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Electromyography Analysis of Forward Lateral Retro Lateral Incline Exercise and the Potential to Reduce ACL Injury

A thesis prepared by Kevin Feldman

In partial fulfillment of the requirements for the degree, Masters of Science in Human Performance and Physical Education, has been approved and accepted by the following:

Dr. Frank Novonty — Date: 7/1/2015
Director of the Graduate School

Dr. Tracey Robinson — Date: 7-1-2015
Chairperson of Thesis Committee

Thesis Committee Members:

Tracey Robinson

Megan Nelson

Jake Mellott

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By

Kevin Feldman

A Thesis

Submitted in Partial Fulfillment of the

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Abstract

The purpose of this study was to determine if forward lateral retro lateral incline (FLRL) exercises on an inclined treadmill are more effective at activating and fatiguing the rectus femoris (RF), rectus abdominis (ABS), gluteus maximus (GMA), gluteus medius (GME), hamstrings (HAM), and gastrocnemius (GA) than current standard rehab exercises used for strengthening the core, hip complex and calf muscles, therefore having the potential to better strengthen and train these muscles, and potentially reduce anterior cruciate ligament (ACL) injuries. Twenty participants (11 males and 9 females) volunteered to be in the study. The mean age of the participants was 21.65 ± 2.62 years, and the mean weight 158.6 ± 31.29 lbs. The participants were tested using surface electromyography (sEMG) to look at activation of the selected muscles, activation levels compared to maximum voluntary contractions (MVC), and fatigue levels while performing the FLRL exercise compared to rehab exercises (a prone bridge, side bridge, lunge, and step up). All exercises were completed on the same day. The results showed significant differences ($p<.05$) between the FLRL exercise and the rehab exercises. The FLRL produced higher means of amplitude, greater potential to create hypertrophy by reaching amplitudes at 40% of MVC or greater, and greater amounts of fatigue in the RF, GMA, GME, HAM, and GA. The FLRL exercise produced greater amounts of fatigue in the ABS. The FLRL exercise has potential to be an exercise used in the rehabilitation setting of a knee injury and preseason training to prevent injury due to its ability to activate and fatigue these muscles of the lumbo-pelvic-hip complex to levels that can produce strength and hypertrophy. The FLRL exercise combined with other exercises used in a training or rehab setting can potentially lead to performance gains, reduced chance of injury, and accelerated recovery.

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Chapter 1: Introduction

Knee injuries account for 15% of all injuries in high school sports (Ingram, Fields, Yard, Comstock, 2008). Swenson et al. (2013) found in a review that 21.2% of knee injuries overall were treated with surgery. The sports, girl's lacrosse and cheerleading, had 40% of knee injuries treated with surgery. Yang et al. (2012) found the knee joint was the most severely injured body region for both acute and overuse injuries, accounting for 27.7% of all major injuries when looking at male and female collegiate athletes (Yang et al., 2012). The frequency of knee injuries needs to be examined, along with strategies to decrease the high occurrence. Though contact injuries cannot be prevented, there is a possibility non-contact injuries can be.

Multiple structures have the potential to be injured in the knee but this study will be focusing on the anterior cruciate ligament (ACL) and prevention of the injury. The ACL will be the focus because it is the structure that requires surgery four times more often than any other structure in the knee, and the surgery can hold an athlete out of training and competition for up to 12 months, and can cost upwards of $9000 (Gianotti, Marshall, Hume, & Bunt, 2009).

Knee injuries can be caused by multiple factors in athletics. Bahr and Krosshaug (2005) cite ten different sources showing injury mechanism involving characteristics of the injury. Natural motions like landing and cutting are among the list of actions that cause injury. Intrinsic factors along with these motions can contribute to injuries. Intrinsic factors like kinematics, hormone levels, fatigue of muscles, and physical fitness can have an effect on injuries. Addressing the intrinsic factors could be the key to reducing injury. A mechanism Flanagan (2014) explains as excessive motion at the hip can lead to a movement pattern referred to as a valgus collapse. Causes of a valgus collapse would be lack of strength/ power/ endurance of the subtalar invertors and hip external rotators as these groups control eccentric motion during lower extremity flexion. A valgus collapse places increased demands at the knee. These demands can result in injury including injuries to the anterior cruciate ligament (p.352).

Looking to prevent injuries, non-contact injuries are considered to be injuries with no physical contact with other players at the time of injury (Alentorn-Geli et al., 2009). Boden, Dean, Feagin and Garrett (2000) examined 71 non-contact knee injuries; of the 71, 38 happened during deceleration and 26 during landing. Both declaration and landing cause the body to slow down the movement of the center of mass. Non-contact knee injuries have a potential to be prevented or the risk of one occurring to be reduced by looking to alter the intrinsic factors through a training intervention.

