The Effects of Augmented Feedback on Knee Valgus Angles and Muscle Activity During a Jump Landing Task

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ABSTRACT

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(Under the direction of Dr. Darin A. Padua)

Objective: To investigate effects of augmented feedback on knee valgus angles and hip muscle activity. **Design:** **R**epeated measures pre-test – post-test design to determine the effects of augmented feedback on knee kinematics and muscle activity. **Setting:** Research Laboratory **Subjects:** 32 healthy, recreationally active females (age= 20.3±1.3 yrs, height= 166.5±7.4cm, mass= 66.6± 12.4 kg) displaying visual knee valgus. **Intervention:** Intervention subjects were given video and verbal feedback regarding their landing technique. **Statistical Analysis:** Mixed model repeated measures ANOVA comparing control and intervention groups, and pre-test versus post-test; correlational analysis. **Main Outcome Measure(s):** Knee valgus angles; EMG amplitude of gluteus medius, gluteus maximus, hip adductors during a jump landing. **Results:** Significant differences in knee valgus angles were observed post intervention; however, muscle amplitude did decrease during the landing phase. **Significance:** Augmented feedback can alter kinematics and muscle activity however, more research is needed. **Key Words:** Augmented feedback, knee valgus, muscle activity, jump landing

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CHAPTER I

INTRODUCTION

The anterior cruciate ligament (ACL) is a strong static supporter of the knee joint and is the most often injured ligament in the knee [1]. Some studies report 200,000 new ACL injuries occurring in the United States each year [2], while others offer a more conservative number of approximately 80,000 [3]. Approximately 30% of estimated injuries every year result from direct contact with another player or object, while the other 70% are non-contact in nature [2-4]. Research also supports the idea that ACL injuries occur at a higher rate in women as compared to men. Women experience ACL injuries at a rate two to eight times greater than males who participate in the same sporting activities [2].

ACL injuries are debilitating and can be season-ending. Long-term effects include a decreased level of physical activity as well as possible knee joint degeneration, after initial care and reconstruction has been completed. These consequences also entail costly medical services. Approximately 50,000 ACL reconstruction surgeries are performed each year, at an estimated cost of $17,000 to $25,000 per injury. These numbers do not include the cost of immediate medical care before surgery or rehabilitative care post-surgery [5, 6]. ACL injury poses a large and costly risk to the active population.

There are many studies that examine the potential predisposing factors for an ACL injury. Both extrinsic and intrinsic risk factors have been shown to play a role in the mechanism of ACL injury. Extrinsic factors include perturbation by another athlete or object, the presence of prophylactic bracing, and shoe-surface interaction. Hewett et al. (2006) reported possible intrinsic influences on injury risk including anthropometric differences in the lower extremity, general joint laxity, hormonal fluctuations, decreased neuromuscular control and proprioceptive capabilities, trunk and lower extremity muscle activity, and excessive knee valgus motion. The position of knee valgus is one of the most researched contributors to the mechanism of ACL injury [2-4, 6-14]. Additional intrinsic factors such as increased static Q-angle measures, excessive femoral anteversion, tibial torsion, and foot pronation all can contribute to an increase in knee valgus position. Knee valgus can also be influenced by muscular forces acting on the knee. [3, 6]

While some of these intrinsic factors are unmodifiable, there are other risk factors that can be manipulated. Studies have begun to examine possible routes toward the prevention of ACL injuries by modification of risk factors. Neuromuscular intervention training programs and movement technique alteration are at the forefront of research in this area because these approaches address modifiable risk factors. Neuromuscular training programs have shown some success in decreasing potential biomechanical risk factors for ACL injury. [15] A number of studies have also examined electromyographical (EMG) activation of the lower extremity (Hewett et al.2006). Research in this area has focused on the activity of various hip, knee and ankle musculature. However, few studies even mention the effect of the hip adductor muscle group on knee kinematics, as this research study plans to do.

Another approach that is being explored in this area is the effect of augmented feedback on modifying potential risk factors. Augmented feedback is defined as information that is provided from an external source that can be added to intrinsic feedback to alter activity patterns of a body [16]. Both verbal and video feedback have been shown to influence biomechanical technique as well as physiological forces such as ground reaction forces [16, 17]. To date, most of the research in this area focuses on the latter. Research on the use of augmented feedback to influence kinematic and electromyographic variables remains limited.

Many predisposing factors to ACL injury as well as possible strategies to correct them have been presented. The purpose of this study is to examine the effects of augmented feedback on knee valgus angles and muscle activity of the gluteus medius, gluteus maximus, and hip adductor muscles, as well as to establish if a correlation exists between those two variables, during a jump landing task.

Independent Variables

1. Augmented Feedback- achieved with a video presentation of correct biomechanical position and a self-model for the performance of the jump landing task. The video will be accompanied by a standardized assessment and verbal cues.

Dependent Variables

1. Knee Valgus Angles- as measured by an electromagnetic motion analysis system
2. Muscle Activity Amplitude of the gluteus medius, gluteus maximus, and hip adductor muscles- as measured by an electromyographic system

Control Variables

1. Gender

Research Questions

1. Does augmented feedback change knee valgus angles at initial contact and peak knee valgus angles during the landing phase of a jump landing task, as measured by an electromagnetic motion analysis system?
2. Does augmented feedback change muscle activity amplitude of the gluteus medius, gluteus maximus and hip adductors during the pre-activation phase and the landing phase of a jump landing task, as measured by an electromyographic system?
3. Is there a relationship between knee valgus angle at initial contact and muscle activity amplitude during the pre-activation phase, as measured by an electromyographic system and electromagnetic motion analysis system?
4. Is there a relationship between peak knee valgus during the landing phase and muscle activity amplitude during the landing phase of a jump landing task, as measured by an electromyographic system and electromagnetic motion analysis system?

Research Hypotheses

1. Augmented feedback will decrease knee valgus angles at initial contact and peak knee valgus angles during the landing phase of a jump landing task.
2. Augmented feedback will increase muscle activity amplitude of the gluteus medius and gluteus maximus, and will decrease muscle activity amplitude of the hip adductors during the jump landing task.
3. There will be a correlation between knee valgus angle at initial contact and muscle activity amplitude during the pre-activation phase.
   - 3a. There will be a negative correlation between knee valgus angles at initial contact and gluteus medius and gluteus maximus muscle activity amplitude during the pre-activation phase.
   - 3b. There will be a positive correlation between knee valgus angles at intial contact and hip adductor muscle activity amplitude during the pre-activation phase.
4. There will be a correlation between peak knee valgus during the landing phase and muscle activity amplitude during the landing phase of a jump landing task.
   - 4a. There will be a negative correlation between peak knee valgus angles during the landing phase and gluteus medius and gluteus maximus muscle activity amplitude during the landing phase.
   - 4b. There will be a positive correlation between peak knee valgus angles during the landing phase and hip adductor muscle activity amplitude during the landing phase.

Null Hypotheses

1. H_0: Augmented feedback will have no effect on knee valgus angles at initial contact and peak knee valgus angles during the landing phase of a jump landing task.
2. H_0: Augmented feedback will have no effect on muscle activity amplitude of the gluteus medius, gluteus maximus, and hip adductors during the pre-activation phase and the landing phase of a jump landing task.
3. H_0: There is no correlation between knee valgus angles at initial contact and muscle activity amplitude during the pre-activation phase.
4. H_0: There is no correlation between peak knee valgus angles during the landing phase and muscle activity amplitude during the landing phase of a jump landing task.

Operational Definitions

Knee Valgus Angle: Measured angle between the tibia reference frame and femur reference frame due to rotation of the tibia about the femur about the anterior-posterior axis of the tibia.

Augmented Feedback: Information about performing a task that comes from an external source and is added to sensory feedback and internal feedback generated by the subject completing the task.

Muscle Pre-activation phase: EMG activity for a period of 100 milliseconds prior to initial contact during a jump landing task.

Landing Phase: The time period during a jump landing task between initial contact and toe-off.

Initial Contact: The point at which the subject's foot comes into contact with the ground and ground reaction forces exceed 5N during the jump-landing.

Toe-off: The last contact of the subject's foot to the ground before the vertical jump and ground reaction forces drop below 5N after initial ground contact.

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

Delimitations

1. The subject population of this study consists of females and males between the ages 18-25 years.
2. All subjects in this study will be recreationally active individuals. To meet this criteria, a participant must exercise for at least twenty minutes, three to four times per week [16].
3. Subjects will have no known lower extremity injuries or conditions that will affect their ability to perform the tasks included in the study.
4. Subjects will have not undergone any previous jump landing or ACL prevention training.
5. All analyses will be completed on the dominant leg.
6. All subjects will perform a jump landing task under the same direction and laboratory condition.

Limitations

1. The subject population of this study is contained within a small age range, so results may not be generalized to people of all ages.

2. The laboratory setting in which the testing will be performed is not the same as a sport setting in which these mechanisms might commonly occur.
3. The subjects chosen for testing are recreational athletes. These results cannot necessarily be generalized to an elite athletic or inactive population.

Assumptions

1. The criteria used to measure knee valgus is an accurate and reliable measure.
2. The electromyographic system is a reliable and valid measure of muscle activity amplitude.
3. The placement of the electrodes is appropriate in order to record muscle activity in the gluteus medius, gluteus maximus and hip adductor complex.
4. Augmented feedback given to the subjects regarding the tasks is appropriate and adequate to illicit changes.
5. Subjects were truthful during the screening process in regards to their medical history.

CHAPTER II

REVIEW OF LITERATURE

Introduction

The anterior cruciate ligament (ACL) is the main stabilizing ligament of the knee. It is also the most injured ligament. Non-contact mechanisms account for 70% of ACL injuries, and the other 30% are attributed to contact mechanisms. [2-4, 18] While the bony and ligamentous anatomy of the knee account for much of the stability of the joint, dynamic stabilization from muscles of the lower extremity is key in protecting the knee from injury during strenuous activity. [1] The recruitment of these muscles, as well as many other extrinsic, anatomical, biomechanical, and hormonal factors have been identified as risk factors for ACL injury. Although the effect of most of the aforementioned variables has not been unanimously confirmed, knee valgus is one such factor that receives consistent support in ACL injury research. Knee valgus and lower extremity muscle activation patterns are the risk factors of focus for this study. Numerous approaches to ACL injury prevention have been discussed in literature. Most of them function using a system of learning called augmented feedback.

The literature review focuses on the static and dynamic stabilization of the knee, ACL injury epidemiology and risk factors, specifically knee valgus and lower extremity muscle activation, and injury prevention strategies, with a focus on augmented feedback.

Static stabilization of the knee joint

The knee joint consists of four bones, which make up the four joints of the knee complex. The femur, tibia, fibula, and patella articulate in different combinations to form the joints. The fibulofemoral joint is the least significant and often ignored joint of the knee complex. It has no function other than accessory motion of the bones that comprise the larger and more functional joints. The proximal tibiofibular joint is an articulation between the tibia and the head of the fibula. While it plays no part in knee function, this plane synovial joint is involved in all ankle activity. [19] Hypomobility at this joint can cause pain in the knee. The patellofemoral joint is a modified plane joint whose main function is to improve the efficiency of movement in the tibiofemoral joint, especially in the last 30 degrees of extension. [1, 19] It also functions to reduce friction of and act as a guide to the quadriceps tendon, control capsular tension at the knee, act as a bony shield for femoral condyle cartilage, and add to the aesthetic appearance of the knee joint. [19]

The tibiofemoral joint is considered the "true" knee joint. It is the largest joint in the body and functions as a modified hinge synovial joint. Primary motions include flexion and extension, but it also allows for tibial rotation within the joint. [1] The distal end of the femur is enlarged to form the lateral and medial condyles, which are convex in shape. The proximal end of the tibia flattens into the tibial plateau, which forms two shallow concavities on which the femoral condyles articulate. [1] Tibial rotation on the femur during flexion and extension is known as the "screw home" mechanism. The screw home mechanism gives the knee the majority of its stability in full extension. [1] When the knee is extended and the tibia is laterally rotated, the joint is in the "close packed position". The resting position of the tibiofemoral joint is in 25 degrees of flexion.[19]

The menisci contribute to the static stability of the knee. Located on the tibial plateau, these fibrocartilage rings serve to add congruency to the articulating surfaces and deepen the concavities of the tibia, as well as cushion any stresses on the knee.[1] The medial meniscus is C-shaped and thicker posteriorly than it is anteriorly, while the O-shaped lateral meniscus has a fairly equal thickness throughout.[19]

A majority of the knee's stability comes from the bony congruency of the tibia and femur as well as the static support of the ligaments. The three part deep medial capsular ligament and the medial collateral ligament which lies superficial to it offer stabilization on the medial side of the joint. Different portions of these fibers are taut at different points in the range of motion. They offer support against valgus and external rotating forces.[1] The lateral collateral ligament offers support on the lateral side of the joint. The LCL is taut in extension, relaxed in flexion, and guards against varus forces.[1]

Two cruciate ligaments (posterior cruciate ligament and anterior cruciate ligament) in the knee cross within the joint cavity, but outside of the synovial membrane. The posterior cruciate ligament (PCL) is the stronger and travels from the posterior surface of the tibia in an upward, medial, forward direction to the anterior medial condyle of the femur.[1] Fibers of the PCL are taut in different parts of the range of motion and this ligament protects against hyperextension of the knee and femur.

The anterior cruciate ligament (ACL) attaches in the front of the tibia and crosses backward and laterally to the inner surface of the lateral condyle.[1] The ACL is comprised of three fibrous bands- the anteromedial, intermediate, and posterolateral. The anteromedial band is taut in knee flexion, and as the knee extends, the posterolateral band tightens. [1] The ACL protects against posterior femoral translation in weight-bearing and excessive tibial internal rotation. It also serves as a secondary restraint for valgus and varus stresses. [1] The ACL provides a large amount of the knee's static stability, but it also receives dynamic stabilization from the surrounding muscular anatomy.

Dynamic stabilization of the knee joint

Muscles of the lower leg and the thigh contribute to the dynamic stabilization of the knee. These muscles move the knee through the range of motion and provide tertiary restraint after bony anatomy and soft tissue static stabilizers such as the menisci and ligaments. The quadriceps muscle group composes the anterior portion of the thigh. The rectus femoris, vastus lateralis, vastus intermedius, and vastus medialis function to extend the knee. [1] These muscles also play an important role in the biomechanical function of the knee joint as well through the quadriceps tendon. The tendon surrounds the patella and functions to guide the sesmoid bone in the femoral groove and increase the efficiency with which that movement occurs. [1]

The hamstring muscle group is composed of the biceps femoris, semitendinosus, and semimembranosus and is the main contributor to knee flexion. The hamstrings are assisted by the gastrocnemius and the plantaris muscles of the lower leg. [20] The biceps femoris originates on the ischial tuberosity of the pelvis and the linea aspera of the femur and inserts on the head of the fibula and the lateral condyle of the tibia, on the posterolateral knee. [20] The semitendinosus and semimembranosus muscles originate on the ischial tuberosity of the pelvis and insert on the proximal shaft and pes anserine, and medial condyle of the tibia, respectively, on the medial side of the knee. [20] This allows the tendons of these muscles to reinforce the collateral ligaments on their respective sides of the joint. In addition, these three muscles contribute to external and internal tibial rotation. The biceps femoris controls external rotation and the other two muscles aid in internal rotation. [1]

The sartorius muscle originates on the anterior superior iliac spine and inserts on proximal medial tibia and knee joint capsule. [20] The gracilis muscle runs along the medial thigh, originating on pubis and ischial ramus and inserting on pes anserine and medial shaft of the tibia. [20] These two muscles aid in knee flexion and internal tibial rotation. [1] On the lateral side, the iliotibial band acts as a dynamic lateral stabilizer. [1] This IT band is part of the tensor fasciae latae muscle, which originates on the anterior superior iliac spine and the iliac crest, and inserts into the IT band. [20] The IT band inserts onto the lateral tibia.

It is important to remember that the joints of the body function together as a kinetic chain. [1] The knee is affected by the structures directly connected to or crossing the joint but is also influenced by the actions of the ankle joint and the hip joint. When a person performs a dynamic activity all joints must work in concert to counteract the forces associated with landing. These forces not only affect the knee but the ankle and hip. The majority of the muscles mentioned thus far have some effect on actions of the hip joint as well as knee function. The hip adductor group, composed of the adductor magnus, adductor brevis, adductor longus, and pectineus, is another important component of the upper leg musculature. This group of muscles originate off various areas of the medial pelvis on the ischium and pubis, and attach on the linea aspera on the medial femur.[20] Another contributor to hip adduction is the gluteus maximus muscle. This muscle originates on the iliac crest and sacrum and coccyx and inserts on the gluteal tuberosity of the femur.[20] Although they do not cross the knee joint, the medial pull that the muscles have on the femur may affect the biomechanics of that joint. This possibility will be discussed further later.

ACL injuries

Studies report that ACL injuries are occurring in the United States at a rate of as many as 200,000 a year.[2] Other sources offer a more conservative estimate of approximately 80,000 a year.[3, 21] In a study done by a large managed-care organization, these injuries were occurring at a rate of one per every 3,500 enrollees.[21]

Females injure their ACL at a significantly higher rate than males.[2, 4] Epidemiological data estimate females are at a 4- to 6-fold greater risk for injury than their male counterparts who participate in similar activities.[2] In a more recent epidemiological study, Agel and Arendt et. al (2005) looked at ACL injury trends over a thirteen year period in collegiate soccer and basketball players. They found a significantly higher incidence of injury in females over both sports than their male counterparts. The possible reasons for these differences will be examined along with the risk factors for injury.

Another focus of ACL injury research is the mechanism of injury. The consensus of the current literature is that approximately 70% of ACL injuries result from a non-contact mechanism, while the other 30% can be attributed to contact incidences.[2-4, 18] Injuries which occurred as a result of contact with another player, equipment, or the playing surface were classified as contact injuries.[3, 4] Non-contact injuries are classified as those that were caused by no apparent contact, be it with another player, a ball, or the playing surface.[4] Although there are many mechanisms that could be included in this category, decelerating, pivoting[3], cutting, rotating and landing from a jump are common high-risk movements that can result in injury.[22, 23]

ACL injuries are accompanied by large physical and economical consequences. While there are conservative approaches to rehabilitation with an ACL sprain, surgery is ultimately necessary for return to activity.[1] There are approximately 50,000 ACL reconstructions performed annually in the United States.[5] The estimated cost of these surgeries ranges from $17,000 to $25,000 each. The yearly financial impact of this injury is estimated at just under a billion dollars.[3, 5, 24] This figure does not account for the initial care and management of these injuries, nor does it include costs of rehabilitative care for injuries that are conservatively managed or the post-surgical rehabilitative costs of surgical patients. It also does not consider the cost of care for long-term complications from injury.

In addition to economic burden, these injuries pose an emotional burden and physical hardships on the patient. Collegiate athletes who suffered an ACL injury incur traumatic social consequences including loss of participation, eligibility, scholarship funding, and lowered academic performance.[25] Long-term physical effects include a decreased level of physical activity and an increased risk of joint degeneration problems. In individuals with ACL injury, osteoarthritis occurs at a rate ten times greater than that of the uninjured population.[26] This can lead to an earlier need for partial or total joint replacement surgeries because of dysfunction and degeneration.

Extrinsic Risk Factors for ACL injury

Extrinsic factors are influences outside of the person's body that add to their risk of injury. Some of these factors have been explored in the literature. Motion perturbations can have an effect on injury rate. These can be classified as any outside influence that changes the motion pattern or coordination of a player. Contact with another player or piece of equipment can alter biomechanical patterns and cause injury. [12] In one study, the presence of an opponent (a laboratory skeleton) during a sidestep cutting maneuver resulted in increased knee valgus and foot pronation angles, and more variability in tibial internal rotation in females in the study. [11] This data suggests that there is an increased risk in injury in this situation, associated with an increase in intrinsic factors related to ACL mechanisms.

