Jumps (S/S)</td>
<td>25 sec</td>
<td>30 sec</td>
</tr>
<tr>
<td>Single Leg Barrier Jumps (F/B)</td>
<td>25 sec</td>
<td>30 sec</td>
</tr>
<tr>
<td>Scissor Jumps</td>
<td>25 sec</td>
<td>30 sec</td>
</tr>
<tr>
<td>Single Leg Hops (stick)</td>
<td>5 reps</td>
<td>5 reps</td>
</tr>
<tr>
<td>Bounding for distance</td>
<td>1 run</td>
<td>2 runs</td>
</tr>
</tbody>
</table>

### Strength Training

<table>
<thead>
<tr>
<th>EXERCISE</th>
<th>20 each leg</th>
<th>20 each leg</th>
<th>20 each leg</th>
<th>25 each leg</th>
<th>25 each leg</th>
<th>25 each leg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotated Step Up</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single Leg Heel Touch off step</td>
<td>15 each leg</td>
<td>15 each leg</td>
<td>15 each leg</td>
<td>20 each leg</td>
<td>20 each leg</td>
<td>20 each leg</td>
</tr>
<tr>
<td>Hamstring Bridge on box</td>
<td>15 each leg</td>
<td>15 each leg</td>
<td>15 each leg</td>
<td>20 each leg</td>
<td>20 each leg</td>
<td>20 each leg</td>
</tr>
<tr>
<td>Adductor Lift w/ band</td>
<td>20 each leg</td>
<td>20 each leg</td>
<td>20 each leg</td>
<td>25 each leg</td>
<td>25 each leg</td>
<td>25 each leg</td>
</tr>
<tr>
<td>Single Leg Balance w/ ball toss</td>
<td>20 each leg</td>
<td>20 each leg</td>
<td>20 each leg</td>
<td>25 each leg</td>
<td>25 each leg</td>
<td>25 each leg</td>
</tr>
<tr>
<td>Walking Lunges w/ MB twist</td>
<td>20 each leg</td>
<td>20 each leg</td>
<td>20 each leg</td>
<td>25 each leg</td>
<td>25 each leg</td>
<td>25 each leg</td>
</tr>
<tr>
<td>Fire Hydrants w/ band</td>
<td>15 each leg</td>
<td>15 each leg</td>
<td>15 each leg</td>
<td>20 each leg</td>
<td>20 each leg</td>
<td>20 each leg</td>
</tr>
<tr>
<td>Hamstring Burners on Physioball</td>
<td>20 reps</td>
<td>20 reps</td>
<td>20 reps</td>
<td>25 reps</td>
<td>25 reps</td>
<td>25 reps</td>
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</table>
**Weeks # 5 & 6**

### Plyometric Training

<table>
<thead>
<tr>
<th>JUMP</th>
<th>TIME</th>
<th>TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall Jumps</td>
<td>20 sec</td>
<td>20 sec</td>
</tr>
<tr>
<td>Tuck Jumps</td>
<td>30 sec</td>
<td>30 sec</td>
</tr>
<tr>
<td>Up Down 180 Vertical</td>
<td>5 total</td>
<td>10 total</td>
</tr>
<tr>
<td>Squat Jumps</td>
<td>25 sec</td>
<td>25 sec</td>
</tr>
<tr>
<td>Sandpit Jumps (S/S)</td>
<td>30 sec</td>
<td>30 sec</td>
</tr>
<tr>
<td>Sandpit Jumps (F/B)</td>
<td>30 sec</td>
<td>30 sec</td>
</tr>
<tr>
<td>Box Jump, Vertical</td>
<td>8 jumps</td>
<td>10 jumps</td>
</tr>
<tr>
<td>Hop, Hop, Hop Stick</td>
<td>5 jumps</td>
<td>5 reps</td>
</tr>
<tr>
<td>Jump into Bounding</td>
<td>3 runs</td>
<td>4 runs</td>
</tr>
</tbody>
</table>