Another issue is re-injury rates. Porucznik (2013) found within a group of athletes who had undergone ACL reconstruction, 29.5 percent of athletes sustained a second ACL injury within 24 months of returning to activity. Approximately 20% were sustained on the opposite leg and 9 percent incurred a graft re-tear injury on the same leg. The question of why this is happening must be evaluated. Looking at current rehab techniques could uncover a problem that is causing this to happen. Understanding the goals to return an athlete back to play is also critical to fix the issues.

The generic goals of rehabilitation for orthopedic injuries, as stated by Andrews, Wilk, & Harrelson (2004, pg.158), are to decrease pain, decrease inflammatory response to trauma, return of full active, pain-free range of motion, decrease swelling, return to full muscular strength, power, and endurance, and return to full asymptomatic functional activities at the pre-injury level (Andrews et al., 2004). Following these generic rules, a rehab process can be introduced to any injury. Achieving the goals helps athletes return to play swiftly with a reduced chance of re-injury.

An exercise the researcher uses in a performance training program and is the cornerstone of it could have the potential to address the issue of knee injuries in sports. The exercise has been developed through personal experiences of the researcher and results obtained through working with over 250 individuals in rehabilitation of knee injuries and performance training settings. The exercise has the athletes that train work forward lateral and retro at an incline. The exercise will be referred to as forward lateral retro lateral (FLRL) exercise throughout the paper. The FLRL exercise trains the body to be strong, resistant of fatigue, and work in proper kinematic form in the multiple directions and planes of motion that injuries often occur. Examples of this are side cuts and lateral motions.

The use of electromyography (EMG) technology can help to determine if the FLRL exercise is effective at working the appropriate musculature so there may possibly be a reduction of injury through its capability to strengthen, train proper kinematics, and create adaptations to fatigue. EMG was used to determine the active musculature in the exercise. The current study used EMG technology to test the ability of the rectus femoris, rectus abdominis, gluteus maximus, gluteus medius, hamstrings, and gastrocnemius to activate, produce a contraction significant enough to strengthen, and the ability of the exercise to create fatigue in order to produce an adaptation. For training exercises to strengthen a muscle it needs an intervention level of at least 40-60% of maximum voluntary contraction (MVC) (Konrad, 2005). If the FLRL exercise can do this, there is potential for it to be used in rehabilitation and performance training settings to help rehab ACL injuries and reduce the occurrence of them.

Purpose of the study

The purpose of this study was to determine if forward lateral retro lateral incline (FLRL) exercises on an inclined treadmill are more effective at activating and fatiguing the rectus femoris, rectus abdominis, gluteus maximus, gluteus medius, hamstrings, and gastrocnemius than current standard rehab exercises used for strengthening the core, hip complex and calf muscles, therefore having the potential to better strengthen and train these muscles.

Hypothesis

The hypothesis of the study was that the use of forward lateral retro lateral incline (FLRL) exercises on an inclined treadmill would activate all of the muscles being studied during the exercise. It was hypothesized the FLRL exercise would create greater amounts of activation, create activation to a level high enough to create hypertrophic effects, and create higher fatigue rates than current rehab techniques, and therefore may be more effective at strengthening the core, hip complex, and gastrocnemius.

Research Questions

RQ 1: Are the rectus femoris, rectus abdominis, gluteus maximus, gluteus medius, hamstrings, and gastrocnemius activated during the FLRL exercise?

RQ 2: Does the FLRL exercise require greater muscle activity of the rectus femoris, rectus abdominis, gluteus maximus, gluteus medius, hamstrings, and gastrocnemius muscles than the current rehab exercises when expressed as a percentage of the maximum voluntary contraction?

RQ 3: When compared to the current rehab exercises, does the FLRL exercise reach at least 40% of the MVC, to cause hypertrophic effects, of the rectus femoris, rectus abdominis, gluteus maximus, gluteus medius, hamstrings, and gastrocnemius?

RQ 4: Does the FLRL exercise produce more fatigue in the rectus femoris, rectus abdominis, gluteus maximus, gluteus medius, hamstrings, and gastrocnemius than current rehab exercises?