Prophylactic bracing may also play a role in ACL injuries. There is no consensus as to whether or not bracing actually decreases the risk of injury or re-injury after a graft. There is literature to support the effect of bracing on decreasing tibial translation [27], and on modifying electromyographic activity of the stabilizing muscles of the knee. [28] Both of these factors can have an effect on ACL injury and lend some credibility to the use of braces. Some early studies showed a decrease in injury rates among braced participants, but later studies actually showed an increase in injuries among braced athletes. [29, 30] There is obviously a need for more research in this area, and as of yet, there is no definitive statement on whether or not braces help or hinder ACL injury prevention.

Minimal research has examined relationships between ACL injury and shoe-surface interaction. Correlations between injury and playing surface in many different settings, including natural grass, artificial turf, wood flooring, and rubberized athletic flooring [6] have been examined without significant conclusion. Some studies have identified a high level of friction between shoes and the playing surface as a major risk factor for ACL injury. [31] Creating an ideal relationship within this variable is difficult however, since higher levels of friction are also associated with increased performance. So while decreasing friction may decrease risk of injury, it also stands to decrease athletic performance.

Intrinsic Risk Factors for ACL Injury

Intrinsic risk factors related to ACL injury have been presented in abundance from the medical research community. Unfortunately in many cases, although there are many theories, there is a lack of scientific evidence necessary to draw hard conclusions. It is this researcher's purpose to present an overview of possible intrinsic risk factors that have been theorized to lead to an increased risk of ACL injury.

Anthropometric differences in the lower extremity are thought to contribute to injury risk. Tibia length, thigh length, and height differences have all been studied in the literature. In one study, increased thigh length was shown to increase injury in female skiers. [32] Although these anatomical differences are mentioned in literature, the base of research in this area is quite small, due to the lack of modification potential in this area.

Another anatomical difference that has been investigated in conjunction with ACL injury is the size of the femoral notch. [6] A smaller notch is hypothesized to correlate with a smaller, weaker ACL. The position of the ligament in a smaller, narrower notch can cause further elongation during high stress situations, compared to elongation in those with larger notches. [33] In one study by Uhorchak et al., they found women with an intercondylar notch width of less than 13 mm had a risk ratio 16.8 times greater than those with larger notches. [34] Another study found that subjects with bilateral ACL injuries had a smaller notch width than those with unilateral injuries, as well as control subjects. [3]

General joint laxity can affect motions of the knee in the sagittal and coronal plane, specifically hyperextension and valgus movements in the case of ACL injury. [10, 34] In a study by Uhorchak et al. (2003), females with generalized joint laxity had a 2.7 times greater risk of ACL injury than those without laxity. That same study applied that risk ratio to anterior tibial translation. Laxity of the ACL allows for increased tibial translation, relative to the femur. A study investigating exercise-associated laxity showed an 18% to 20% increase in anterior and posterior knee laxity after subjects spent 30 minutes playing basketball or jogging. [35] More research must be done in this area to establish a relationship between this laxity and subsequent ligament injury.

Another risk factor related more specifically to gender is the hormonal influence associated with the menstrual cycle that may predispose females to ACL injuries. Levels of estrogen and progesterone, as well as estradiol and relaxin, influence the ligament's strength. [6] Receptors for estrogen and progesterone have been found in human ACL cells. [36] Estradiol and relaxin have been shown to decrease ligament strength and decrease soft tissue stiffness respectively. [37, 38] Various researchers have also tried to link ACL injury rate with menstrual cycle phase. ACL injury is theorized to occur in the later stages of the menstrual cycle when levels of estrogen and progesterone concentration are greatest. However, epidemiological studies have not been able to determine which phase of the menstrual cycle, if any, are associated with the greatest injury rate. Many found evidence to support that the hormone fluctuations within the cycle are correlated with injury numbers [22, 39], but with no consensus on exactly when they are most prevalent. One possible reason is that these studies lack consistency in methods of dividing and naming the different phases of the menstrual cycle.

Hormones, estrogen in particular, have been theorized to affect the neuromuscular function of a female athlete, thereby predisposing them to injury. Hormones are theorized to influence the central nervous system [40] and alter lower extremity strength ratios, anaerobic and aerobic capacity, and endurance of the female athlete [40, 41], as well as motor skill function. [42]

Knee valgus angles and lower extremity muscle activation patterns are also considered influences on ACL injury prevalence. It is these two risk factors and the things that influence them that are the focus of this study.

Knee valgus, as related to ACL injury

The posture of knee valgus is theorized to be a risk factor of non-contact ACL injury. Knee valgus angles are influenced by a number of factors. Increased Q-angle is a proposed contributor to increased knee valgus angles. The Q-angle represents the pull of the quadriceps muscle through the patella to its insertion on the tibial tuberosity [43], therefore the position of the patella is extremely important in this measure. The angle of muscle contraction may affect knee angles in the coronal plane, specifically an increased valgus angle with a larger Q-angle. The width of the pelvis also contributes to the Q-angle, which may explain why women tend to have larger angles, because they traditionally have wider pelvises. [3] Despite the anatomical defense of this theory, little research has been done that actually proves a relationship between Q-angle and knee valgus. [6, 13] Thus, this is not a reliable predictor of dynamic knee valgus.

Another anatomical factor that has been studied in relation to knee valgus is tibial torsion. In one biomechanical video analysis of non-contact ACL injuries, external tibial rotation was seen as part of the most common injury mechanism. [7] This external rotation in closed chain exercises can increase the force load that the ACL must bear, in turn causing injury to the ligament. Along the same lines, excessive internal rotation of the femur can cause an increase in knee valgus angles. [14]

Foot pronation, as measured by navicular drop, has been investigated as potential risk factors associated with ACL and knee valgus. [6] An increase in navicular drop can affect lower extremity alignment. Along these same lines, the subtalar pronation that occurs in conjuction with navicular drop has been related to increased anterior tibial translation, tibial internal rotation and altered lower extremity alignment, which puts additional stress on the ACL. [44] Knee valgus, as mentioned earlier, is also thought to be influenced by the pull of the lower extremity musculature.

Lower extremity muscle activation

The majority of the research in the area of muscle activation and ACL injury seems to focus on the antagonist-agonist relationship of the quadriceps and hamstrings. Those two muscle groups act in a co-activation pattern to provide dynamic stabilization to the knee joint against anterior force, knee abduction, and knee valgus. [6] Deficits in hamstring strength and activation limit the co-contraction potential to protect the ligaments of the knee, specifically the ACL. Low hamstrings-to-quadriceps peak torque ratios are thought to increase risk of injury, because there is a lack of ability to balance muscular recruitment in high joint loading situations. [10] Higher quadriceps muscle activation can also lead to an increase in anterior tibial shear forces during dynamic flexion exercises, such as a jump-landing task. [45] Activation of the knee flexors in conjunction with the extensors causes compression of the joint and protection of the ACL against anterior forces; this allows more of the valgus load to be carried by the articular surfaces, thereby protecting the ligaments. [6]

Differences in magnitude and timing of muscle activation could increase ACL injury. Females have been shown to have a slower and less efficient hamstring activation response to anterior stress on the ACL than male athletes. [46] Activation patterns have also been shown to be significantly different between preplanned and unanticipated activities such as sidestepping. This difference in muscle activation may allow for more coronal plane movement, because the muscles are not activated to achieve the maximal dynamic stabilization for the movement. [32, 47]

The gluteus medius muscle acts primarily to abduct the hip, but it also works as a medial rotator with the hip in a flexed position. [1, 19] When that muscle is weak or inactive, compared to other lower extremity musculature, the hip tends to move into adduction in a loaded position. This in turn allows for internal rotation of the femur, and subsequent valgus position at the knee. In unpublished data from Kibler, it was found that females had a significantly shorter duration of gluteus medius activity in the stance phase of a cutting maneuver than males, which results in higher loads in the valgus/varus direction of the knee. [3]

The gluteus maximus muscle's primary action is hip extension, but it also functions to abduct and laterally rotate the hip. [1, 19] Its effect on knee valgus is similar to that of the gluteus medius, in that a weak or inactive muscle can allow the hip to adduct and cause a greater valgus moment in the knee. To date, there has been no research that focuses on the role of the gluteus maximus in ACL prevention literature.

The hip adductor group has thus far not been a large focus of research in ACL injury literature. However, the point has been made in some studies that there seems to be presence of great hip adduction angles, often accompanied by large knee valgus angles. In one study comparing the differences in EMG and kinematics of the lower extremity during a single leg squat, Zeller et al, (2003) found that female subjects experienced a valgus knee position in combination with greater hip adduction at the onset of the squat. Though there was not any direct causal relationship drawn between these two factors, it stands to reason that they are linked in the kinetic chain. As explained above, hip adduction causes internal rotation of the femur, which in turn forces the knee into a more valgus angle. There is a clear association between these two events.

The purpose of this study is to focus on EMG activity of the gluteus medius, gluteus maximus, and hip adductor complex, in relation to knee valgus angles during a task which mimics an ACL mechanism of injury. Those muscles have not been looked at on a large scale in injury prediction and prevention literature, but there is a biomechanical basis to support their proposed effect on kinetics of the lower extremity. Perhaps more insight into the function of these muscles as well as other risk factors previously discussed can lead the medical community to more effective ways of injury prevention.

ACL injury prevention

The multitude of literature available and the extensive research that has been done to look into identifying potential risk factors for ACL injury shows that this injury is of great interest to the medical community. Although many potential risk factors have been identified, there is a lack of effective screening programs to identify these factors in athletes. Research must look at the possibility of identifying these factors accurately and completely enough to consistently pick out at-risk individuals. Kinematic data collected for the lower limb during sporting activities is the most reliable measure available at present time [9, 48], but the availability of this technology as a screening tool is hindered by the cost and time commitment required by these systems. Research suggests that these 3D measures may correlate to 2D measures which would be easier and more time- and cost-effective for large scale screening. [9] By identifying risk factors in the kinematics of an athlete's movement, the hope is that those problems could be corrected through training methods.

Avoidance strategies are a major aspect of ACL prevention. By teaching athletes to avoid high risk athletic maneuvers, clinicians may reduce ACL injuries. An example of this theory is demonstrated by Griffin et al. (2000), who emphasized a retraining process in which athletes were encouraged to avoid actions that were routinely associated with ACL injury. Athletes were taught alternative motions to the pivot and cut, landing with their knee deeper in flexion, and an elongated stopping technique preferable to a one-step stop with the knee in hyperextension. In preliminary data collected on Division-I basketball players there was an 89% decrease in ACL injuries. This lends credibility to the teaching of avoidance strategies.

Training programs that emphasize a combination of multiple methods are also presented in ACL injury prevention literature. One program designed by Hewett et al. (1999) combined stretching, plyometrics, and strength training protocols. The program resulted in decreased landing forces and valgus and varus moments, and an increase in hamstring strength and hamstrings-to-quadriceps ratio. However, the training did not result in a lower injury rate between trained and untrained subjects. While a protocol such as this seems to have a positive effect on some identified risk factors to ACL injury, more research is needed to create a design with convincing prevention effects.

Neuromuscular training programs have increased in popularity in the past few years. This type of training is believed to teach joint stabilization patterns and muscle activation patterns. The athlete learns muscular recruitment strategies to decrease joint motion and protect the ACL from extreme loading. In laboratory settings, neuromuscular training has been shown to increase active stabilization at the knee, and decrease the risk of ACL injury. [24] Programs that emphasize body control during dynamic motion, especially about the knee and hip, have been shown to reduce ACL injury and increase performance. [3]

While avoidance strategies and neuromuscular training are two types of interventions that have been approached in ACL prevention, the method by which these strategies operates comes from the use of some form of augmented feedback.

Augmented feedback

Augmented feedback is defined as the process of providing extrinsic information to people regarding their movement and technique, usually in a biomechanical sense.

This provides an individual with supplemental information in addition to the intrinsic and instinctive information that is usually available to them during performance of a skill. [16] The process of providing feedback to aid in learning motor skills, improving performance and decreasing potential risk factors for injury has been investigated. Ground reaction forces are one risk variable that has been investigated for the use of augmented feedback. Large ground reaction forces create large forces on the body and moments that can cause injury. Success in the decreasing ground reaction forces during jump landing tasks has been found in recent years. [17, 49-51] Biomechanical technique, such as changing joint angles during skilled tasks, is another area of interest in research. Because of the success found in the aforementioned areas, it is reasonable to suggest that similar types of feedback may positively influence kinematics in the same tasks.

There are numerous types of instruction that can be included in augmented feedback. To date, most studies have looked at the effects of verbal or auditory feedback. In one study by McNair et al. (2003), various sources of auditory feedback were used to decrease ground reaction forces. Subjects' movements were influenced by either technical verbal instruction, auditory cues, or verbal imagery cues. They found significant differences in peak ground reaction forces from the control group for the technical instruction and auditory cues.

Visual augmented feedback has been used in research to guide subjects to refine gross motor tasks. The study used sEMG data to give subjects feedback on how far away their movements were from a target movement. Subjects showed lower muscle activity with visual feedback, which correlated with better performance in the task. [52]

Another form of augmented feedback involves viewing videos of a motor skill in order to receive feedback about that skill. Both self-model, in which the subject views a video of themselves performing the task, and expert model, where the video is of a person executing the skill in an "expert" fashion, techniques have been used. Onate et al. (2005) examined the effect of augmented feedback from video instruction on ground reaction forces in combinations of self-model and expert-model. Groups of subjects watched one of the following videos: self-model, expert model, combination of self and expert model, or none. His results stated that the combination self and expert model group reduced their peak ground reaction forces more significantly than the self model and expert model groups, although all three treatments showed some decrease in ground reaction force.

Augmented feedback is an effective way of altering biomechanical technique. Research is needed to find the most efficient form of feedback that is fast, effective, and easy to implement in the clinical setting. If this can be accomplished, clinicians can implement and share this tool with those most likely to suffer an ACL injury, in order to prevent future injury.

CHAPTER III

METHODS

Experimental Design

To investigate the effect of augmented feedback on knee valgus angles and muscle activity amplitude, we used a mixed model, repeated measures ANOVA with one between subject factor (control vs. intervention) and one within subject factor (pre-test and post-test). Subjects were randomly assigned to either the control or intervention group. Data was collected twice within one testing session, before and after an intervention period.

Subjects

Thirty-one collegiate recreationally active females (age range 18-22) participated in this study. Subjects were eligible for participation if they were identified as having knee valgus present in their dominant leg during an screening process. Subjects were required to be recreationally active, participating in physical activity for at least twenty minutes, three to four times per week. [16] Exclusion criteria included any known lower extremity injury within six months prior to testing that affected their ability to perform the study tasks. An injury was defined as any traumatic event or presence of injury symptoms that restricted activity for more than three days. [53] Subjects were also not permitted to participate in the study if they had a history of an ACL injury or reconstruction in their dominant leg, or if they had ever participated in jump landing training or an ACL prevention program. Prior to the start of testing, all subjects read and signed an informed consent form, approved by the Institutional Review Board of the School of Medicine at the University of North Carolina at Chapel Hill.

Instrumentation

2-D Videography

Two-dimensional video analysis was used in the initial screening process. Subjects were recorded executing a set of three jump landings. The analysis was performed in the frontal and sagittal plane. Video playback allowed for identification of knee valgus present in each subject's activity pattern. Each video trial was analyzed by the primary investigator. If the midline of the subject's patella moved medial to the great toe during the stance phase of the jump landing, they were classified as having knee valgus.

Electromagnetic Tracking System

Lower extremity kinematics were collected using the Flock of Birds electromagnetic motion analysis system (Ascension Technologies, Inc., Burlington, VT) at a sampling rate of 144 Hz.. The measurements were recorded by the Motion Monitor software system (Innovative Sports Training, Inc., Chicago, IL). The electromagnetic tracking system was calibrated prior to data collection. The transmitter was affixed to a stationary stand, .914 meters in height, to establish the global reference system. An embedded right-hand Cartesian coordinate system was defined for the shank, thigh, hip, and trunk to describe the three-dimensional position and orientation of these segments. Euler angles were used to calculate the knee joint angle between the shank and thigh and the hip joint angle between the thigh and pelvis in an order of rotations of (1) flexion-extension about the Y-axis, (2) valgus-varus (knee) about the X-axis, and (3) internal and external rotation about the Z-axis. Kinematic data was filtered using a 4^{th} order zero phase lag Butterworth low-pass filter at 14.5 Hz [54].

Electromagnetic tracking sensors were placed on each subject over the spinous process of C7, apex of the sacrum, midpoint of the lateral thigh, and shank of the tibia. Sensors of the thigh and tibia were placed on the dominant leg in areas consisting of the least amount of muscle mass to minimize potential artifact induced by muscle contraction. The sensors were affixed to the body using double-sided tape, prewrap and athletic tape.

Once the electromagnetic sensors were attached, the subjects were asked to stand in a neutral posture with their arms relaxed at their sides. The following bony landmarks were digitized, in the following order, using a mobile electromagnetic sensor attached to a stylus: spinous process of T12, xiphoid process, medial femoral condyle, lateral femoral condyle, medial malleolus, lateral malleolus, left anterior superior iliac spine, and right anterior superior iliac spine. Digitization of bony landmarks served to define the segment end-points and joint centers of the lower extremity segments. The ankle joint center is located at the midpoint between the medial and lateral malleoli. Knee joint center is located at the midpoint between the medial and lateral femoral condyles. The hip joint center was determined by the Bell method [55]. This method consists of estimating the hip joint center using the left and right anterior superior iliac spine as landmarks to mathematically estimate the hip joint center.

Electromyography

An electromyographic system (EMG) was used to measure muscle activity amplitude of the gluteus maximus, gluteus medius, and the hip adductor complex. The system was non-telemetered and utilized surface EMG (Delsys Bagnoli-8, Boston, MA). The measurements were collected by the Motion Monitor software system (Innovative Sports Training, Inc., Chicago, IL). Data were collected with a gain of 1000 and sampling rate of 1440 Hz. EMG data were collected immediately prior to and throughout the jump landing task.

Single bar adhesive Ag/AgCl surface EMG electrode (Delsys Inc., Boston, MA) were placed over the midsection of the muscle belly for each muscle. The placement for the gluteus medius muscle was found by measuring from the subject's iliac crest to the greater trochanter of the same leg, and taking the midpoint of this distance. [56] The gluteus maximus electrode placement was found by marking a distance ten centimeters distal to the greater trochanter, and then palpating the S2 spinous process. The distance from S2 to the mark below the greater trochanter was measured and the electrode was affixed at a point 20% of the distance from S2. [57] The hip adductor electrode was placed over the medial aspect of the mid-thigh. The electrode location was found by measuring the distance from the greater trochanter to the lateral epicondyle, finding the midpoint, then moving that point directly medial. [57] For all of these placements, a manual muscle test was performed to ensure placement over the muscle belly. A single reference electrode was placed over the tibial tuberosity. To reduce impedance to the EMG signal and allow for proper electrode fixation, electrode sites were prepared by shaving any hair from the immediate vicinity of the muscle belly, lightly abrading the skin with an abrasive pad, and cleansing the skin with isopropyl alcohol. To prevent movement of the electrodes and subsequent alteration of the EMG signal, electrodes were secured to the site using prewrap and athletic tape. During the electrode placement process, a tester of the same sex as the subject was present to apply the electrodes.