### Strength Training

<table>
<thead>
<tr>
<th>EXERCISE</th>
<th>15 reps</th>
<th>15 reps</th>
<th>15 reps</th>
<th>20 reps</th>
<th>20 reps</th>
<th>20 reps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bosu Squats</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>3 Way MB Reach</td>
<td>5 reps each</td>
<td>5 reps each</td>
<td>5 reps each</td>
<td>8 reps each</td>
<td>8 reps each</td>
<td>8 reps each</td>
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<tr>
<td>Lateral Step Down w/ band pull</td>
<td>15 each leg</td>
<td>15 each leg</td>
<td>15 each leg</td>
<td>20 each leg</td>
<td>20 each leg</td>
<td>20 each leg</td>
</tr>
<tr>
<td>Hamstring Bridge on box (hold knee to chest)</td>
<td>15 each leg</td>
<td>15 each leg</td>
<td>15 each leg</td>
<td>15 each leg</td>
<td>15 each leg</td>
<td>15 each leg</td>
</tr>
<tr>
<td>Quick Step Ups</td>
<td>2 sets 30 sec</td>
<td>2 sets 30 sec</td>
<td>2 sets 30 sec</td>
<td>2 sets 40 sec</td>
<td>2 sets 40 sec</td>
<td>2 sets 40 sec</td>
</tr>
<tr>
<td>Steamboats w/ band</td>
<td>15 each leg</td>
<td>15 each leg</td>
<td>15 each leg</td>
<td>20 each leg</td>
<td>20 each leg</td>
<td>20 each leg</td>
</tr>
<tr>
<td>Leg In-Out-Diagonal</td>
<td>15 each leg</td>
<td>15 each leg</td>
<td>15 each leg</td>
<td>20 each leg</td>
<td>20 each leg</td>
<td>20 each leg</td>
</tr>
<tr>
<td>Single Leg Balance w/ partner push</td>
<td>2 sets 30 sec</td>
<td>2 sets 30 sec</td>
<td>2 sets 30 sec</td>
<td>2 sets 40 sec</td>
<td>2 sets 40 sec</td>
<td>2 sets 40 sec</td>
</tr>
<tr>
<td>PLYOMETRIC TRAINING</td>
<td>MAX EFFORT</td>
<td>TOTAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------------------------</td>
<td>------------</td>
<td>-------</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wall Jumps</td>
<td>30 Seconds</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tuck Jumps</td>
<td>30 Seconds</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Squat Jumps</td>
<td>30 Seconds</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scissor Jumps</td>
<td>30 Seconds</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barrier Hops</td>
<td>30 Seconds</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Box Jump, Vertical</td>
<td>10 Jumps</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Up, Down, 180, Vertical</td>
<td>10 Jumps</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hop, Hop, Hop Stick</td>
<td>5 each leg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jump into Bounding</td>
<td>4 runs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STRENGTH TRAINING</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lateral Step Up with Lunge</td>
<td>20 each leg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hamstring Bridge</td>
<td>15 each leg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quick Step Ups</td>
<td>3 x 20sec</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single Leg Squats</td>
<td>20 each leg</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Wall Sits</td>
<td>3 x 40sec</td>
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## Appendix D

### Expert Analysis Check Off Sheet

<table>
<thead>
<tr>
<th></th>
<th>Normal Speed</th>
<th>50% of Normal Speed</th>
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</thead>
<tbody>
<tr>
<td><strong>Frontal View</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Trial 1</td>
<td>Trial 2</td>
</tr>
<tr>
<td>Landing with feet shoulder width apart</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landing with knees in a neutral position</td>
<td></td>
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<tr>
<td><strong>Side View</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Trial 3</td>
<td>Trial 4</td>
</tr>
<tr>
<td>Landing with both feet at the same time</td>
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<tr>
<td>Landing on toes, rocking back to heels</td>
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<tr>
<td>Landing with increased bending in knees</td>
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</tbody>
</table>

### Self Analysis Check Off Sheet

<table>
<thead>
<tr>
<th></th>
<th>Normal Speed</th>
<th>50% of Normal Speed</th>
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</thead>
<tbody>
<tr>
<td><strong>Frontal View</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Trial 1</td>
<td>Trial 2</td>
</tr>
<tr>
<td>Landing with feet shoulder width apart</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landing with knees in a neutral position (not knock-kneed or bow-legged)</td>
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<tr>
<td><strong>Side View</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Trial 3</td>
<td>Trial 4</td>
</tr>
<tr>
<td>Landing with both feet at the same time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landing on toes and rocking back to heels</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landing with increased bending in knees: &gt;30°</td>
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<tr>
<td>Landing with increased bending in hips</td>
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<tr>
<td>Landing with trunk in a neutral position</td>
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</tbody>
</table>
Appendix E

Knee Kinematics

Figure 5: Knee Extension Angle between groups over time
Figure 6: Knee Adduction Angle between groups over time
Hip Kinematics

**Figure 7:** Hip Extension Angles between groups over time

**Figure 8:** Hip Adduction angles between groups over time
Knee Kinetics

**Figure 9:** Knee Extension Moments between groups over time

**Figure 10:** Knee Adduction Moments between groups over time
Hip Kinetics

Figure 11: Hip Flexion Moment between groups over time

Figure 12: Hip Adduction Moment between groups over time
Figure 13: Peak vGRF between groups over time