Delimitations

The study had a few delimitations. The study was delimited to well-trained males and females who were familiar with and had previously performed the exercises in a training setting at a fitness center in Alamosa, Colorado, and have never sustained any lower extremity injury needing surgery. The FLRL exercises were done on a moving surface of the treadmill which has a possibility to alter how the exercises would happen on ground surface. The exercises were done at an altitude of 7544 feet which could be different than if done at low altitude. The age group of the participants was between 18 and 28 years. The rehab exercises used for comparison were delimited to four chosen by the researcher based on previous experiences and similarity to FLRL exercises in the ability to target the rectus femoris, rectus abdominis, gluteus maximus, gluteus medius, hamstrings, and gastrocnemius. The study was delimited to surface EMG and the measurement of muscle activation. The muscles chosen for the study were a delimitation. The study was delimited to researching the effects of FLRL exercise which were based off the researcher's past experience. The researcher chose to do manually resisted maximum voluntary contractions.

Limitations

The study had a few limitations. The group chosen was from a small population. The participants chosen may not have had the ability to perform the exercises and muscle contractions correctly and with full effort. The rehab exercises chosen to test have the possibility of not being the best examples of exercises for the hips and core. The test was done on a moving surface of a treadmill which has a possibility to alter how the test would be done on a ground surface. The test could show different results if it was done at low altitude. The study was limited to six EMG sites. The rectus femoris, rectus abdominis, gluteus maximus, gluteus medius, hamstrings, and gastrocnemius may not have been the most activated muscles in the exercises, and therefore not the best to test. The FLRL exercise was based off of the researcher's personal experiences and the study was limited to this exercise, which is not yet a validated exercise protocol. The study was limited to manually resisted maximum voluntary contractions. The study was limited to EMG's only being placed on the dominate side of the body.

Assumptions

It was assumed every participant gave maximal effort in every exercise. It was also assumed that the signals being picked up by the EMG are only from the rectus femoris, rectus abdominis, gluteus maximus, gluteus medius, hamstrings, and gastrocnemius, although cross-talk was likely, due to the nature of surface EMG. It was assumed the population being tested is fully capable of performing the exercises and the population represents a good sample of the general population. It was assumed that the results from the one exercise bout/test used in this study would have the same effect as if a full standard 8-week program were to be done. It was assumed the rehab exercises selected for this study were the best choice for the control.

Definition of terms

Anterior Drawer- test of stability/integrity of lateral collateral ligaments of ankle joint, i.e. flex knee to >45° (to relax posterior muscle group), stabilize lower tibia (with one hand) whilst grasping posterior aspect of patient's heel (with the other); calcaneus is pulled forward as a simultaneous retrograde force is applied to lower tibia. This motion helps to explain an injury mechanism of the ACL (The Free Medical dictionary, 2014).

Biomechanical mechanism- The action of external and internal forces on the living body, especially on the skeletal system completing a functional motion like being part of a large machine.

Core- all muscles of the hip, pelvis, and spine.

Dorsiflexion- flexion or bending toward the extensor aspect of a limb, as of the hand or foot.

Electrical dipole- the wave formed by the depolarization- repolarization cycle of a muscle (Konrad, 2005).

Electromyography (EMG) - This measures muscle activity and tension. In this study EMG will be used to evaluate the effectiveness of exercises through muscle activation and tension produced.

Forward lateral retro lateral incline (FLRL) - an exercise done on the treadmill; the participant will start by walking forward for ten steps then turning one way to do 10 lateral steps, then 20 steps retro, turn to do 20 steps lateral the opposite way, turning back to retro for 20 steps, then turning lateral to the starting way doing 10 steps, and finishing walking forward for 10 steps. This is done one time. The exercise is used in a performance training protocol the researcher has had success with training over 250 athletes in rehabilitation and performance training settings. The experience of the subjects doing this exercise used in the study allowed for the use of the exercise.

Kinetic chain- a linked system of body segments working together to produce a desired movement. This study looks at the idea that in human movement one segment, the hip joint, cannot move without affecting another segment, the knee joint.

Maximum voluntary contraction (MVC) - The greatest amount of tension a muscle can generate isometrically and hold, however briefly, as in muscle testing. MVC will be measured in the six muscles of interest and used as a baseline. In this study the amount of muscle activity produced in the FLRL exercise and rehab exercise will be compared as a percentage of MVC (The Free Medical dictionary, 2014).

Muscle Activation- The process of a muscle contracting through a signal sent by the central nervous system creating an action potential causing the muscle cell to depolarize-repolarize. This sends out an electrical dipole which will be analyzed to look at activation, amplitude, and frequency of the muscle contraction (Konrad, 2005).

Planter flexion- movement of the foot that flexes the foot or toes downward toward the sole.

Valgus- Descriptive of any of the paired joints of the extremities with a static angular deformity in which the bone distal to the joint deviates laterally from the longitudinal axis of the proximal bone, and from the midline of the body, when the subject is in anatomic position (The Free Medical dictionary, 2014).