Manual muscle tests for the three muscle groups were performed after the jump landing protocol and consisted of three five-second maximal voluntary contractions against a manual resistance. These trials were used to normalize muscle activity. Muscled activity collected during the jump landing tasks was normalized to the average activity amplitude calculated during the maximal voluntary contractions. Data collection took place from 100 ms before initial contact through the end of the stance phase of the jump landing task. Signals from the electrodes were passed to a wired transmitter worn by the subject. A receiver and analog-to-digital converter converted the analog signal to digital data whereby it was able to be further analyzed by a computer utilizing custom software.

Force Plate

A nonconductive force plate (Bertec Corporation, Columbus, OH) was used to record ground reaction forces during the jump landing to define the phases of the task. A sampling rate of 1440 Hz was used to collect data. For each trial, the test leg landed on the force plate to signal the loading phase and kinematic data was collected between initial contact and toe-off. Initial contact was defined as the point at which the ground reaction forces exceed 10N, and toe-off was defined as the point at which ground reaction forces drop below 10N.

Procedures

Potential subjects reported to a sports medicine research laboratory during a general screening session to be evaluated for a knee valgus position. Subjects were videotaped while performing three trials of a jump landing task. The video trials were analyzed for knee valgus, as defined by the aforementioned criteria. Eligible subjects that presented with knee valgus were contacted for participation in the study. Previous studies using a squat task as a screening tool identified approximately 45% of the population as having knee valgus. Based on this number, the need to screen 80-100 people in order to successfully fill the study groups was anticipated. In reality, fifty-nine people were screened in order to identify the full testing population. The chosen subjects were randomly assigned to the control or intervention group.

Subjects who were identified as having knee valgus reported again to the laboratory for a single testing session that lasted approximately one hour. All subjects were dressed in clothing appropriate for physical activity (t shirt and shorts) and their personal athletic shoes. Subjects completed a questionnaire to ensure compliance with the inclusion criteria. Subjects were weighed on a digital scale, and investigators collected information regarding age, height, and leg dominance.

Prior to testing, the subjects completed a five-minute warm-up on a stationary bicycle at a self-selected moderate intensity, which they were told to judge using the Rating of Perceived Exertion (RPE) scale. Electrodes for EMG data collection and electromagnetic tracking sensors were placed on the subject according to the procedures detailed earlier. Once the subject was digitized, they were instructed to stand relaxed with their arms at their side allowing the computer to calibrate the subject's neutral position. A standing trial was recorded for data comparison. The jump landing task was explained to the subject and they were given practice trials until they were comfortable, with a maximum of three allowed. On average, subjects performed one practice trial.

Each jump was performed from a 30-cm high box. The box was set at a horizontal distance equal to 50% of the subject's body height from the front edge of the force-plate. Each subject was instructed to jump straight forward off the box and land with the foot of the dominant leg on the force-plate and the foot of the non-dominant leg off of the force-plate. Immediately after landing, the subjects were instructed to perform a vertical jump for maximum height, limiting horizontal motion and then return to the starting position.

The subject performed the first set of jump landing trials, which served as the pre-test measurements. Each subject performed five trials of the jump landing, with 30 seconds of rest in between each trial to minimize the risk of fatigue. Trials with incorrect landings or errors in data collection were considered invalid and a new trial was performed.

Once the first five trials were recorded, each subject completed an intervention period. Subjects in the control group rested for a period of ten minutes while subjects in the intervention group received augmented feedback regarding their jump landing technique. After the ten minute intervention period, each subject performed five more trials of the jump landing for post-test data collection. The same testing conditions applied here as in the pre-test trials.

Augmented Feedback Protocol

All subjects in the intervention group were first presented with a modified Landing Error Scoring Sheet (LESS). This form gave them standardized guidelines with which to evaluate the performance. The four grading criteria for the jump were explained to the subject prior to viewing any video so that they were clear on what characteristics of the jump they should be observing. Subjects first viewed a video of an expert model performing a jump landing task and were asked to score the model's technique using the modified LESS form. Following this viewing, the subjects watched a video of themselves performing the jump landing task and scored that video using the same guidelines as for the expert video. Each of the two videos contained a front and side view of the jump landing, and were played for the subject twice, once in real time and once in slow motion. [16] Each subject was given standardized verbal cues directly related to their performance during the video viewing process. These cues served to reinforce the criteria listed in the LESS by giving subjects a verbal and visual image of the technique they were trying to achieve.

Data Reduction

Following data collection, kinematic and electromyographical data were reduced. Specific EMG data points were pulled off during the pre-activity phase and during the landing phase of the jump landing task. We determined muscle activity amplitude of the gluteus maximus, gluteus medius, and hip adductor complex during the pre-activation phase and during the landing phase, as well as knee valgus angles at initial contact, peak knee valgus angles during the landing phase, and peak knee valgus angles during the entire jump landing from pre-activation to toe-off. Although not initially variables of interest, and not a focus of the research questions, peak knee flexion angles during the landing phase and peak knee flexion during the entire jump landing task from pre-activation to toe-off were also determined. Pre-activation was defined as 100 ms preceding initial contact. [58] The landing phase was defined from initial contact to toe-off. All processing was performed through customized software in Matlab 7.0 (The Mathworks, Inc., Natick, MA).

Raw data were converted to the aligned anatomical coordinate axes. The three dimensional global and local coordinate systems were defined as follows: the positive x-axis was the direction the subject faced, the positive y-axis was to the right of the subject, and the positive z-axis pointed upward. In order to describe joint motions in clinically relevant terms, joint motions were determined through a joint coordinate system. This system was recommended by the International Society of Biomechanics and proposed by Grood and Suntay (1983). [59] Analysis of the kinematic data, independent of the order the rotations were entered into the matrix calculations, was possible due to the use of the joint coordinate system. Sagittal plane motions occurred about the y-axis and frontal plane motions occurred about the x-axis. The Motion Monitor software processed the raw sensor data and a Butterworth low pass digital filter (4^{th} order, zero phase lag) smoothed the data at an estimated cutoff frequency of 14.5 Hz. [54]

Statistical Analysis

A mixed model repeated measures 2x2 ANOVA was run for each variable examined: knee valgus, gluteus maximus activity, gluteus medius activity, and hip adductor complex activity. Two grouping factors, control versus intervention and pre-test versus post-test were used. A correlational analysis was used to determine a relationship between knee valgus angles and muscle activity amplitude of the aforementioned muscles for a within- and between-subjects analysis. All analyses were performed using SPSS 13.0 software (SPSS Inc., Chicago, IL). An alpha level was set a priori at 0.05.

RQ	Description	Data Source	Method
1	**What is the effect of augmented feedback on knee valgus angles at initial contact and peak knee valgus angles during the landing phase of a jump landing task, as measured by an electromagnetic motion analysis system?**	<u>Dependent Variable</u>: Knee valgus angles at initial contact and peak angle during the landing phase <u>Independent Variable</u>: Group (intervention vs. control) Time (pretest vs. posttest)	Mixed model repeated measures 2x2 ANOVA for interaction between knee valgus, group and time
2	**Does augmented feedback change muscle activity amplitude of the gluteus medius, gluteus maximus and hip adductors during the pre-landing and landing phases of a jump landing task?**	<u>Dependent Variable</u>: Muscle activity amplitude of the gluteus medius, gluteus maximus, and hip adductor complex <u>Independent Variable</u>: Group (intervention vs. control) Time (pretest vs. posttest)	Mixed model repeated measures 2x2 ANOVA for interaction between muscle activity amplitude, group and time
3	**Do changes in muscle activity amplitude of the gluteus medius, gluteus maximus, and hip adductors during the pre-landing phase correlate with changes in knee valgus angles at initial contact during the stance phase of a jump landing task?** **Do changes in muscle activity amplitude of the gluteus medius,**	<u>Dependent Variables:</u> Knee valgus angles and muscle activity amplitude of the gluteus medius, gluteus maximus, and hip adductor complex	Correlation analysis to determine if a relationship exists between knee valgus and muscle activity amplitude

	gluteus maximus, and hip adductors during the landing phase correlate with changes in peak knee valgus angles during the landing phase of a jump landing task?		

CHAPTER IV

RESULTS

Thirty-one female subjects (age = 20.3 ± 1.3 years, height = 166.5 ± 7.4 centimeters, weight = 66.6 ± 12.4 kilograms) were tested. However, the kinematic data for one subject was not included for the analysis due to a placement error of one of the sensors which led to inaccurate data collection. Subject demographics are also presented in Table 1.

Kinematic Data

Means, standard deviations, p values, and effect size are presented for knee valgus angles at initial contact, peak knee valgus angles, and peak knee valgus during the landing phase of the jump landing in Table 2. One subject's data for knee valgus at initial contact and at peak knee valgus was not used due to unnaturally large change scores for this variable, which caused researchers to think that there may have been an underlying data collection issue with this subject (Intervention Subject 10).

There was a significant difference, therefore a significant interaction effect, in knee valgus angles at initial contact ($F = 13.479$, $p = 0.001$, $\eta_p^2 = 0.333$) (Figure 1). The intervention group displayed a decrease in knee valgus angles from pre-test to post-test, meaning they were moving toward more varus angles at initial contact.

There were no significant interaction or main effects for peak knee valgus or peak knee valgus during the landing phase between groups or testing conditions.

There was a significant group x test interaction effect ($F = 6.024$, $p = 0.021$, $\eta_p^2 = 0.177$) for peak knee flexion angles during the landing phase (Figure 2). The intervention group demonstrated an increase in knee flexion after the intervention protocol. There was also a significant test main effect ($F = 7.505$, $p = 0.011$, $\eta_p^2 = 0.211$) for knee flexion angles at initial contact. Regardless of group, subjects displayed less knee flexion at the point of initial contact in post test trials. These values are presented in Table 3.

Electromyographical Data

Means, standard deviations, p values, and effect size for muscle activity during the pre-activation phase of the jump landing are shown for the gluteus medius, gluteus maximus, and the hip adductors in Table 4. There were no significant differences found for any of the muscles' activity amplitudes during the pre-activation phase. Means, standard deviations, p values, and effect size for muscle activity during the landing phase for the same three muscles are shown in Table 5. Significant differences were found in muscle activity amplitude during the landing phase of the jump in some of the muscles measured. A group x test interaction effect ($F = 4.342$, $p = 0.046$, $\eta_p^2 = 0.130$) was found for the gluteus medius (Figure 3). The intervention group showed a significant decrease in gluteus medius activity from the pre-test to post-test conditions. A group x test interaction effect ($F = 9.702$, $p = 0.004$, $\eta_p^2 = 0.251$) was also found for the gluteus maximus muscle activity during the landing phase (Figure 4). There was a significant decrease in muscle activity from pre- to post-test conditions in the intervention group.

Although there were no significant findings in muscle activity amplitude for the hip adductor muscle group, the average muscle activity amplitude values of the intervention subjects followed the same trend of decreasing from pre-test to post-test as was shown in the gluteal muscles.

Correlational Analyses

Pearson correlation coefficients and p-values for change scores of the gluteus maximus, gluteus medius, and hip adductor complex muscle activity amplitude during the pre-activation phase correlated with change scores of knee valgus angles at initial contact are presented in Table 6. There were no significant correlations for any of the muscles to knee valgus angles at initial contact.

Pearson correlation coefficients and p-values for the gluteus maximus, gluteus medius, and hip adductor complex muscle activity amplitude during the landing phase correlated with peak knee valgus angles during the landing phase are presented in Table 7. There was a significant correlation between change scores for gluteus medius activity amplitude during the landing phase and peak knee valgus angles during the landing phase ($r = -0.442$, $p = 0.014$) (Figure 5). There were no significant correlations between change scores for gluteus maximus or hip adductor complex activity amplitude and peak knee valgus angles during the landing phase.

CHAPTER V

DISCUSSION

Knee Valgus Findings

The most important finding of our study was the effect of an augmented feedback protocol on knee valgus angles during a jumping task. There was a significant finding observed for the variable of knee valgus at initial contact, but no significant differences observed at overall peak knee valgus or peak knee valgus during the landing phase. This correlates with our original hypotheses that there would be significant changes in knee valgus angles after an intervention protocol, although we expected to see differences in knee valgus measured at various angles during the jump, as opposed to just at initial contact. Other studies [16, 17, 49-51] have also shown success in using similar feedback protocols to manipulate variables such as EMG activity and ground reaction forces, although most of them implemented more in depth protocols. This study utilized a similar combination of self-model and expert-model video demonstration, which has been found to be successful in reducing ground reaction forces. [16] The most notable study in this area is the Onate study which dealt primarily with ground reaction forces. Those researchers utilized a similar intervention protocol, but with a much more extensive project, as far as the time which the subjects spent undergoing the intervention and practicing techniques. They also branched into retention aspects of augmented feedback, having the subjects return for multiple testing sessions after the initial intervention, which this study did not set out to do. This study, while not claiming to be as intensive or involved as previous studies such at that, still did illicit some significant changes in the variable of knee valgus with a relatively short and basic augmented feedback protocol. It would be interesting to see the results that could be found if this same protocol was extended to a more in-depth training study or a retention study of the same nature as those previously performed.

While significant results were found in the variable of knee valgus at initial contact, there were no significant findings in changes of knee valgus during the landing phase. This did not support our original hypotheses for peak knee valgus angles and peak knee valgus during the landing phase. One possible influence on this is the large standard deviations that were recorded for the post-test trials. The standard deviations for peak knee valgus angles in both the control and intervention groups were large for the pre-test trials (6.161 and 5.531 degrees, respectively), but in the post test trials, the standard deviation for the intervention group was even larger (7.814 degrees). This large value to begin with, and increase in value for post-test trials may be influencing the chance to see significant results.

Another possible influence on the results is the degree to which each subject went into knee valgus to begin with. Based on the previously set inclusion criteria for this study, excessive knee valgus was simply defined as the movement of the midline of the patella medial to the great toe during the jump landing task. During the initial screening process, this criteria was visually determined by the researchers through viewing videotaped performances of jump landings. Initially, the subjects were easily identifiable with excessive knee valgus, which could be defined as a very obvious, exaggerated medial motion of the patella past the great toe. As the screening process progressed, subjects still displayed knee valgus but anecdotally appeared to land with less knee valgus compared with the initial subjects. It is possible that those who did not have as severe knee valgus to begin with were not influenced as significantly as those that did. Change scores for knee valgus angles at initial contact are graphed in Figure 6. Eight of the first nine intervention subjects had changes in the positive direction from pre- to post-test measures, meaning that knee valgus decreased after the intervention protocol. The last seven subjects did not follow the same trend. This observation supports the idea that a positive change was seen in the subjects who presented with more knee valgus during the screening process. Future research may look into classifying varying degrees of knee valgus, such as mild, moderate, or severe based on how far medial to the great toe the midline of the patella moves.

Knee Flexion Findings

Although this was not originally a variable of interest, data for knee flexion angles at initial contact, peak knee flexion angles during the jump landing task, and peak knee flexion angles during the landing phase of the jump were collected and analyzed for possible future research. Individuals in the intervention group displayed significant increases in peak knee flexion during the landing phase after undergoing the intervention protocol. Interestingly, regardless of group, subjects landed with less knee flexion at the exact point of initial contact in the post-test trials. The position of knee flexion to at least 45 degrees during the jump landing task was one variable that the subject graded using the modified LESS form while watching the expert model and self-model videos. Subjects were also given verbal cues to remember that knee flexion during the landing was important in order to “cushion” the landing and lessen the force with which they hit the ground. They were also told that they should try to bend their knees as they were landing, as opposed to after they had already hit the ground. Knee flexion angles lower than 45 degrees in other studies have been related to increased injury rates and ACL strain, due mainly to increased anterior shear, decreased co-contraction of quadriceps and hamstrings, and decreased compression of the joint space. [12, 18, 60] The intervention protocol in this study was successful with increasing the knee flexion angle during the jump landing task, which in theory will help to protect the ACL from injury.

EMG Findings

The original hypotheses stated that there would be an increase in gluteus medius and gluteus maximus activity, and a decrease in hip adductor activity during both the pre-activation and the landing phases of the jump landing task. There were no significant differences found for any of the three muscles tested during the pre-activation phase. This leads to the conclusion that these hip muscles do not seem to play a significant role in preparing the lower extremity position for landing.

There were significant findings for EMG activity during the landing phase of the jump for the gluteus medius and gluteus maximus. The intervention subjects showed a significant decrease in muscle activity amplitude for the gluteus medius and the gluteus maximus in the post-test trials. These two hip external rotators are thought to be helpful in countering hip internal rotation and adduction, which is a proposed contributor to knee valgus. The expectation was that these muscles would show an increase in muscle activity amplitude after the intervention protocol, because they would be functioning to control hip rotation and put the subject in a theoretically better body position for landing. One possible explanation to this contrary result is that if the subject were in less of a knee valgus position, and therefore a more externally rotated position, after the intervention protocol, the gluteus medius and gluteus maximus muscles may not have to be as active to control the position. The muscles may work more efficiently when the body is in a more mechanically advantageous position.

Another possible influence on this finding is the fact that there were significant increases in knee flexion seen in the intervention subjects from pre- to post-testing. The gluteus medius and gluteus maximus also function as hip extensors, which means that they are more active in a more extended hip position. When the subjects begin to land in a more knee flexed position, it stands to reason that they are also experiencing more hip flexion. This more flexed hip position may take away some of the effect of the gluteal muscles, because they are not as active in that position.

One other observation that was made during the post-test trials is that after the intervention protocol, many of the subjects widened their stance upon landing. This seemed to be an unconscious compensation mechanism in order to keep their knees from "falling together" into the position of knee valgus, as was described to them during the intervention. Although instruction was given to keep their feet approximately shoulder width apart, as they had done in the pre-test trials, many continued to land with a widened stance. This may have also influenced the muscle activity amplitude of the gluteus medius and gluteus maximus, as an increased stance width would decrease the ability of those muscles to act as hip abductors.

Correlational Findings

We did not observe a correlation between pre-activation phase muscle activity amplitude and knee valgus angles at initial contact. This supports the previously stated finding in this research that the gluteus medius, gluteus maximus, and hip adductor complex do not play a significant role in altering lower extremity position at initial contact during the jump landing task.

Correlations conducted on change scores of muscle activity amplitude and peak knee valgus angles during the landing phase showed a significant positive correlation of gluteus medius activity amplitude and peak knee valgus angles during the landing phase. As gluteus medius activity decreased, so did peak knee valgus angles. Although not what was originally hypothesized, this correlation fits with the earlier findings of this study.

Limitations

One limitation to this study was the effect size and power of some of the variables measured. For the non-significant kinematic and electromyographical variables, the partial Eta squared (η_p^2) values and the observed power values all very small. Additionally, observed power and effect size for the gluteus medius muscle activity amplitude during the landing phase were low, even though those statistics run did produce significant results. This lends to the idea that in order to find significant effects, the researcher would need to test so large of a population that this variable could no longer be deemed clinically relevant. The variables in question may be too minute to measure accurately during this task.

Another limitation is that these findings cannot be generalized across population boundaries. The researchers in this study chose to test recreationally active, young adult females. Since no male subjects were tested, these results cannot be generalized across gender. Past research has shown that males move differently during sport-specific and activity-specific tasks such as jump landings or cutting maneuvers.[2, 61, 62] It is also possible that males and females learn and respond to instruction differently, so the same intervention techniques may not have the same effect on males.

Additionally, the activity requirement specified only the time and frequency that the subject must participate in, with no specific sport activity criteria. Therefore, these results cannot be generalized to any specific sport mechanism. It is possible that people with more experience in a jumping task may have responded differently to the intervention protocol.

Along those same lines, these results should not be generalized to varsity or elite level athletes. Anyone who competes at that level has undergone many years of coaching instruction. It is very likely that they would respond differently to technique instruction, such as the intervention protocol, than someone who does not play organized sports or has not had the same exposure to technical instruction.

Future Research

When speaking in terms of injury prevention and technique instruction, retention of the feedback is always important to address. This study did not test for any kind of long-term retention. Future research should point in the direction of using similar feedback protocols as a training tool in repeated technique modification sessions, as well as testing for retention of the technique modification over an extended period of time.

Another area in which this research can be expanded is the types of activities that it is used in. Most of the research up to this point has focused on some kind of jumping technique. The kinematic and electromyographic variables important to injury prediction and prevention can be tested in a number of other ways. Future studies should look to implement the use of augmented feedback training protocols in a squatting task, cutting and pivoting tasks, and in tasks with unanticipated movements.

Conclusion

This current study examined the variables of knee valgus and muscle activity amplitude of the gluteus medius, gluteus maximus, and hip adductor complex in a jump landing task with an augmented feedback intervention. Based on the results of this study, we conclude the following:

1. Knee valgus angles were not significantly influenced by the intervention protocol. A larger sample size or a more potent intervention may be needed in order to evoke significant changes in this variable. Additionally, this intervention may be more effective on people with more extreme presentation of knee valgus.
2. The use of a combination of expert and self-model video instruction and verbal cues were effective in significantly increasing knee flexion angles during landing from a jump task.
3. The gluteus medius, gluteus maximus, and hip adductor muscle complex do not appear to play a significant role during the pre-activation phase of a jump landing task. Additionally, there is no correlation between the pre-activity of these muscles and the position of knee valgus at initial contact.
4. The gluteus medius and gluteus maximus muscles showed a decrease in muscle activity after an intervention protocol. One hypothesis for this is increased muscular efficiency due to a better biomechanical position of the body during landing.

Table 1: Subject Demographics

	Mean ± SD	Minimum Value	Maximum Value
Age (years)	20.3 ± 1.3	18	23
Height (cm)	166.5 ± 7.4	155	183
Weight (kg)	66.6 ± 12.4	51.2	107

Table 2: Means, standard deviations, p values, effect size, and observed power for knee valgus angles

Variable	Group	Pre-test Mean		SD	Post-test Mean		SD	Group x Test Interaction	Test Main Effect
Knee Valgus Angles	Control	-0.393	±	3.587	-0.932	±	3.878	$F = 13.479$ $p = 0.001$	$F = 4.482$ $p = 0.044$
at Initial Contact	Intervention	1.036	±	1.876	3.046	±	2.57	$\eta_p^2 = 0.333$ $1-\beta = 0.943$	$\eta_p^2 = 0.142$ $1-\beta = 0.533$
Peak Knee	Control	-15.359	±	6.161	-17.762	±	5.556	$F = 3.258$ $p = 0.082$	$F = 1.984$ $p = 0.170$
Valgus Angles	Intervention	-15.203	±	5.531	-14.906	±	7.814	$\eta_p^2 = 0.108$ $1-\beta = 0.413$	$\eta_p^2 = 0.068$ $1-\beta = 0.274$
Peak Knee Valgus Angles	Control	-15.004	±	6.101	-17.166	±	5.452	$F = 2.694$ $p = 0.112$	$F = 1.571$ $p = 0.221$
During Landing Phase	Intervention	-15.17	±	5.537	-14.88	±	7.776	$\eta_p^2 = 0.091$ $1-\beta = 0.353$	$\eta_p^2 = 0.055$ $1-\beta = 0.227$

Table 3: Means, standard deviations, p values, effect size, and observed power for knee flexion

Variable	Group	Pre-test Mean		SD	Post-test Mean		SD	Group x Test Interaction	Test Main Effect
Peak Knee Flexion Angles	Control	75.931	±	13.155	77.035	±	13.599	$F = 6.024$ $p = 0.021$	$F = 15.797$ $p < 0.0001$
During Landing Phase	Intervention	79.578	±	11.846	84.247	±	11.293	$\eta_p^2 = 0.177$ $1\text{-}\beta = 0.659$	$\eta_p^2 = 0.361$ $1\text{-}\beta = 0.970$
Knee Flexion Angles	Control	5.412	±	4.951	4.603	±	5.127	$F = 0.593$ $p = 0.448$	$F = 7.505$ $p = 0.011$
At Initial Contact	Intervention	6.554	±	5.861	5.113	±	5.374	$\eta_p^2 = 0.021$ $1\text{-}\beta = 0.115$	$\eta_p^2 = 0.211$ $1\text{-}\beta = 0.753$

Table 4: Means, standard deviations, p values, effect size, and observed power for muscle activity amplitudes during pre-activation phase

Variable	Group	Pre-test Mean		Pre-test SD	Post-test Mean		Post-test SD	Group x Test Interaction	Test Main Effect
Muscle Activity Amplitude	Control	0.414	±	0.201	0.392	±	0.181	F = 0.142 p = 0.709	F = 1.099 p = 0.303
of the Gluteus Medius	Intervention	0.457	±	0.372	0.411	±	0.17	$\eta_p^2 = 0.005$ 1-β = 0.065	$\eta_p^2 = 0.037$ 1-β = 0.174
Muscle Activity Amplitude	Control	0.244	±	0.113	0.249	±	0.121	F = 0.025 p = 0.875	F = 0.232 p = 0.634
of the Gluteus Maximus	Intervention	0.173	±	0.068	0.176	±	0.058	$\eta_p^2 = 0.001$ 1-β = 0.053	$\eta_p^2 = 0.008$ 1-β = 0.075
Muscle Activity Amplitude	Control	0.701	±	0.261	0.673	±	0.245	F = 0.063 p = 0.803	F = 2.806 p = 0.105
of the Hip Adductor Complex	Intervention	0.642	±	0.642	0.606	±	0.244	$\eta_p^2 = 0.002$ 1-β = 0.057	$\eta_p^2 = 0.088$ 1-β = 0.367

Table 5: Means, standard deviations, p values, effect size, and observed power for muscle activity amplitudes during landing phase

Variable	Group	Pre-test Mean		Pre-test SD	Post-test Mean		Post-test SD	Group x Test Interaction	Test Main Effect
Muscle Activity Amplitude	Control	0.867	±	0.578	0.849	±	0.668	$F = 4.342$ $p = 0.046$	$F = 5.545$ $p = 0.026$
of the Gluteus Medius	Intervention	1.076	±	0.963	0.792	±	0.598	$\eta_p^2 = 0.130$ $1\text{-}\beta = 0.522$	$\eta_p^2 = 0.161$ $1\text{-}\beta = 0.624$
Muscle Activity Amplitude	Control	0.895	±	0.421	0.918	±	0.466	$F = 9.702$ $p = 0.004$	$F = 5.270$ $p = 0.029$
of the Gluteus Maximus	Intervention	0.789	±	0.293	0.635	±	0.234	$\eta_p^2 = 0.251$ $1\text{-}\beta = 0.853$	$\eta_p^2 = 0.154$ $1\text{-}\beta = 0.602$
Muscle Activity Amplitude	Control	1.115	±	0.629	1.145	±	0.531	$F = 1.557$ $p = 0.222$	$F = 0.560$ $p = 0.460$
of the Hip Adductor Complex	Intervention	1.075	±	0.765	0.953	±	0.601	$\eta_p^2 = 0.051$ $1\text{-}\beta = 0.226$	$\eta_p^2 = 0.019$ $1\text{-}\beta = 0.112$

Table 6: Pearson correlation coefficients and p values for pre-activation muscle activity correlated with knee valgus at initial contact

	Knee Valgus at Initial Contact	
	Pearson r value	p value
Gluteus Medius Pre-activity	-0.267	0.154
Gluteus Maximus Pre-activity	-0.257	0.171
Hip Adductor Pre-activity	0.083	0.662

Table 7: Pearson correlation coefficients and p values for landing phase muscle activity correlated with peak knee valgus during landing phase

	Peak Knee Valgus during Landing Phase	
	Pearson r value	p value
Gluteus Medius Activity in Landing Phase	-0.446	0.013
Gluteus Maximus Activity in Landing Phase	-0.129	0.496
Hip Adductor Activity in Landing Phase	0.043	0.822

Figure 1: Average Knee Valgus Angles at Initial Contact

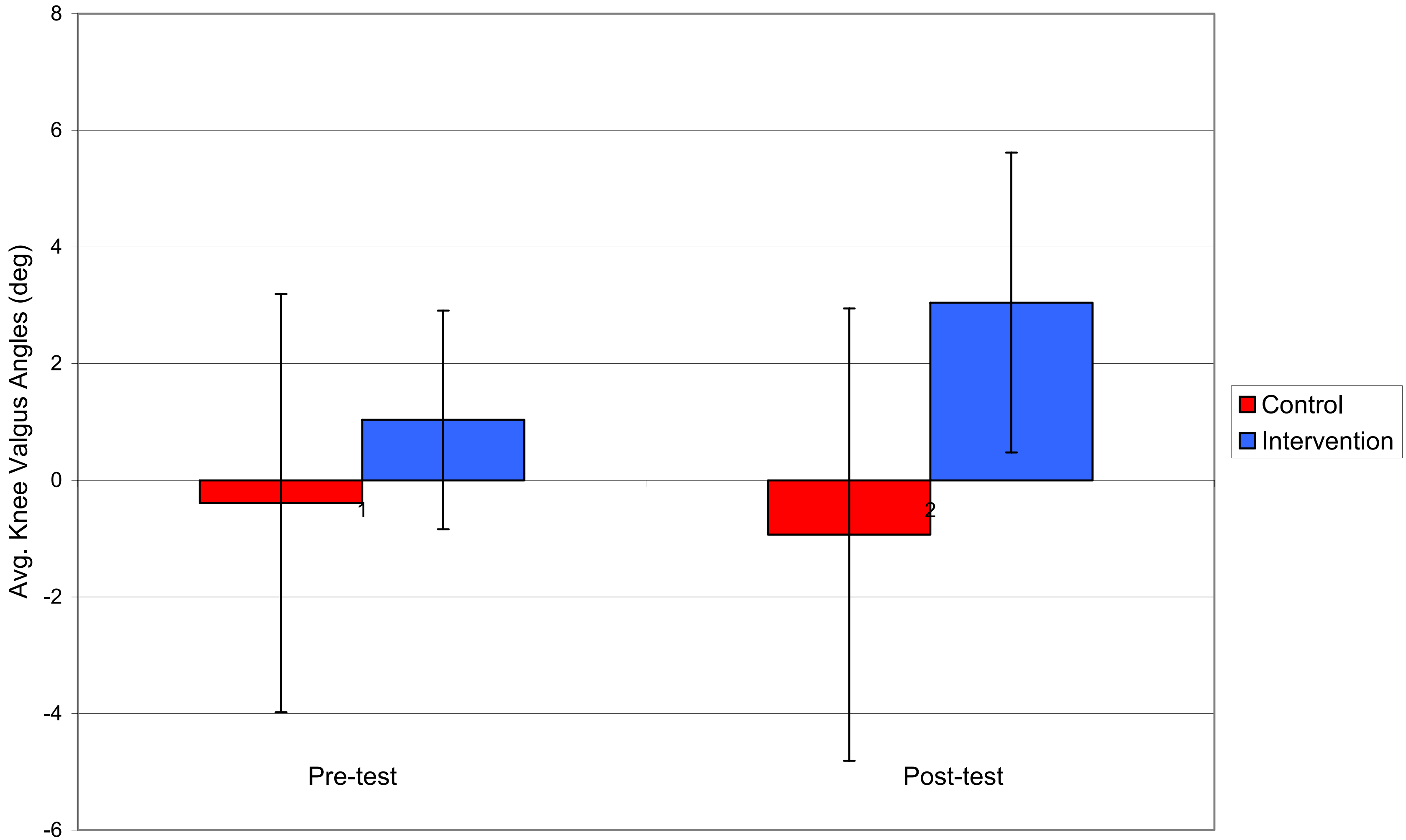


Figure 2: Average Peak Knee Flexion Angles During Landing Phase

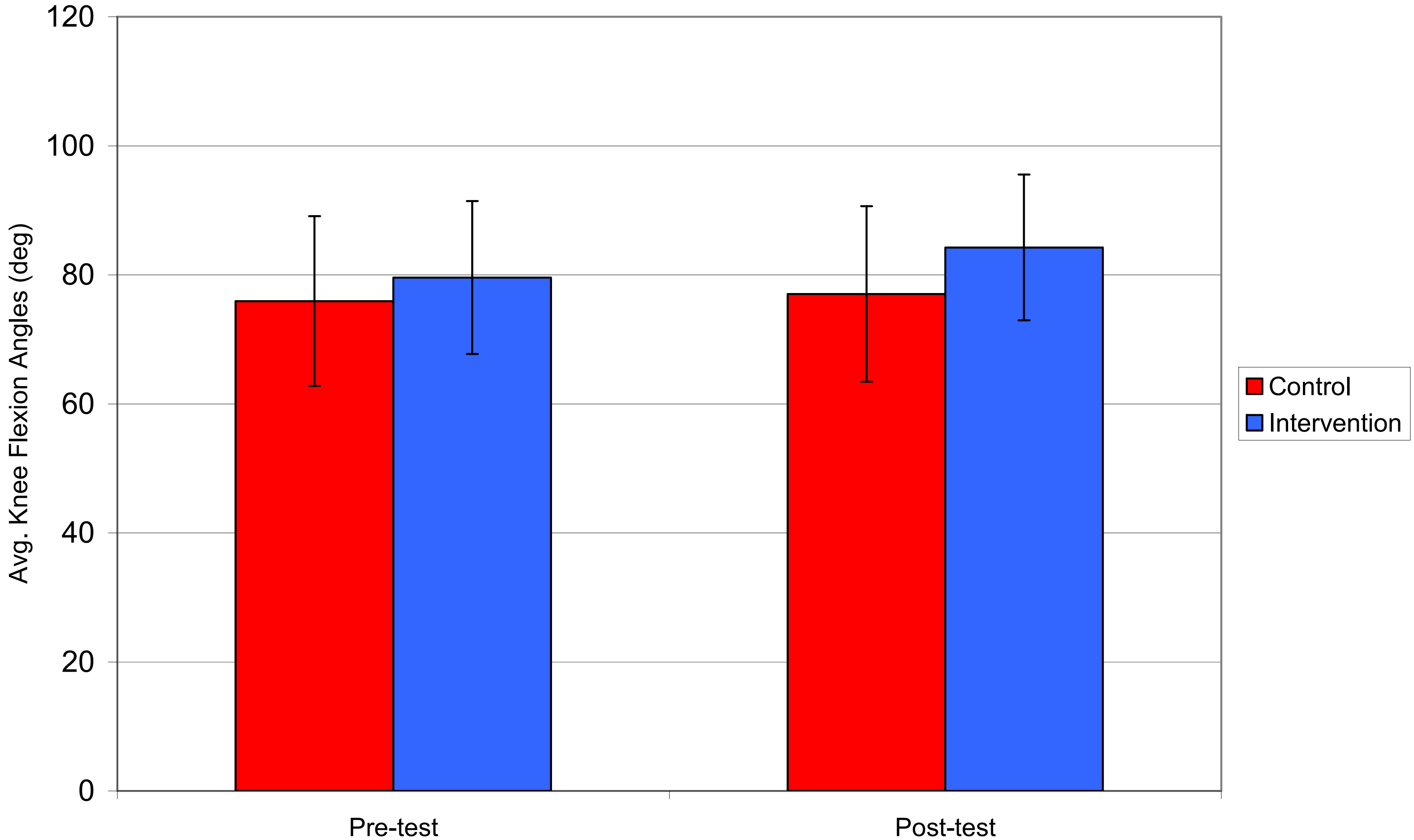


Figure 3: Average Muscle Activity Amplitude for the Gluteus Medius During the Landing Phase

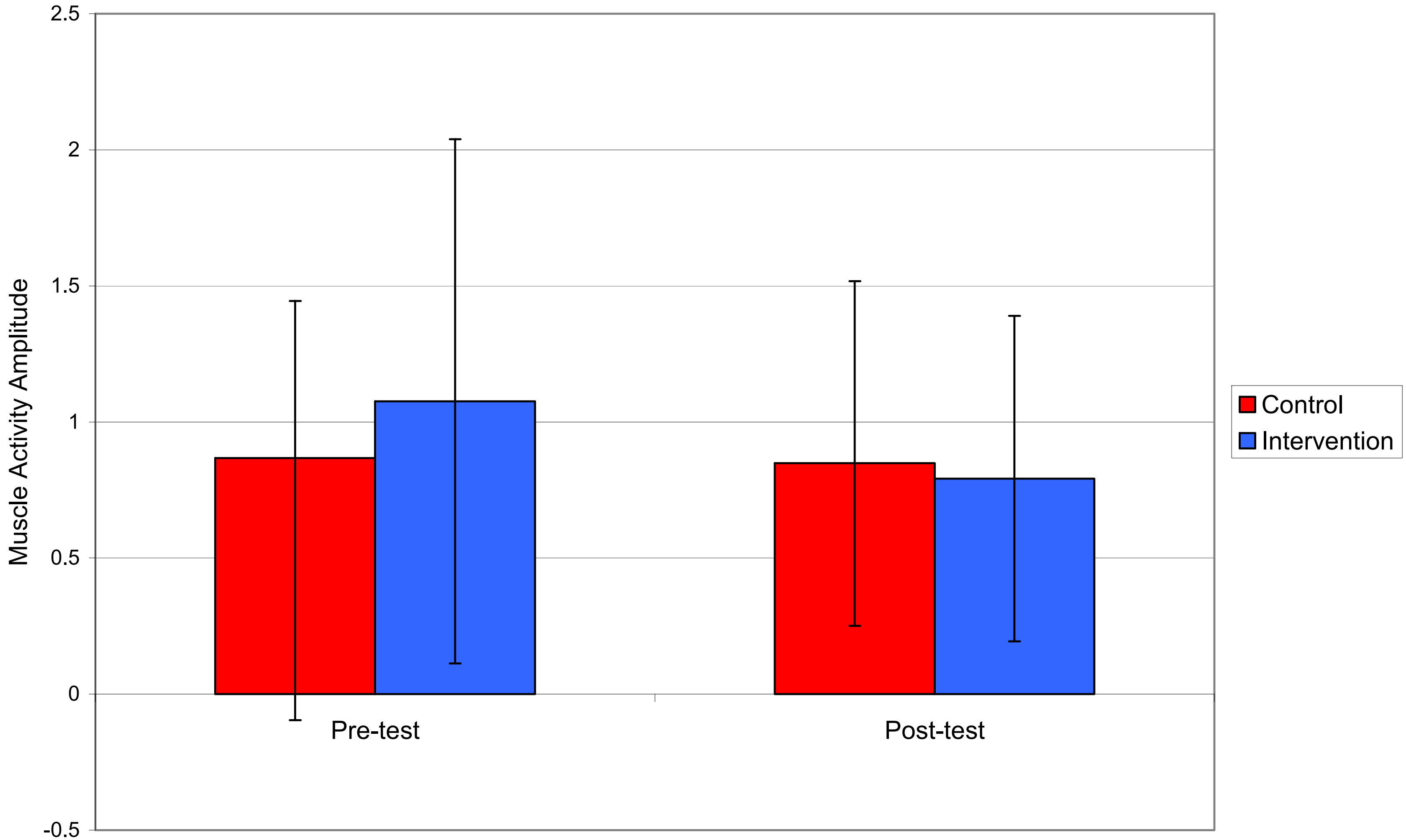


Figure 4: Average Muscle Activity Amplitude for the Gluteus Maximus During the Landing Phase

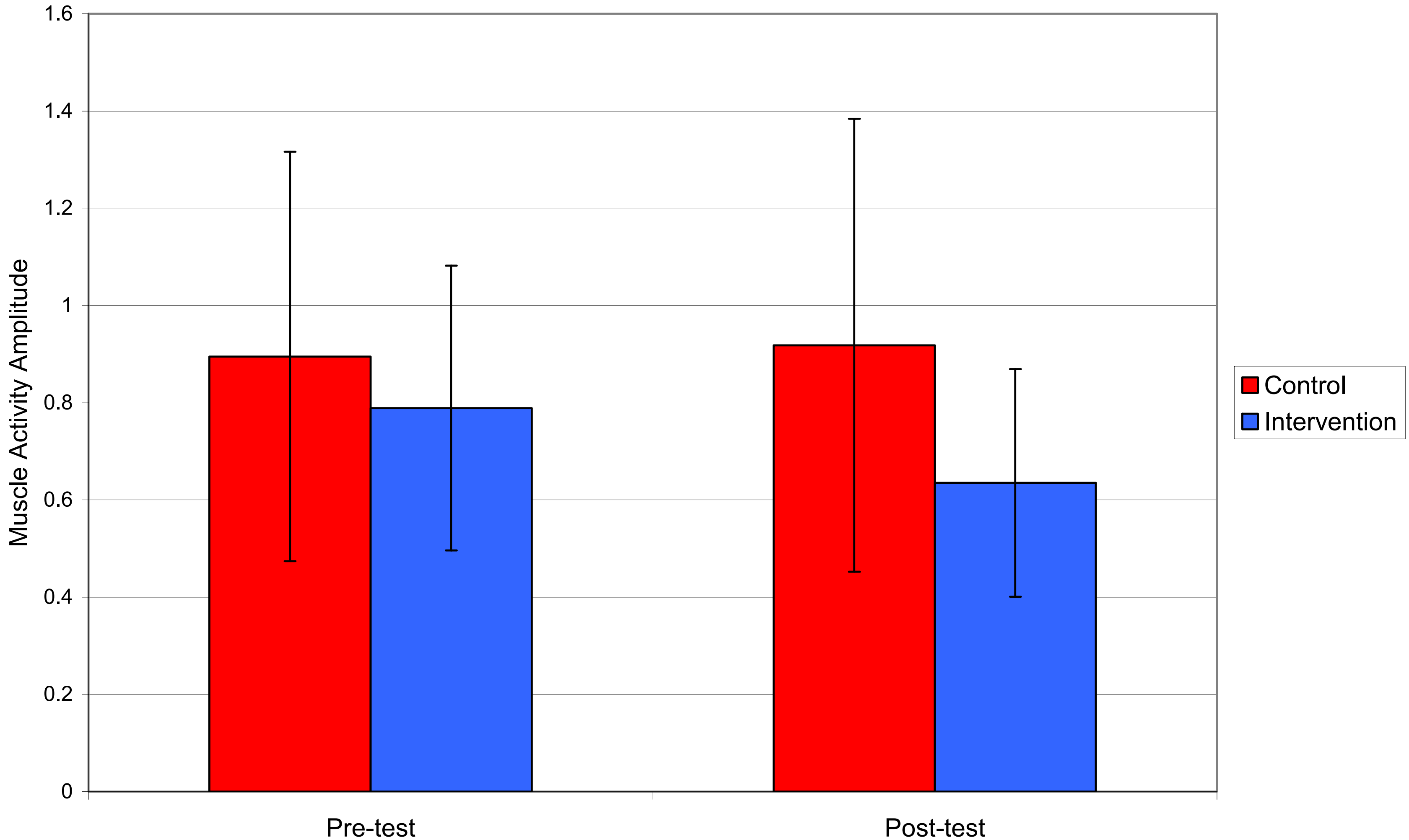


Figure 5: Correlational graph for gluteus medius activity during landing phase and peak knee valgus angles

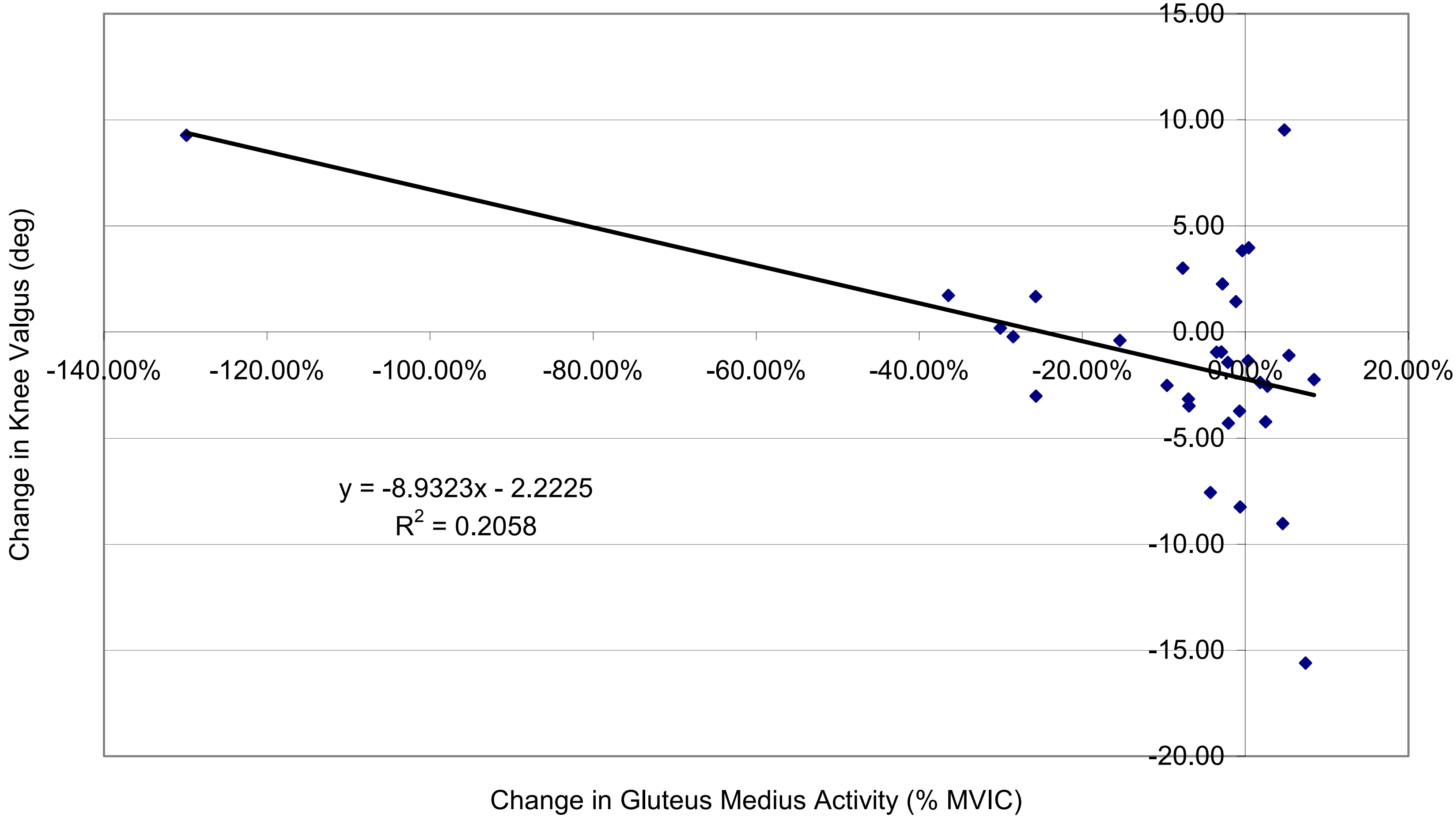
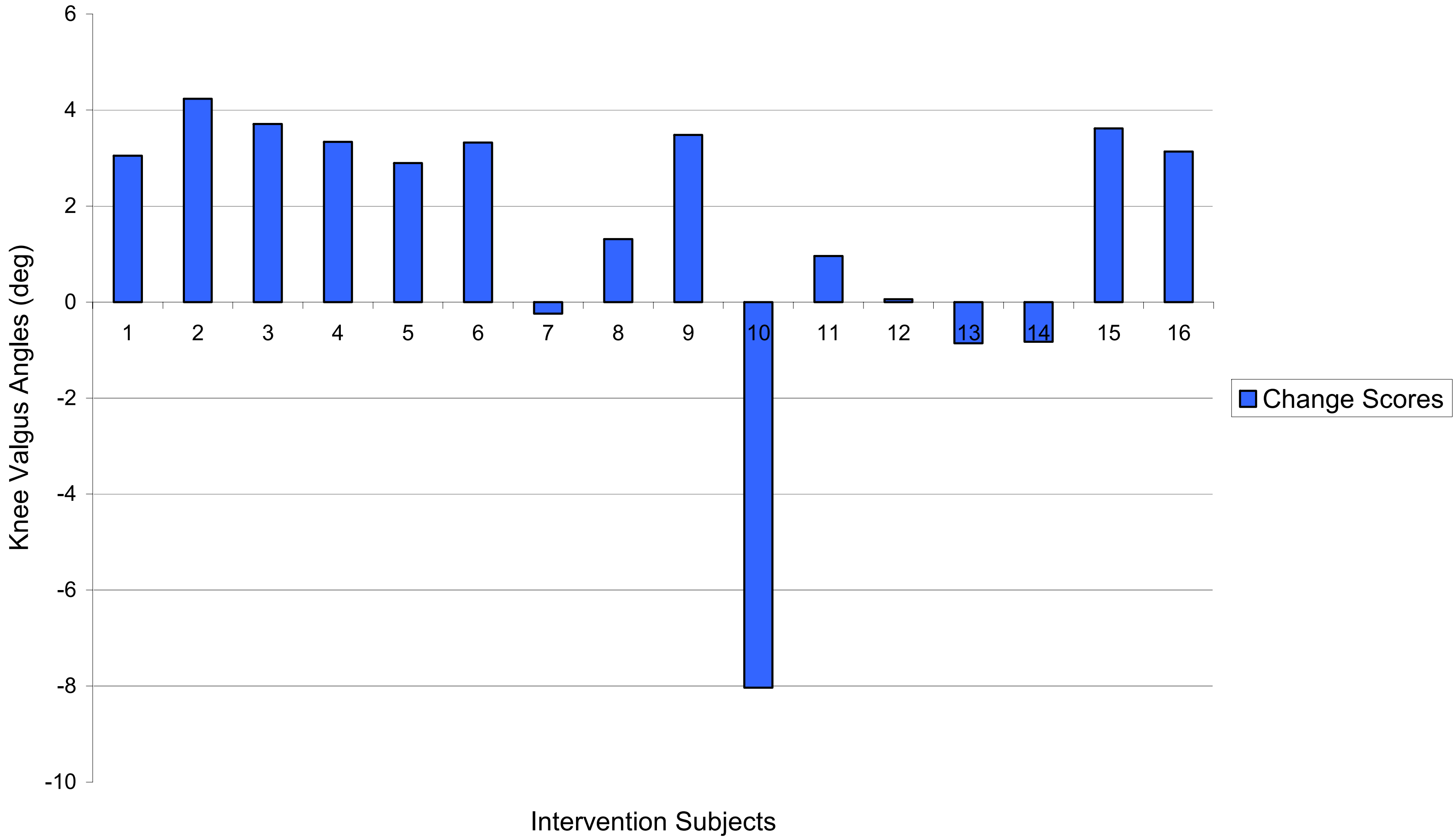


Figure 6: Change scores for knee valgus at initial contact,
graphed by subject for intervention group



APPENDIX A

University of North Carolina-Chapel Hill
Consent to Participate in a Research Study Screening
Adult Subjects
Biomedical Form

IRB Study #__06-0474___________
Consent Form Version Date: __11/13/06_______

Title of Study: The Effect of Augmented Feedback on Knee Valgus Angles and Muscle Activity During a Jump Landing Task

Principal Investigator: Michelle Bensman LAT, ATC
UNC-Chapel Hill Department: Exercise and Sport Science
UNC-Chapel Hill Phone number: (919) 962-0018
Email Address: bensman@email.unc.edu
Co-Investigators: Dr. Kevin Guskiewiecz, Lindsay Strickland, David Bell
Faculty Advisor: Dr. Darin Padua
Funding Source: none

Study Contact telephone number: (919) 962-7187
Study Contact email: bensman@email.unc.edu

<u>What are some general things you should know about research studies?</u>
You are being asked to take part in screening session for a research study. To join the study is voluntary. You may refuse to join, or you may withdraw your consent to be in the study, for any reason.

Research studies are designed to obtain new knowledge that may help other people in the future. You may not receive any direct benefit from being in the research study. There also may be risks to being in research studies.

Deciding not to be in the study or leaving the study before it is done will not affect your relationship with the researcher, your health care provider, or the University of North Carolina-Chapel Hill. If you are a patient with an illness, you do not have to be in the research study in order to receive health care.

Details about this study are discussed below. It is important that you understand this information so that you can make an informed choice about being in this research study. You will be given a copy of this consent form. You should ask the researchers named above, or staff members who may assist them, any questions you have about this study at any time.

What is the purpose of this study?
The primary purpose of this screening session is to identify individuals that display excessive knee valgus motion, or "knock knees" during a jump landing task.
You are being asked to be in the study because you are a healthy, recreationally active individual. You will be asked to continue in this study if you are identified as having excessive knee valgus during this initial screening process.

Are there any reasons you should not be in this study?
You should not be in this screening if you have had a lower extremity injury within the past six months that could impair your ability to perform jumping tasks. You should also not participate in this screening if you have a history of ACL injury or if you have ever participated in jump landing training or ACL injury prevention programs prior to this testing.

Women who are pregnant should not participate in this screening, as a fall from a height above floor level has the potential to cause harm to the fetus.

How many people will take part in this study?
If you decide to participate, you will be one of approximately one hundred people screened for this research study.

How long will your part in this study last?
This initial screening session will last approximately 15 minutes.

What will happen if you take part in the study?
If you choose to volunteer for this study, you will be asked to participate in this initial screening process. All subjects are asked to wear shorts, a t shirt and sneakers. During this session, you will be asked to perform a series of three jump landing tasks that will be demonstrated and explained for you. You will be jumping from a platform 30 cm off the ground onto a stable surface. You will then be instructed to jump immediately for maximum vertical height. You will be videotaped while you are completing these tasks. If you are identified as having knee valgus motion during your jump landing task, you will be asked to return for a second testing session. Subjects who do not display noticeable knee valgus will be excused from participation after this initial screening session.

What are the possible benefits from being in this study?
Research is designed to benefit society by gaining new knowledge. You may not benefit personally from participating in this screening.

What are the possible risks or discomforts involved with being in this study?
As with any physical activity, participation in this study carries a risk of bodily injury. The motions that you will be asked to perform are ones that repeatedly occur during physical activity. Therefore, you should be familiar and able to perform the tasks with minimal injury risk. To further minimize injury risk, you will be allowed to warm up and stretch to prepare for testing. In case of injury, medical personnel (certified athletic trainers) will be located in the same building as the testing session.

In addition, there may be uncommon or previously unknown risks that might occur. You should report any problems to the researchers.

What if we learn about new findings or information during the study?
You will be given any new information gained during the course of the study that might affect your willingness to continue your participation.

How will your privacy be protected?
No subjects will be identified in any report or publication about this study. Although every effort will be made to keep research records private, there may be times when federal or state law requires the disclosure of such records, including personal information. This is very unlikely, but if disclosure is ever required, UNC-Chapel Hill will take steps allowable by law to protect the privacy of personal information. In some cases, your information in this research study could be reviewed by representatives of the University, research sponsors, or government agencies for purposes such as quality control or safety.

As part of the initial screening process and the data collection and intervention session, each subject will be videotaped. The videos will not be identified by name, but by a subject number. The videotapes will be stored in a secure area, and will be kept for the duration of the data collection and analysis, after which they will be destroyed.

All paper documentation will be identified with a subject number as well. They will be kept in a secured location for the duration of the study and destroyed once they are no longer needed for research purposes.

Any data stored on a computer will be identified by a subject number and protected by a password which only the primary investigator and anyone else directly involved in data collection and reduction for this study will have access to.

What will happen if you are injured by this research?
All research involves a chance that something bad might happen to you. This may include the risk of personal injury. In spite of all safety measures, you might develop a reaction or injury from being in this study. If such problems occur, the researchers will help you get medical care, but any costs for the medical care will be billed to you and/or your insurance company. The University of North Carolina at Chapel Hill has not set aside funds to pay you for any such reactions or injuries, or for the related medical care. However, by signing this form, you do not give up any of your legal rights.

What if you want to stop before your part in the study is complete?
You can withdraw from this study at any time, without penalty. The investigators also have the right to stop your participation at any time. This could be because you have had an unexpected reaction, or have failed to follow instructions, or because the entire study has been stopped.

Will you receive anything for being in this study?
You will not receive any compensation for taking part in this study.

Will it cost you anything to be in this study?
It will not cost you anything to participate in this study. You are only responsible for your transportation to and from the testing site in Fetzer Gymnasium on the campus of the University of North Carolina at Chapel Hill.

What if you are a UNC student?

You may choose not to be in the study or to stop being in the study before it is over at any time. This will not affect your class standing or grades at UNC-Chapel Hill. You will not be offered or receive any special consideration if you take part in this research.

What if you are a UNC employee?
Taking part in this research is not a part of your University duties, and refusing will not affect your job. You will not be offered or receive any special job-related consideration if you take part in this research.

Who is sponsoring this study?
There is no sponsorship for this study.

What if you have questions about this study?
You have the right to ask, and have answered, any questions you may have about this research. If you have questions, or if a research-related injury occurs, you should contact the researchers listed on the first page of this form.

What if you have questions about your rights as a research subject?
All research on human volunteers is reviewed by a committee that works to protect your rights and welfare. If you have questions or concerns about your rights as a research subject you may contact, anonymously if you wish, the Institutional Review Board at 919-966-3113 or by email to IRB_subjects@unc.edu.

- -

Subject's Agreement:

I have read the information provided above. I have asked all the questions I have at this time. I voluntarily agree to participate in this research study.

_______________________________________ __________________
Signature of Research Subject Date

____
Printed Name of Research Subject

_______________________________________ __________________
Signature of Person Obtaining Consent Date

____
Printed Name of Person Obtaining Consent

APPENDIX B

University of North Carolina-Chapel Hill
Research Study Questionnaire
Adult Subjects

IRB Study # ___06-0474______

Title of Study: The Effect of Augmented Feedback on Knee Valgus Angles and Muscle Activity During a Jump Landing Task

Principal Investigator: Michelle Bensman LAT, ATC
UNC-Chapel Hill Department: Exercise and Sport Science
UNC-Chapel Hill Phone number: (919) 962-0018
Email Address: bensman@email.unc.edu
Co-Investigators: Dr. Kevin Guskiewiecz, Lindsay Strickland, David Bell
Faculty Advisor: Dr. Darin Padua
Funding Source: none

Study Contact telephone number: (919) 962-7187
Study Contact email: bensman@email.unc.edu

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1. Are you currently in general good health?
YES / NO

2. Are you suffering from any current symptoms of lower extremity injury?
YES / NO

3. How often do you exercise per week? _________ Days

4. Approximately how many minutes do you exercise each session? _______ Minutes

5. What type of exercise do you most often participate in? (walking, running, basketball, soccer)

____

6. Have you had an ACL injury or reconstructive surgery in either knee? If yes, please indicate which one. ____

7. Which leg would you kick a ball with for maximum distance? __________________

8. Have you ever participated in jump landing training or ACL prevention program?
YES / NO

APPENDIX C

Email to potential subjects

Subject:
Are you interested in participating in research aimed at preventing knee injuries?

Script:
You may be eligible to participate in a research study investigating anterior cruciate ligament (ACL) injury risk factors and strategies to prevent injury. This study is sponsored by the UNC Department of Exercise and Sport Science.

Volunteers for this study will be asked to participate in a short screening session involving a jump landing task during which you will be videotaped. This session will last approximately 15 minutes. If you meet the qualification criteria, you will be asked back to participate in a data collection session lasting approximately one hour. This session will consist of performing jump landings while EMG and joint motion data are recorded. This testing includes the placement of adhesive electrodes on the buttocks and halfway down the inner thigh.

Criteria for inclusion consists of having what the tester judges to be knee valgus (knock knees) alignment while performing a jump landing.

To volunteer, you must be a healthy, recreationally active individual between the ages of 18-25. People with current lower extremity injury or a history of ACL injury are not eligible to participate.

All interested individuals should contact the principal investigator, Michelle Bensman, at bensman@email.unc.edu

Flyer for potential subjects

Are you interested in contributing to research aimed at prevention of knee injuries?

You may be eligible to participate in a research study investigating anterior cruciate ligament (ACL) injury risk factors and strategies to prevent injury. This study is sponsored by the UNC Department of Exercise and Sport Science.

Volunteers for this study will be asked to participate in a short screening session involving a jump landing task during which you will be videotaped. This session will last approximately 15 minutes.

If you meet the qualification criteria, you will be asked back to participate in a data collection session lasting approximately one hour. This session will consist of performing jump landings while EMG and joint motion data are recorded. This testing includes the placement of adhesive electrodes on the buttocks and halfway down the inner thigh.

Criteria for inclusion consists of having what the tester judges to be knee valgus (knock knees) alignment while performing a jump landing.

To volunteer, you must be a healthy, recreationally active individual between the ages of 18-25. People with current lower extremity injury or a history of ACL injury are not eligible to participate.

To receive more information, contact:

Michelle Bensman, LAT, ATC
bensman@email.unc.edu

UNC Sports Medicine Research Lab
919-962-7187

APPENDIX D

University of North Carolina-Chapel Hill
Consent to Participate in a Research Study
Adult Subjects
Biomedical Form

IRB Study #____06-0474__________
Consent Form Version Date: __11/13/06_______

Title of Study: The Effect of Augmented Feedback on Knee Valgus Angles and Muscle Activity During a Jump Landing Task

Principal Investigator: Michelle Bensman LAT, ATC
UNC-Chapel Hill Department: Exercise and Sport Science
UNC-Chapel Hill Phone number: (919) 962-0018
Email Address: bensman@email.unc.edu
Co-Investigators: Dr. Kevin Guskiewiecz, Lindsay Strickland, David Bell
Faculty Advisor: Dr. Darin Padua
Funding Source: none

Study Contact telephone number: (919) 962-7187
Study Contact email: bensman@email.unc.edu

<u>What are some general things you should know about research studies?</u>
You are being asked to take part in a research study. To join the study is voluntary.
You may refuse to join, or you may withdraw your consent to be in the study, for any reason.

Research studies are designed to obtain new knowledge that may help other people in the future. You may not receive any direct benefit from being in the research study. There also may be risks to being in research studies.

Deciding not to be in the study or leaving the study before it is done will not affect your relationship with the researcher, your health care provider, or the University of North Carolina-Chapel Hill. If you are a patient with an illness, you do not have to be in the research study in order to receive health care.

Details about this study are discussed below. It is important that you understand this information so that you can make an informed choice about being in this research study. You will be given a copy of this consent form. You should ask the researchers named above, or staff members who may assist them, any questions you have about this study at any time.

What is the purpose of this study?

The primary purpose of this research study is to determine the influence of feedback given to an individual following a jumping task on knee motion and muscle activation. A secondary purpose of this study is to determine the relationship between muscle activation and knee valgus motion ("knock knee") during a jumping task

You are being asked to be in the study because you are a healthy, recreationally active individual who was identified as having excessive knee valgus during this study's initial screening process.

Are there any reasons you should not be in this study?

You should not be in this study if you have had a lower extremity injury within the past six months that could impair your ability to perform jumping tasks. You should also not participate in this study if you have a history of ACL injury or if you have ever participated in jump landing training or ACL injury prevention programs prior to this testing.

Women who are pregnant should not participate in this study, as a fall from a height above floor level has the potential to cause harm to the fetus.

How many people will take part in this study?

You will be one of approximately forty subjects displaying knee valgus that will be tested.

How long will your part in this study last?

You will be asked to report for a data collection session that will last approximately one hour.

What will happen if you take part in the study?

The data session consists of performance of two series of jump landing tasks. You are asked to wear clothing (t shirt and shorts) and running shoes appropriate for participating in physical activity. When you arrive at the laboratory, you will be asked to fill out a short questionnaire and your height and weight will be measured by the primary investigator. Band-aid like electrodes and sensors that will monitor muscle activity and joint motion will be attached over muscles in the buttocks, outer hip and inner thigh on your dominant leg (the leg used to kick a ball for maximum distance). Once the electrodes are in place, three five-second maximal voluntary contractions will be taken for each muscle we are monitoring. You will then be allowed to practice the jump landing task. You will be jumping from a platform 30 cm off the ground onto a stable surface. When you land, you will then be instructed to jump straight up for maximum vertical distance. When you feel comfortable with the task, you will be asked to perform a series of five jump landings with thirty seconds of rest between each jump. After the first series, you will be given a rest period of ten minutes in which you may be asked to watch a video and score your jumping technique. Whether or not you are part of the evaluation or rest group will be assigned by random selection, like flipping a coin. After that rest period, you will be asked to complete a second series of five jump landings. In order to be eligible for participation in the study, you must complete all portions listed here.

What are the possible benefits from being in this study?

Research is designed to benefit society by gaining new knowledge. You may not benefit personally from participating in this study. However, you will learn techniques for jumping that may help prevent you from sustaining an ACL injury in the future.

What are the possible risks or discomforts involved with being in this study?

As with any physical activity, participation in this study carries a risk of bodily injury. The motions that you will be asked to perform are ones that repeatedly occur during physical activity. Therefore, you should be familiar and able to perform the tasks with minimal injury risk. To further minimize injury risk, you will be allowed to warm up and stretch to prepare for testing. In case of injury, medical personnel (certified athletic trainers) will be located in the same building as the testing session. During the electrode and sensor placement, you will be properly draped with a towel to ensure privacy and minimize risk of embarrassment, and the electrodes will be applied by an investigator of the same sex. It is also possible that the application of the electrodes may cause minor skin irritation. You are free to cease participation at any time.

In addition, there may be uncommon or previously unknown risks that might occur. You should report any problems to the researchers.

What if we learn about new findings or information during the study?

You will be given any new information gained during the course of the study that might affect your willingness to continue your participation.

How will your privacy be protected?

No subjects will be identified in any report or publication about this study. Although every effort will be made to keep research records private, there may be times when federal or state law requires the disclosure of such records, including personal information. This is very unlikely, but if disclosure is ever required, UNC-Chapel Hill will take steps allowable by law to protect the privacy of personal information. In some cases, your information in this research study could be reviewed by representatives of the University, research sponsors, or government agencies for purposes such as quality control or safety.

As part of the initial screening process and the data collection and intervention session, each subject will be videotaped. The videos will not be identified by name, but by a subject number. The videotapes will be stored in a secure area, and will be kept for the duration of the data collection and analysis, after which they will be destroyed.

All paper documentation will be identified with a subject number as well. They will be kept in a secured location for the duration of the study and destroyed once they are no longer needed for research purposes.

Any data stored on a computer will be identified by a subject number and protected by a password which only the primary investigator and anyone else directly involved in data collection and reduction for this study will have access to.

What will happen if you are injured by this research?

All research involves a chance that something bad might happen to you. This may include the risk of personal injury. In spite of all safety measures, you might develop a reaction or injury from being in this study. If such problems occur, the researchers will help you get medical care, but any costs for the medical care will be billed to you and/or your insurance company. The University of North Carolina at Chapel Hill has not set aside funds to pay you for any such reactions or injuries, or for the related medical care. However, by signing this form, you do not give up any of your legal rights.

What if you want to stop before your part in the study is complete?

You can withdraw from this study at any time, without penalty. The investigators also have the right to stop your participation at any time. This could be because you have had an unexpected reaction, or have failed to follow instructions, or because the entire study has been stopped.

Will you receive anything for being in this study?

You will not receive any compensation for taking part in this study.

Will it cost you anything to be in this study?

It will not cost you anything to participate in this study. You are only responsible for your transportation to and from the testing site in Fetzer Gymnasium on the campus of the University of North Carolina at Chapel Hill.

What if you are a UNC student?

You may choose not to be in the study or to stop being in the study before it is over at any time. This will not affect your class standing or grades at UNC-Chapel Hill. You will not be offered or receive any special consideration if you take part in this research.

What if you are a UNC employee?

Taking part in this research is not a part of your University duties, and refusing will not affect your job. You will not be offered or receive any special job-related consideration if you take part in this research.

Who is sponsoring this study?

There is no sponsorship for this study.

What if you have questions about this study?

You have the right to ask, and have answered, any questions you may have about this research. If you have questions, or if a research-related injury occurs, you should contact the researchers listed on the first page of this form

What if you have questions about your rights as a research subject?

All research on human volunteers is reviewed by a committee that works to protect your rights and welfare. If you have questions or concerns about your rights as a research subject you may contact, anonymously if you wish, the Institutional Review Board at 919-966-3113 or by email to IRB_subjects@unc.edu.

- -

Subject's Agreement:

I have read the information provided above. I have asked all the questions I have at this time. I voluntarily agree to participate in this research study.

_______________________________________ ________________

Signature of Research Subject Date

____

Printed Name of Research Subject

_______________________________________ ________________

Signature of Person Obtaining Consent Date

____

Printed Name of Person Obtaining Consent

Data Collection Sheet

Subject ID: ______________________________________ Date: ______________

Height: ______________ cm Age: ____________ yrs Gender: ____________

Weight: ____________________ kg Leg Dominance: _______________________

Subject will perform a 5 minute stationary bicycle warm-up. Intensity set at an RPE between 11 and 15 on the Borg Scale.

EMG Set-up ____________ -With MMT to ensure placement over muscle belly

Gluteus Medius- Measure from iliac crest to greater trochanter and take midpoint.
Gluteus Maximus- Place a dot 10cm distal to greater trochanter. Palpate the S2 spinous process and measure the distance from S2 to that dot; multiply it by .2
Hip Adductors- Measure greater trochanter to lateral epicondyle. Take half the distance and move it over to the medial side over the muscle belly.

Flock Set-up ____________

RMS Error: ________________

Testing CONTROL or INTERVENTION

# of Practice Trials Performed: ________________

Collect static trial

Trial#	Pre-Test		Post-Test	
	Successful	Problem if not	Successful	Problem if not
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

****Recalibrate force plate after 5 trials**

APPENDIX F

Landing Scoring Sheet

Expert Model (Front view)

Knee stays over center of foot	YES _____	NO _____
Knee falls inside of big toe	YES _____	NO _____
Toes pointing straight forward	YES _____	NO _____

Expert Model (Side view)

Knee bends more than 45°	YES _____	NO _____

Self Model (Front view)

Knee stays over center of foot	YES _____	NO _____
Knee falls inside of big toe	YES _____	NO _____
Toes pointing straight forward	YES _____	NO _____

Self Model (Side view)

Knee bends further than 45°	YES _____	NO _____

APPENDIX G

Effect of Augmented Feedback on Knee Valgus and Muscle Activity

The anterior cruciate ligament (ACL) is a strong static supporter of the tibiofemoral joint and is the most often injured ligament in the knee. [1] Some studies report 200,000 new ACL injuries occurring in the United States each year [2], while others offer a more conservative number of approximately 80,000. [3] Approximately 30% of estimated injuries every year result from direct contact with another player or object, while the other 70% are non-contact in nature. [2-4] Research also supports the idea that ACL injuries occur at a higher rate in women as compared to men. Women experience ACL injuries at a rate two to eight times greater than males who participate in the same sporting activities. [2] These injuries can result in debilitating and long-term consequences such as decreased levels of physical activity, knee joint degeneration, eventual joint replacement surgery, and costly repair and rehabilitation. [5, 6]

Previous studies have explored a large list of potential extrinsic and intrinsic risk factors. Among those is the position of knee, which is thought to be a large contributor to the mechanism of ACL injury. [2-4, 6-14] Knee valgus can be measured in both static and dynamic positions, and is defined as the measured angle in the frontal plane between the tibia and femur due to rotation of the tibia on the femur about the anterior-posterior axis of the tibia. [19] Knee valgus presents as a "knock-kneed" position in which the knees appear to fall in toward each other and can be assessed visually by observing the midline of the patella move medial past the great toe of the ipsilateral limb. Intrinsic factors, such as increased Q-angle, excessive femoral anteversion, tibial torsion, and foot pronation, can contribute to an increase in a knee valgus position. Knee valgus can also be influenced by muscular forces acting on the knee. [3, 6]

The role of lower extremity muscle activation is also important in injury prevention. Differences in magnitude and timing of muscle activation may affect a person's risk of ACL injury. Up to this point, much of the research in this area has focused on quadricep and hamstring activation patterns. The role of the gluteal muscles and hip adductor complex have been of recent interest, but there is little research in this area to date. The gluteus medius muscle acts primarily to abduct the hip, but also works as a hip medial rotator in a hip flexion position. [1, 19] When the gluteus medius is weak or inactive, the hip tends to adduct in a loaded position allowing for femoral internal rotation, and subsequent valgus position at the knee. [3] The gluteus maximus muscle's primary action is hip extension, but it also functions to abduct and laterally rotate the hip. [1, 19] A weak or inactive gluteus maximus can result in hip adduction and cause a greater valgus moment in the knee. To date, there has been minimal research that focuses on the role of the gluteus maximus in regards to ACL prevention. The hip adductor complex has not been a large focus of ACL injury research as well. However, hip adduction results in femoral internal rotation, which in turn forces the knee into a more valgus position. [14] There is a clear theoretical association between these two events.

Early detection of these potential risk factors and employment of correctional strategies are essential in the role of ACL injury prevention. Teaching of avoidance strategies, technique training, lower extremity strengthening, and improving neuromuscular control are methods that have shown some success reducing ACL injuries or ACL injury risk factors. [3, 9, 24, 48] All of these programs utilize some method of augmented feedback, which is defined as the process of providing extrinsic supplemental information to an individual above and beyond the inherent information that is naturally available to them.[16] In the case of ACL injury prevention, this is information provided regarding their movement and technique, usually in a biomechanical sense. This type of feedback gives an individual supplemental information from an outside source in addition to the intrinsic and instinctive information that is usually available to them during performance of a skill. [16] Different forms of augmented feedback include auditory cues, visual feedback in the form of expert model and self-model video demonstrations, and verbal instruction. Past studies have shown the most success using combinations of verbal instruction and expert and self-model videos. [16, 17, 52] The process of providing feedback to aid in learning motor skills, improving performance and decreasing potential risk factors for injury has been investigated in recent years. Most of the success with augmented feedback has focused on decreasing ground reaction forces during jump landing tasks. [17, 49-51] Similar types of feedback may positively influence kinematic alterations in the same tasks.

The purpose of this study was to determine the effects of augmented feedback on knee valgus position and muscle activity amplitude of the gluteus medius, gluteus maximus, and hip adductor complex during a jump landing task, and to determine if a correlation exists between these two variables. The first hypothesis was that augmented feedback will decrease knee valgus angles during the jump landing, as well as increase muscle activity amplitude of the gluteus medius and gluteus maximus, and decrease muscle activity amplitude of the hip adductor complex. The second hypothesis was that there will be a correlation between changes in knee valgus angles and muscle activity during the jump landing task.

METHODS

Subjects

Thirty-one recreationally active females (age 18-22) participated in this study. Subjects were eligible for participation if they were identified as having knee valgus present in their dominant leg during an initial screening process. Subjects were required to be recreationally active, participating in physical activity for at least twenty minutes, three to four times per week. [16] Exclusion criteria included any known lower extremity injury within six months prior to testing that affected their ability to perform the study tasks. An injury was defined as any traumatic event or presence of injury symptoms that restricted activity for more than three days. [53] Subjects were also not permitted to participate in the study if they had a history of an ACL injury or reconstruction in their dominant leg, or if they had ever participated in jump landing training or an ACL prevention program. Prior to the start of testing, all subjects read and signed an informed consent form approved by the Institutional Review Board of the School of Medicine at the University of North Carolina at Chapel Hill.

Procedures

Potential subjects reported to a sports medicine research laboratory during a general screening session to be evaluated for a knee valgus position. Subjects were videotaped while performing three trials of a jump landing task. The video trials were analyzed for knee valgus. If the midline of the subject's patella moved medial to the great toe during the stance phase of the jump landing, they were classified as having knee valgus. Eligible subjects that presented with knee valgus were contacted for participation in the study. In total, fifty-nine people were screened in order to identify the full testing population.

Subjects who were identified as having knee valgus reported again to the laboratory for a single testing session that lasted approximately one hour. All subjects were dressed in clothing appropriate for physical activity (t shirt and shorts) and their personal running shoes. Subjects completed a questionnaire to ensure compliance with the inclusion criteria. Subjects were weighed on a digital scale, and investigators collected information regarding age, height, and leg dominance. Subjects were randomly assigned to the control or intervention group. Both groups performed two sets of five jump landing trials during the testing session. Prior to testing, the subjects completed a five minute warm-up on a stationary bicycle at a self-selected moderate intensity, which they were told to judge using the Rating of Perceived Exertion (RPE) scale.

Electromagnetic tracking sensors for the Flock of Birds electromagnetic motion analysis system were placed on each subject over the spinous process of C7, apex of the sacrum, midpoint of the lateral thigh, and shank of the tibia. Sensors of the thigh and tibia were placed on the dominant leg in areas consisting of the least amount of muscle mass to minimize potential artifact induced by muscle contraction. The sensors were affixed to the body using double-sided tape, prewrap and athletic tape. Once the electromagnetic sensors were attached, the subjects were asked to stand in a neutral posture with their arms relaxed at their sides. The following bony landmarks were digitized, in the following order, using a mobile electromagnetic sensor attached to a stylus: spinous process of T12, xiphoid process, medial femoral condyle, lateral femoral condyle, medial malleolus, lateral malleolus, left anterior superior iliac spine, and right anterior superior iliac spine. Digitization of bony landmarks served to define the segment end-points and joint centers of the lower extremity segments. The ankle joint center is located at the midpoint between the medial and lateral malleoli. Knee joint center is located at the midpoint between the medial and lateral femoral condyles. The hip joint center was determined by the Bell method. [55] This method consists of estimating the hip joint center using the left and right anterior superior iliac spine as landmarks to mathematically estimate the hip joint center.

A non-telemetered, surface EMG (Delsys Bagnoli-8, Boston, MA) was used to monitor muscle activity amplitude. Single bar adhesive Ag/AgCl surface EMG electrodes (Delsys Inc., Boston, MA) were placed over the midsection of the muscle belly for each muscle. The placement for the gluteus medius muscle was found by measuring from the subject's iliac crest to the greater trochanter of the same leg, and taking the midpoint of this distance. [56] The gluteus maximus electrode placement was found by marking a distance ten centimeters distal to the greater trochanter of the femur, and then palpating the S2 spinous process. The distance from S2 to the mark below the greater trochanter was measured and the electrode was affixed at a point 20% of the distance from S2. [57] The hip adductor electrode was placed over the medial aspect of the mid-thigh. The electrode location was found by measuring the distance from the greater trochanter to the lateral epicondyle, finding the midpoint, then moving that point directly medial. [57] For all of these placements, a manual muscle test was performed to ensure placement over the muscle belly. A single reference electrode was placed over the tibial tuberosity. To reduce impedance to the EMG signal and allow for proper electrode fixation, electrode sites were prepared by shaving any hair from the immediate vicinity of the muscle belly, lightly abrading the skin with an abrasive pad, and cleansing the skin with isopropyl alcohol. To prevent movement of the electrodes and subsequent alteration of the EMG signal, electrodes were secured to the site using prewrap and athletic tape.

Once all sensors were attached, the subject was instructed to stand relaxed with their arms at their side allowing the computer to calibrate the subject's neutral position. The jump landing task was explained to the subject and they were given practice trials until they felt comfortable, with a maximum of three allowed. On average, subjects performed one practice trial.

Each jump landing task was performed from a 30-cm high box. The box was set at a horizontal distance equal to 50% of the subject's body height from the front edge of the force-plate. Each subject was instructed to jump straight forward off the box and land with the foot of the dominant leg on the force-plate and the foot of the non-dominant leg off of the force-plate. Immediately after landing, the subjects were instructed to perform a vertical jump for maximum height, and then return to the landing position.

The subject performed the first set of jump landing trials, which served as the pre-test measurements. Each subject performed five trials of the jump landing, with 30 seconds of rest in between each trial to minimize the risk of fatigue. Trials with incorrect landings or errors in data collection were considered invalid and a new trial was performed.

Once the first five trials were recorded, each subject completed an intervention period. Subjects in the control group rested for a period of ten minutes while subjects in the intervention group received augmented feedback regarding their jump landing technique. After the ten minute intervention period, each subject performed five more trials of the jump landing for post-test data collection. The same testing conditions applied here as in the pre-test trials.

Augmented Feedback Protocol

All subjects in the intervention group were first presented with a modified Landing Error Scoring Sheet (LESS). This form gave them standardized guidelines with which to evaluate the performance. The four grading criteria for the jump were explained to the subject prior to viewing any video so that they were clear on what characteristics of the jump they should be observing. Subjects first viewed a video of an expert model performing a jump landing task and were asked to score the model's technique using the modified LESS. Following this viewing, the subjects watched a video of themselves performing the jump landing task and scored this video using the same guidelines as for the expert video. Each of the two videos contained a front and side view of the jump landing, and were played for the subject twice, once in real time and once in slow motion. [16] Each subject was given standardized verbal cues directly related to their performance after the video viewing process. These cues served to reinforce the criteria listed in the LESS by giving subjects a visual image of the technique they were trying to achieve.

After the ten minute intervention period, each subject performed five more trials of the jump landing for post-test data collection. The same testing conditions applied here as in the pre-test trials.

Manual muscle tests for the three muscle groups were performed after the jump landing protocol and consisted of three five-second maximal voluntary contractions against a manual resistance. These trials were used to normalize muscle activity. Muscle activity collected during the jump landing tasks was normalized to the average activity amplitude calculated during the maximal voluntary contractions.

Instrumentation

2-D Videography

Two-dimensional video analysis was used in the initial screening process. Subjects were recorded executing a set of three jump landings. The analysis was performed in the frontal and sagittal plane. Video playback allowed for identification of knee valgus present in each subject's activity pattern. Each video trial was analyzed by the primary investigator.

Electromagnetic Tracking System

Lower extremity kinematics were collected using the Flock of Birds electromagnetic motion analysis system (Ascension Technologies, Inc., Burlington, VT) at a sampling rate of 144 Hz.. The measurements were recorded by the Motion Monitor software system (Innovative Sports Training, Inc., Chicago, IL). The electromagnetic tracking system was calibrated prior to data collection. A standard transmitter was affixed to a stationary stand, .914 meters in height, to establish the global reference system. An embedded right-hand Cartesian coordinate system was defined for the shank, thigh, hip, and trunk to describe the three-dimensional position and orientation of these segments. Euler angles were used to calculate the knee joint angle between the shank and thigh and the hip joint angle between the thigh and pelvis in an order of rotations of (1) flexion-extension about the Y-axis, (2) valgus-varus (knee) about the X-axis, and (3) internal and external rotation about the Z-axis. Kinematic data were filtered using a 4^{th} order zero phase lag Butterworth low-pass filter at 14.5 Hz. [54]

Electromyography

An electromyographic system (EMG) was used to measure muscle activity amplitude of the gluteus maximus, gluteus medius, and the hip adductor complex. The system was non-telemetered and utilized surface EMG (Delsys Bagnoli-8, Boston, MA) and the measurements were collected by the Motion Monitor software system (Innovative Sports Training, Inc., Chicago, IL). Data were collected with a gain of 1000 and used a sampling rate of 1440 Hz. EMG data were collected immediately prior to and throughout the jump landing task.

Force Plate

A nonconductive force plate (Bertec Corporation, Columbus, OH) was used to record ground reaction forces during the jump landing to define the phases of the task. A sampling rate of 1440 Hz was used to collect data. Initial contact was defined as the point at which the ground reaction forces exceed 5N, and toe-off was defined as the point at which ground reaction forces drop below 5N.

Data Reduction

Following data collection, kinematic and electromyographical data were reduced. Specific EMG data points were pulled off during the pre-activity phase and during the landing phase of the jump landing task. We determined muscle activity amplitude of the gluteus maximus, gluteus medius, and hip adductor complex during the pre-activation phase and during the landing phase, as well as knee valgus angles at initial contact, peak knee valgus angles during the landing phase, and peak knee valgus angles during the entire jump landing from pre-activation to toe-off. Although not initially variables of interest, and not a focus of the research questions, peak knee flexion angles during the landing phase and peak knee flexion during the entire jump landing task from pre-activation to toe-off were also determined. Pre-activation was defined as 100 ms preceding initial contact. [58] The landing phase was defined from initial contact to toe-off. All processing was performed through customized software in Matlab 7.0 (The Mathworks, Inc., Natick, MA).

Raw data were converted to the aligned anatomical coordinate axes. The three dimensional global and local coordinate systems were defined as follows: the positive x-axis was the direction the subject faced, the positive y-axis was to the right of the subject, and the positive z-axis pointed upward. In order to describe joint motions in clinically relevant terms, joint motions were determined through a joint coordinate system. This system was recommended by the International Society of Biomechanics and proposed by Grood and Suntay (1983). [59] Analysis of the kinematic data, independent of the order the rotations were entered into the matrix calculations, was possible due to the use of the joint coordinate system. Sagittal plane motions occurred about the y-axis and frontal plane motions occurred about the x-axis. The Motion Monitor software processed the raw sensor data and a Butterworth low pass digital filter (4^{th} order, zero phase lag) smoothed the data at an estimated cutoff frequency of 14.5 Hz. [54]

Statistical Analysis

A mixed model repeated measures 2x2 ANOVA was run for each variable examined: knee valgus, gluteus maximus activity, gluteus medius activity, and hip adductor complex activity. Two grouping factors, control versus intervention and pre-test versus post-test were used. A correlational analysis was used to determine a relationship between knee valgus angles and muscle activity amplitude of the aforementioned muscles for a within- and between-subjects analysis. All analyses were performed using SPSS 13.0 statistical software (SPSS Inc., Chicago, IL). An alpha level was set a priori at 0.05.

RESULTS

Thirty-one female subjects (age = 20.3 ± 1.3 years, height = 166.5 ± 7.4 centimeters, weight = 66.6 ± 12.4 kilograms) were tested. However, the kinematic data for one subject was not included for the analysis due to a placement error of one of the sensors which led to inaccurate data collection. Subject demographics are also presented in Table 1.

Kinematic Data

Means, standard deviations, p values, and effect size are presented for knee valgus angles at initial contact, peak knee valgus angles, and peak knee valgus during the landing phase of the jump landing in Table 2. One subject's data for knee valgus at initial contact and at peak knee valgus was not used due to unnaturally large change scores for this variable, which caused researchers to think that there may have been an underlying data collection issue with this subject (Intervention Subject 10).

There was a significant difference, therefore a significant interaction effect, in knee valgus angles at initial contact ($F = 13.479$, $p = 0.001$, $\eta_p^2 = 0.333$) (Figure 1). The intervention group displayed a decrease in knee valgus angles from pre-test to post-test, meaning they were moving toward more varus angles at initial contact.

There were no significant interaction or main effects for peak knee valgus or peak knee valgus during the landing phase between groups or testing conditions.

There was a significant group x test interaction effect ($F = 6.024$, $p = 0.021$, $\eta_p^2 = 0.177$) for peak knee flexion angles during the landing phase (Figure 2). The intervention group demonstrated an increase in knee flexion after the intervention protocol. There was also a significant test main effect ($F = 7.505$, $p = 0.011$, $\eta_p^2 = 0.211$) for knee flexion angles at initial contact. Regardless of group, subjects displayed less knee flexion at the point of initial contact in post test trials. These values are presented in Table 3.

Electromyographical Data

Means, standard deviations, p values, and effect size for muscle activity during the pre-activation phase of the jump landing are shown for the gluteus medius, gluteus maximus, and the hip adductors in Table 4. There were no significant differences found for any of the muscles' activity amplitudes during the pre-activation phase. Means, standard deviations, p values, and effect size for muscle activity during the landing phase for the same three muscles are shown in Table 5. Significant differences were found in muscle activity amplitude during the landing phase of the jump in some of the muscles measured. A group x test interaction effect ($F = 4.342$, $p = 0.046$, $\eta_p^2 = 0.130$) was found for the gluteus medius (Figure 3). The intervention group showed a significant decrease in gluteus medius activity from the pre-test to post-test conditions. A group x test interaction effect ($F = 9.702$, $p = 0.004$, $\eta_p^2 = 0.251$) was also found for the gluteus maximus muscle activity during the landing phase (Figure 4). There was a significant decrease in muscle activity from pre- to post-test conditions in the intervention group. Although there were no significant findings in muscle activity amplitude for the hip adductor muscle group, the average muscle activity amplitude values of the intervention subjects followed the same trend of decreasing from pre-test to post-test as was shown in the gluteal muscles.

Correlational Analyses

Pearson correlation coefficients and p-values for change scores of the gluteus maximus, gluteus medius, and hip adductor complex muscle activity amplitude during the pre-activation phase correlated with change scores of knee valgus angles at initial contact are presented in Table 6. There were no significant correlations for any of the muscles to knee valgus angles at initial contact.

Pearson correlation coefficients and p-values for the gluteus maximus, gluteus medius, and hip adductor complex muscle activity amplitude during the landing phase correlated with peak knee valgus angles during the landing phase are presented in Table 7. There was a significant correlation between change scores for gluteus medius activity amplitude during the landing phase and peak knee valgus angles during the landing phase ($r = -0.442$, $p = 0.014$) (Figure 5). There were no significant correlations between change scores for gluteus maximus or hip adductor complex activity amplitude and peak knee valgus angles during the landing phase.

DISCUSSION

Knee Valgus Findings

The most important finding of our study was the effect of an augmented feedback protocol on knee valgus angles during a jumping task. There was a significant finding observed for the variable of knee valgus at initial contact, but no significant differences observed at peak or peak during the landing phase. This correlates with our original hypotheses that there would be significant changes in knee valgus angles after an intervention protocol, although we expected to see differences in knee valgus measured at various angles during the jump, as opposed to just at initial contact. Other studies [16, 17, 49-51] have also shown success in using similar feedback protocols to manipulate variables such as EMG activity and ground reaction forces, although most of them implemented more in depth protocols. This study utilized a similar combination of self-model and expert-model video demonstration, which has been found to be successful in reducing ground reaction forces. [16] The most notable study in this area is the Onate study which dealt primarily with ground reaction forces. Those researchers utilized a similar intervention protocol, but with a much more extensive project, as far as the time which the subjects spent undergoing the intervention and practicing techniques. They also branched into retention aspects of augmented feedback, having the subjects return for multiple testing sessions after the initial intervention, which this study did not set out to do. This study, while not claiming to be as intensive or involved as previous studies such at that, still did illicit some significant changes in the variable of knee valgus with a relatively short and basic augmented feedback protocol. It would be interesting to see the results that could be found if this same protocol was extended to a more in-depth training study or a retention study of the same nature as those previously performed.

While significant results were found in the variable of knee valgus at initial contact, there were no significant findings in changes of knee valgus during the landing phase. This did not support our original hypotheses for peak knee valgus angles and peak knee valgus during the landing phase. One possible influence on this is the large standard deviations that were recorded for the post-test trials. The standard deviations for peak knee valgus angles in both the control and intervention groups were large for the pre-test trials (6.161 and 5.531 degrees, respectively), but in the post test trials, the standard deviation for the intervention group was even larger (7.814 degrees). This large value to begin with, and increase in value for post-test trials may be influencing the chance to see significant results.

Another possible influence on the results is the degree to which each subject went into knee valgus to begin with. Based on the previously set inclusion criteria for this study, excessive knee valgus was simply defined as the movement of the midline of the patella medial to the great toe during the jump landing task. During the initial screening process, this criteria was visually determined by the researchers through viewing videotaped performances of jump landings. Initially, the subjects were easily identifiable with excessive knee valgus, which could be defined as a very obvious, exaggerated medial motion of the patella past the great toe. As the screening process progressed, subjects still displayed knee valgus but anecdotally appeared to land with less knee valgus compared with the initial subjects. It is possible that those who did not have as severe knee valgus to begin with were not influenced as significantly as those that did. Change scores for knee valgus angles at initial contact are graphed in Figure 6. Eight of the first nine intervention subjects had changes in the positive direction from pre- to post-test measures, meaning that knee valgus decreased after the intervention protocol. The last seven subjects did not follow the same trend. This observation supports the idea that a positive change was seen in the subjects who presented with more knee valgus during the screening process. Future research may look into classifying varying degrees of knee valgus, such as mild, moderate, or severe based on how far medial to the great toe the midline of the patella moves.

Knee Flexion Findings

Although this was not originally a variable of interest, data for knee flexion angles at initial contact, peak knee flexion angles during the jump landing task, and peak knee flexion angles during the landing phase of the jump were collected and analyzed for possible future research. Individuals in the intervention group displayed significant increases in peak knee flexion during the landing phase after undergoing the intervention protocol. Interestingly, regardless of group, subjects landed with less knee flexion at the exact point of initial contact in the post-test trials. The position of knee flexion to at least 45 degrees during the jump landing task was one variable that the subject graded using the modified LESS form while watching the expert model and self-model videos. Subjects were also given verbal cues to remember that knee flexion during the landing was important in order to "cushion" the landing and lessen the force with which they hit the ground. They were also told that they should try to bend their knees as they were landing, as opposed to after they had already hit the ground. Knee flexion angles lower than 45 degrees in other studies have been related to increased injury rates and ACL strain, due mainly to increased anterior shear, decreased co-contraction of quadriceps and hamstrings, and decreased compression of the joint space.[12, 18, 60] The intervention protocol in this study was successful with increasing the knee flexion angle during the jump landing task, which in theory will help to protect the ACL from injury.

EMG Findings

The original hypotheses stated that there would be an increase in gluteus medius and gluteus maximus activity, and a decrease in hip adductor activity during both the pre-activation and the landing phases of the jump landing task. There were no significant differences found for any of the three muscles tested during the pre-activation phase. This leads to the conclusion that these hip muscles do not seem to play a significant role in preparing the lower extremity position for landing.

There were significant findings for EMG activity during the landing phase of the jump for the gluteus medius and gluteus maximus. The intervention subjects showed a significant decrease in muscle activity amplitude for the gluteus medius and the gluteus maximus in the post-test trials. These two hip external rotators are thought to be helpful in countering hip internal rotation and adduction, which is a proposed contributor to knee valgus. The expectation was that these muscles would show an increase in muscle activity amplitude after the intervention protocol, because they would be functioning to control hip rotation and put the subject in a theoretically better body position for landing. One possible explanation to this contrary result is that if the subject were in less of a knee valgus position, and therefore a more externally rotated position, after the intervention protocol, the gluteus medius and gluteus maximus muscles may not have to be as active to control the position. The muscles may work more efficiently when the body is in a more mechanically advantageous position.

Another possible influence on this finding is the fact that there were significant increases in knee flexion seen in the intervention subjects from pre- to post-testing. The gluteus medius and gluteus maximus also function as hip extensors, which means that they are more active in a more extended hip position. When the subjects begin to land in a more knee flexed position, it stands to reason that they are also experiencing more hip flexion. This more flexed hip position may take away some of the effect of the gluteal muscles, because they are not as active in that position.

One other observation that was made during the post-test trials is that after the intervention protocol, many of the subjects widened their stance upon landing. This seemed to be an unconscious compensation mechanism in order to keep their knees from "falling together" into the position of knee valgus, as was described to them during the intervention. Although instruction was given to keep their feet approximately shoulder width apart, as they had done in the pre-test trials, many continued to land with a widened stance. This may have also influenced the muscle activity amplitude of the gluteus medius and gluteus maximus, as an increased stance width would decrease the ability of those muscles to act as hip abductors.

Correlational Findings

We did not observe a correlation between pre-activation phase muscle activity amplitude and knee valgus angles at initial contact. This supports the previously stated finding in this research that the gluteus medius, gluteus maximus, and hip adductor complex do not play a significant role in altering lower extremity position at initial contact during the jump landing task.

Correlations conducted on change scores of muscle activity amplitude and peak knee valgus angles during the landing phase showed a significant positive correlation of gluteus medius activity amplitude and peak knee valgus angles during the landing phase. As gluteus medius activity decreased, so did peak knee valgus angles. Although not what was originally hypothesized, this correlation fits with the earlier findings of this study.

Limitations

One limitation to this study was the effect size and power of some of the variables measured. For the non-significant kinematic and electromyographical variables, the partial Eta squared (η_p^2) values and the observed power values all very small. Additionally, observed power and effect size for the gluteus medius muscle activity amplitude during the landing phase were low, even though those statistics run did produce significant results. This lends to the idea that even if the researcher had tested a much larger population under the same conditions, significant effects would not have been found. The variables in question may be too minute to measure accurately during this task.

Another limitation is that these findings cannot be generalized across population boundaries. The researchers in this study chose to test recreationally active, young adult females. Since no male subjects were tested, these results cannot be generalized across gender. Past research has shown that males move differently during sport-specific and activity-specific tasks such as jump landings or cutting maneuvers.[2, 61, 62] It is also possible that males and females learn and respond to instruction differently, so the same intervention techniques may not have the same effect on males.

Additionally, the activity requirement specified only the time and frequency that the subject must participate in, with no specific sport activity criteria. Therefore, these results cannot be generalized to any specific sport mechanism. It is possible that people with more experience in a jumping task may have responded differently to the intervention protocol.

Along those same lines, these results should not be generalized to varsity or elite level athletes. Anyone who competes at that level has undergone many years of coaching instruction. It is very likely that they would respond differently to technique instruction, such as the intervention protocol, than someone who does not play organized sports or has not had the same exposure to technical instruction.

Future Research

When speaking in terms of injury prevention and technique instruction, retention of the feedback is always important to address. This study did not test for any kind of long-term retention. Future research should point in the direction of using similar feedback protocols as a training tool in repeated technique modification sessions, as well as testing for retention of the technique modification over an extended period of time.

Another area in which this research can be expanded is the types of activities that it is used in. Most of the research up to this point has focused on some kind of jumping technique. The kinematic and electromyographic variables important to injury prediction and prevention can be tested in a number of other ways. Future studies should look to implement the use of augmented feedback training protocols in a squatting task, cutting and pivoting tasks, and in tasks with unanticipated movements.

Conclusion

This current study examined the variables of knee valgus and muscle activity amplitude of the gluteus medius, gluteus maximus, and hip adductor complex in a jump landing task with an augmented feedback intervention. Based on the results of this study, we conclude the following:

1. Knee valgus angles were not significantly influenced by the intervention protocol. A larger sample size or a more potent intervention may be needed in order to evoke

significant changes in this variable. Additionally, this intervention may be more effective on people with more extreme presentation of knee valgus.

2. The use of a combination of expert and self-model video instruction and verbal cues were effective in significantly increasing knee flexion angles during landing from a jump task.
3. The gluteus medius, gluteus maximus, and hip adductor muscle complex do not appear to play a significant role during the pre-activation phase of a jump landing task. Additionally, there is no correlation between the pre-activity of these muscles and the position of knee valgus at initial contact.
4. The gluteus medius and gluteus maximus muscles showed a decrease in muscle activity after an intervention protocol. One hypothesis for this is increased muscular efficiency due to a better biomechanical position of the body during landing.

REFERENCES

1. Arnheim D, Prentice W. *Principles of Athletic Training, Tenth Edition*. Boston: McGraw-Hill; 2000.

2. Arendt E, Dick R. Knee injury patterns among men and women in collegiate basketball and soccer. NCAA data and review of literature. *Am J Sports Med.* Nov-Dec 1995;23(6):694-701.

3. Griffin LY, Agel J, Albohm MJ, et al. Noncontact anterior cruciate ligament injuries: risk factors and prevention strategies. *J Am Acad Orthop Surg.* May-Jun 2000;8(3):141-150.

4. Agel J, Arendt EA, Bershadsky B. Anterior cruciate ligament injury in national collegiate athletic association basketball and soccer: a 13-year review. *Am J Sports Med.* Apr 2005;33(4):524-530.

5. Frank CB, Jackson DW. The science of reconstruction of the anterior cruciate ligament. *J Bone Joint Surg Am.* Oct 1997;79(10):1556-1576.

6. Hewett TE, Myer GD, Ford KR. Anterior cruciate ligament injuries in female athletes: Part 1, mechanisms and risk factors. *Am J Sports Med.* Feb 2006;34(2):299-311.

7. Boden BP, Dean GS, Feagin JA, Jr., Garrett WE, Jr. Mechanisms of anterior cruciate ligament injury. *Orthopedics.* Jun 2000;23(6):573-578.

8. Chappell JD, Yu B, Kirkendall DT, Garrett WE. A comparison of knee kinetics between male and female recreational athletes in stop-jump tasks. *Am J Sports Med.* Mar-Apr 2002;30(2):261-267.

9. Ford KR, Myer GD, Hewett TE. Valgus knee motion during landing in high school female and male basketball players. *Med Sci Sports Exerc.* Oct 2003;35(10):1745-1750.

10. Hewett TE, Myer GD, Ford KR, et al. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. *Am J Sports Med.* Apr 2005;33(4):492-501.

11. McLean SG, Lipfert SW, van den Bogert AJ. Effect of gender and defensive opponent on the biomechanics of sidestep cutting. *Med Sci Sports Exerc.* Jun 2004;36(6):1008-1016.

12. Olsen OE, Myklebust G, Engebretsen L, Bahr R. Injury mechanisms for anterior cruciate ligament injuries in team handball: a systematic video analysis. *Am J Sports Med.* Jun 2004;32(4):1002-1012.

13. Pantano KJ, White SC, Gilchrist LA, Leddy J. Differences in peak knee valgus angles between individuals with high and low Q-angles during a single limb squat. *Clin Biomech (Bristol, Avon).* Nov 2005;20(9):966-972.

14. Zeller BL, McCrory JL, Kibler WB, Uhl TL. Differences in kinematics and electromyographic activity between men and women during the single-legged squat. *Am J Sports Med.* May-Jun 2003;31(3):449-456.

15. Magee D. *Orthopedic Physical Assessment, Fourth Edition*. Fourth ed. Philadelphia: Saunders; 2002.

16. Besier TF, Lloyd DG, Cochrane JL, Ackland TR. External loading of the knee joint during running and cutting maneuvers. *Med Sci Sports Exerc.* Jul 2001;33(7):1168-1175.

17. Hewett TE, Lindenfeld TN, Riccobene JV, Noyes FR. The effect of neuromuscular training on the incidence of knee injury in female athletes. A prospective study. *Am J Sports Med.* Nov-Dec 1999;27(6):699-706.

18. Onate JA, Guskiewicz KM, Marshall SW, Giuliani C, Yu B, Garrett WE. Instruction of jump-landing technique using videotape feedback: altering lower extremity motion patterns. *Am J Sports Med.* Jun 2005;33(6):831-842.

19. van Dijk H, Hermens HJ. Effects of age and timing of augmented feedback on learning muscle relaxation while performing a gross motor task. *Am J Phys Med Rehabil.* Feb 2006;85(2):148-155; quiz 156-148.

20. McNair PJ, Prapavessis H, Callender K. Decreasing landing forces: effect of instruction. *Br J Sports Med.* Aug 2000;34(4):293-296.

21. Prapavessis H, McNair PJ. Effects of instruction in jumping technique and experience jumping on ground reaction forces. *J Orthop Sports Phys Ther.* Jun 1999;29(6):352-356.

22. Prapavessis H, McNair PJ, Anderson K, Hohepa M. Decreasing landing forces in children: the effect of instructions. *J Orthop Sports Phys Ther.* Apr 2003;33(4):204-207.

23. Onate JA, Guskiewicz KM, Sullivan RJ. Augmented feedback reduces jump landing forces. *J Orthop Sports Phys Ther.* Sep 2001;31(9):511-517.

24. Strickland LJ. *Ankle bracing affects lower extremity kinematics but not ground reaction forces during a jump-landing*. Chapel Hill: Exercise and Sport Science, University of North Carolina at Chapel Hill; 2005.

25. Bell AL, Pedersen DR, Brand RA. A comparison of the accuracy of several hip center location prediction methods. *J Biomech.* 1990;23(6):617-621.

26. Kleissen RF. Effects of electromyographic processing methods on computer-averaged surface electromyographic profiles for the gluteus medius muscle. *Phys Ther.* Nov 1990;70(11):716-722.

27. Leveau B, Andersson G. *Output forms: Data Analysis and Applications. Selected Topics in Surface Electromyography for Use in the Occupational Setting: Expert Perspectives*: National Institute for Occupational Safety and Health 1992.

28. Yu B, Gabriel D, Noble L, An K-N. Estimate of the Optimum Cutoff Frequency for the Butterworth Low-Pass Digital Filter. *Journal of Applied Biomechanics.* August 1999;15(3):318-329.

29. Komi PV GA, Schmidtbleicher D, Frick U. . Interaction between man and shoe in running: considerations for a more comprehensive measurement approach. *Int J Sports Med.* . June 1987;8(3):196-202.

30. Grood ES, Suntay WJ. A joint coordinate system for the clinical description of three-dimensional motions: application to the knee. *J Biomech Eng.* May 1983;105(2):136-144.

31. McNair PJ, Marshall RN, Matheson JA. Important features associated with acute anterior cruciate ligament injury. *N Z Med J.* Nov 14 1990;103(901):537-539.

32. Markolf KL, Graff-Redford A, Amstutz H. In vivo knee stability: a quantitative assessment using an instrumented clinical testing apparatus. *J Bone Joint Surg Am.* Jul 1978;60(5):664-674.

33. Myer GD, Ford KR, Palumbo J, Hewett TE. Neuromuscular training improves performance and lower extremity biomechanics in female athletes. *J Strength Cond Res.* 2005;19:51-60.

34. Myer GD, Hewett TE, Noyes FR. The use of video analysis to identify athletes with increased valgus knee excursion: effects of gender and training. *Med Sci Sports Exerc.* 2000;32:298.

REFERENCES

1. Arnheim D, Prentice W. *Principles of Athletic Training, Tenth Edition*. Boston: McGraw-Hill; 2000.

2. Arendt E, Dick R. Knee injury patterns among men and women in collegiate basketball and soccer. NCAA data and review of literature. *Am J Sports Med.* Nov-Dec 1995;23(6):694-701.

3. Griffin LY, Agel J, Albohm MJ, et al. Noncontact anterior cruciate ligament injuries: risk factors and prevention strategies. *J Am Acad Orthop Surg.* May-Jun 2000;8(3):141-150.

4. Agel J, Arendt EA, Bershadsky B. Anterior cruciate ligament injury in national collegiate athletic association basketball and soccer: a 13-year review. *Am J Sports Med.* Apr 2005;33(4):524-530.

5. Frank CB, Jackson DW. The science of reconstruction of the anterior cruciate ligament. *J Bone Joint Surg Am.* Oct 1997;79(10):1556-1576.

6. Hewett TE, Myer GD, Ford KR. Anterior cruciate ligament injuries in female athletes: Part 1, mechanisms and risk factors. *Am J Sports Med.* Feb 2006;34(2):299-311.

7. Boden BP, Dean GS, Feagin JA, Jr., Garrett WE, Jr. Mechanisms of anterior cruciate ligament injury. *Orthopedics.* Jun 2000;23(6):573-578.

8. Chappell JD, Yu B, Kirkendall DT, Garrett WE. A comparison of knee kinetics between male and female recreational athletes in stop-jump tasks. *Am J Sports Med.* Mar-Apr 2002;30(2):261-267.

9. Ford KR, Myer GD, Hewett TE. Valgus knee motion during landing in high school female and male basketball players. *Med Sci Sports Exerc.* Oct 2003;35(10):1745-1750.

10. Hewett TE, Myer GD, Ford KR, et al. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. *Am J Sports Med.* Apr 2005;33(4):492-501.

11. McLean SG, Lipfert SW, van den Bogert AJ. Effect of gender and defensive opponent on the biomechanics of sidestep cutting. *Med Sci Sports Exerc.* Jun 2004;36(6):1008-1016.

12. Olsen OE, Myklebust G, Engebretsen L, Bahr R. Injury mechanisms for anterior cruciate ligament injuries in team handball: a systematic video analysis. *Am J Sports Med.* Jun 2004;32(4):1002-1012.

13. Pantano KJ, White SC, Gilchrist LA, Leddy J. Differences in peak knee valgus angles between individuals with high and low Q-angles during a single limb squat. *Clin Biomech (Bristol, Avon).* Nov 2005;20(9):966-972.

14. Zeller BL, McCrory JL, Kibler WB, Uhl TL. Differences in kinematics and electromyographic activity between men and women during the single-legged squat. *Am J Sports Med.* May-Jun 2003;31(3):449-456.

15. Hewett TE, Ford KR, Myer GD. Anterior Cruciate Ligament Injuries in Female Athletes: Part 2, A Meta-analysis of Neuromuscular Interventions Aimed at Injury Prevention. *Am J Sports Med.* Dec 28 2005.

16. Onate JA, Guskiewicz KM, Marshall SW, Giuliani C, Yu B, Garrett WE. Instruction of jump-landing technique using videotape feedback: altering lower extremity motion patterns. *Am J Sports Med.* Jun 2005;33(6):831-842.

17. McNair PJ, Prapavessis H, Callender K. Decreasing landing forces: effect of instruction. *Br J Sports Med.* Aug 2000;34(4):293-296.

18. McNair PJ, Marshall RN, Matheson JA. Important features associated with acute anterior cruciate ligament injury. *N Z Med J.* Nov 14 1990;103(901):537-539.

19. Magee D. *Orthopedic Physical Assessment, Fourth Edition*. Fourth ed. Philadelphia: Saunders; 2002.

20. Hislop H, Montgomery J. *Daniels and Worthingham's Muscle Testing: Techniques of Manual Examination*. 7th ed. Philadelphia: W.B. Saunders Company; 2002.

21. Daniel D, Fritschy D. *Orthopaedic Sports Medicine: Principles and Practice.* Vol 2. Philadelphia: WB Saunders; 1994.

22. Myklebust G, Maehlum S, Holm I, Bahr R. A prospective cohort study of anterior cruciate ligament injuries in elite Norwegian team handball. *Scand J Med Sci Sports.* Jun 1998;8(3):149-153.

23. Stacoff A, Steger J, Stussi E, Reinschmidt C. Lateral stability in sideward cutting movements. *Med Sci Sports Exerc.* Mar 1996;28(3):350-358.

24. Hewett TE, Lindenfeld TN, Riccobene JV, Noyes FR. The effect of neuromuscular training on the incidence of knee injury in female athletes. A prospective study. *Am J Sports Med.* Nov-Dec 1999;27(6):699-706.

25. Freedman KB, Glasgow MT, Glasgow SG, Bernstein J. Anterior cruciate ligament injury and reconstruction among university students. *Clin Orthop Relat Res.* Nov 1998(356):208-212.

26. Fleming BC. Biomechanics of the anterior cruciate ligament. *J Orthop Sports Phys Ther.* Aug 2003;33(8):A13-15.

27. Wojtys EM, Kothari SU, Huston LJ. Anterior cruciate ligament functional brace use in sports. *Am J Sports Med.* Jul-Aug 1996;24(4):539-546.

28. Nemeth G, Lamontagne M, Tho KS, Eriksson E. Electromyographic activity in expert downhill skiers using functional knee braces after anterior cruciate ligament injuries. *Am J Sports Med.* Sep-Oct 1997;25(5):635-641.

29. Rovere GD, Haupt HA, Yates CS. Prophylactic knee bracing in college football. *Am J Sports Med.* Mar-Apr 1987;15(2):111-116.

30. Teitz CC, Hermanson BK, Kronmal RA, Diehr PH. Evaluation of the use of braces to prevent injury to the knee in collegiate football players. *J Bone Joint Surg Am.* Jan 1987;69(1):2-9.

31. Myklebust G, Maehlum S, Engebretsen L, Strand T, Solheim E. Registration of cruciate ligament injuries in Norwegian top level team handball. A prospective study covering two seasons. *Scand J Med Sci Sports.* Oct 1997;7(5):289-292.

32. Besier TF, Sturnieks DL, Alderson JA, Lloyd DG. Repeatability of gait data using a functional hip joint centre and a mean helical knee axis. *J Biomech.* Aug 2003;36(8):1159-1168.

33. Emerson RJ. Basketball knee injuries and the anterior cruciate ligament. *Clin Sports Med.* Apr 1993;12(2):317-328.

34. Uhorchak JM, Scoville CR, Williams GN, Arciero RA, St Pierre P, Taylor DC. Risk factors associated with noncontact injury of the anterior cruciate ligament: a prospective four-year evaluation of 859 West Point cadets. *Am J Sports Med.* Nov-Dec 2003;31(6):831-842.

35. Steiner ME, Grana WA, Chillag K, Schelberg-Karnes E. The effect of exercise on anterior-posterior knee laxity. *Am J Sports Med.* Jan-Feb 1986;14(1):24-29.

36. Liu SH, al-Shaikh R, Panossian V, et al. Primary immunolocalization of estrogen and progesterone target cells in the human anterior cruciate ligament. *J Orthop Res.* Jul 1996;14(4):526-533.

37. Booth FW, Tipton CM. Ligamentous strength measurements in pre-pubescent and pubescent rats. *Growth.* Jun 1970;34(2):177-185.

38. Eiling E, Bryant AL, Petersen W, Murphy A, Hohmann E. Effects of menstrual-cycle hormone fluctuations on musculotendinous stiffness and knee joint laxity. *Knee Surg Sports Traumatol Arthrosc.* Jul 5 2006.

39. Wojtys EM, Huston LJ, Lindenfeld TN, Hewett TE, Greenfield ML. Association between the menstrual cycle and anterior cruciate ligament injuries in female athletes. *Am J Sports Med.* Sep-Oct 1998;26(5):614-619.

40. Lebrun CM. The effect of the phase of the menstrual cycle and the birth control pill on athletic performance. *Clin Sports Med.* Apr 1994;13(2):419-441.

41. Sarwar R, Niclos BB, Rutherford OM. Changes in muscle strength, relaxation rate and fatiguability during the human menstrual cycle. *J Physiol.* May 15 1996;493 (Pt 1):267-272.

42. Posthuma BW, Bass MJ, Bull SB, Nisker JA. Detecting changes in functional ability in women with premenstrual syndrome. *Am J Obstet Gynecol.* Feb 1987;156(2):275-278.

43. Huberti HH, Hayes WC. Patellofemoral contact pressures. The influence of q-angle and tendofemoral contact. *J Bone Joint Surg Am.* Jun 1984;66(5):715-724.

44. Trimble MH, Bishop MD, Buckley BD, Fields LC, Rozea GD. The relationship between clinical measurements of lower extremity posture and tibial translation. *Clin Biomech (Bristol, Avon).* May 2002;17(4):286-290.

45. Markolf KL, Burchfield DM, Shapiro MM, Shepard MF, Finerman GA, Slauterbeck JL. Combined knee loading states that generate high anterior cruciate ligament forces. *J Orthop Res.* Nov 1995;13(6):930-935.

46. Huston LJ, Wojtys EM. Neuromuscular performance characteristics in elite female athletes. *Am J Sports Med.* Jul-Aug 1996;24(4):427-436.

47. Besier TF, Lloyd DG, Ackland TR. Muscle activation strategies at the knee during running and cutting maneuvers. *Med Sci Sports Exerc.* Jan 2003;35(1):119-127.

48. Besier TF, Lloyd DG, Cochrane JL, Ackland TR. External loading of the knee joint during running and cutting maneuvers. *Med Sci Sports Exerc.* Jul 2001;33(7):1168-1175.

49. Prapavessis H, McNair PJ. Effects of instruction in jumping technique and experience jumping on ground reaction forces. *J Orthop Sports Phys Ther.* Jun 1999;29(6):352-356.

50. Prapavessis H, McNair PJ, Anderson K, Hohepa M. Decreasing landing forces in children: the effect of instructions. *J Orthop Sports Phys Ther.* Apr 2003;33(4):204-207.

51. Onate JA, Guskiewicz KM, Sullivan RJ. Augmented feedback reduces jump landing forces. *J Orthop Sports Phys Ther.* Sep 2001;31(9):511-517.

52. van Dijk H, Hermens HJ. Effects of age and timing of augmented feedback on learning muscle relaxation while performing a gross motor task. *Am J Phys Med Rehabil.* Feb 2006;85(2):148-155; quiz 156-148.

53. Strickland LJ. *Ankle bracing affects lower extremity kinematics but not ground reaction forces during a jump-landing*. Chapel Hill: Exercise and Sport Science, University of North Carolina at Chapel Hill; 2005.

54. Yu B, Gabriel D, Noble L, An K-N. Estimate of the Optimum Cutoff Frequency for the Butterworth Low-Pass Digital Filter. *Journal of Applied Biomechanics.* August 1999;15(3):318-329.

55. Bell AL, Pedersen DR, Brand RA. A comparison of the accuracy of several hip center location prediction methods. *J Biomech.* 1990;23(6):617-621.

56. Kleissen RF. Effects of electromyographic processing methods on computer-averaged surface electromyographic profiles for the gluteus medius muscle. *Phys Ther.* Nov 1990;70(11):716-722.

57. Leveau B, Andersson G. *Output forms: Data Analysis and Applications. Selected Topics in Surface Electromyography for Use in the Occupational Setting: Expert Perspectives*: National Institute for Occupational Safety and Health 1992.

58. Komi PV GA, Schmidtbleicher D, Frick U. . Interaction between man and shoe in running: considerations for a more comprehensive measurement approach. *Int J Sports Med.* . June 1987;8(3):196-202.

59. Grood ES, Suntay WJ. A joint coordinate system for the clinical description of three-dimensional motions: application to the knee. *J Biomech Eng.* May 1983;105(2):136-144.

60. Markolf KL, Graff-Redford A, Amstutz H. In vivo knee stability: a quantitative assessment using an instrumented clinical testing apparatus. *J Bone Joint Surg Am.* Jul 1978;60(5):664-674.

61. Myer GD, Ford KR, Palumbo J, Hewett TE. Neuromuscular training improves performance and lower extremity biomechanics in female athletes. *J Strength Cond Res.* 2005;19:51-60.

62. Myer GD, Hewett TE, Noyes FR. The use of video analysis to identify athletes with increased valgus knee excursion: effects of gender and training. *Med Sci Sports Exerc.* 2000;32:298.