Varus- Descriptive of any of the paired joints of the limbs with a static angular deformity in which the bone distal to the joint deviates medially from the longitudinal axis of the proximal bone, and toward the midline of the body, when the subject is in the anatomic position (The Free Medical dictionary, 2014).

Chapter 2: Review of Literature

Anatomy

Knee Anatomy

Anderson, Parr, & Hall (2009) and Starkey, Brown, & Ryan (2009) show the anatomy of the knee to include ligaments, tendons, meniscus, capsule, and bone. The bony structures of the knee are the medial and lateral condyles of the femur, the medial and lateral tibial plateaus, the patella, and the fibular head. The tibiofemoral joint is a joint in the knee. The bones of this joint are the distal femur and proximal tibia. Inside this joint sit two menisci, the medial and lateral. The major ligaments of the knee include the medial collateral ligament (MCL), the lateral collateral ligament (LCL), the anterior cruciate ligament (ACL), and the posterior cruciate ligament (PCL). Other ligaments in the knee include the transverse ligament and the menisocofemoral ligament. Figure 1 from the American Academy of Orthopedic Surgeons (2009) shows the ligaments, menisci and bones of the knee. This study will be focusing on the ACL. The American Academy of Orthopedic Surgeons (2009) explains the ACL as the ligament that connects the femur and the tibia. The ACL along with the other ligaments of the knee hold these bones together. The ACL keeps these bones together by preventing anterior translation of the tibia (The American Academy of Orthopedic Surgeons, 2009).

The knee has two capsules, a fibrous joint capsule and a synovial joint capsule. The fibrous joint capsule surrounds the circumference of the knee joint, along the medial, anterior, and lateral aspects of the joint. The synovial capsule surrounds the articular condyles of the femur and tibia medially, anteriorly, and laterally. On the posterior portion of the articulation, the synovial capsule invaginates anteriorly along the femur's intercondylar notch and the tibia's intercondylar notch. The capsules of the knee joint exclude the cruciate ligaments. The exclusion explains why the cruciate ligaments have poor healing properties (Anderson, Parr, & Hall, 2009).

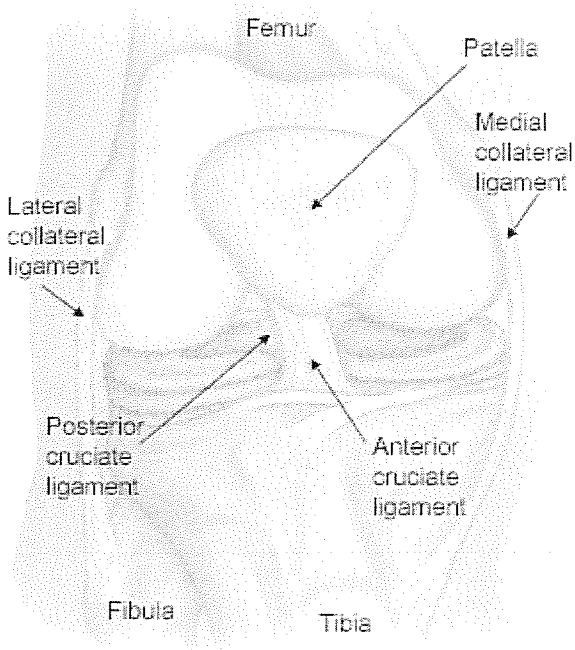

Figure 1. A detailed image and labeling of the ligaments, menisci, and bony structures of the knee (American Academy of Orthopedic Surgeons, 2009).

Muscles that act on the extension of the knee joint include and are pictured in Figure 2. Anteriorly, the quadriceps femoris muscle group consists of four muscles, the vastus lateralis, vastus intermedius, vastus medialis, and the rectus femorus. All have a common insertion on the tibial tuberosity via the patellar tendon. The muscles posterior which flex the knee joint include: The semitendinosus which inserts the medial portion of the tibial flare, semimembranosus which inserts at the posterior medial portion of the tibia's medial condyle, and the biceps femoris which inserts into the lateral fibular head and lateral condyle of the tibia. This group of muscles is known as the hamstring muscles. The posterolateral corner of the knee is reinforced by the popliteus muscle which provides both dynamic and static stabilization (Figure 2). There is also the sartorius muscle which inserts into the proximal portion of the antero-medial tibial flare. The sartorius along with assisting in knee flexion acts on the hip through flexion, abduction, and external rotation (Anderson et al., 2009; Starkey, Brown, & Ryan, 2009).

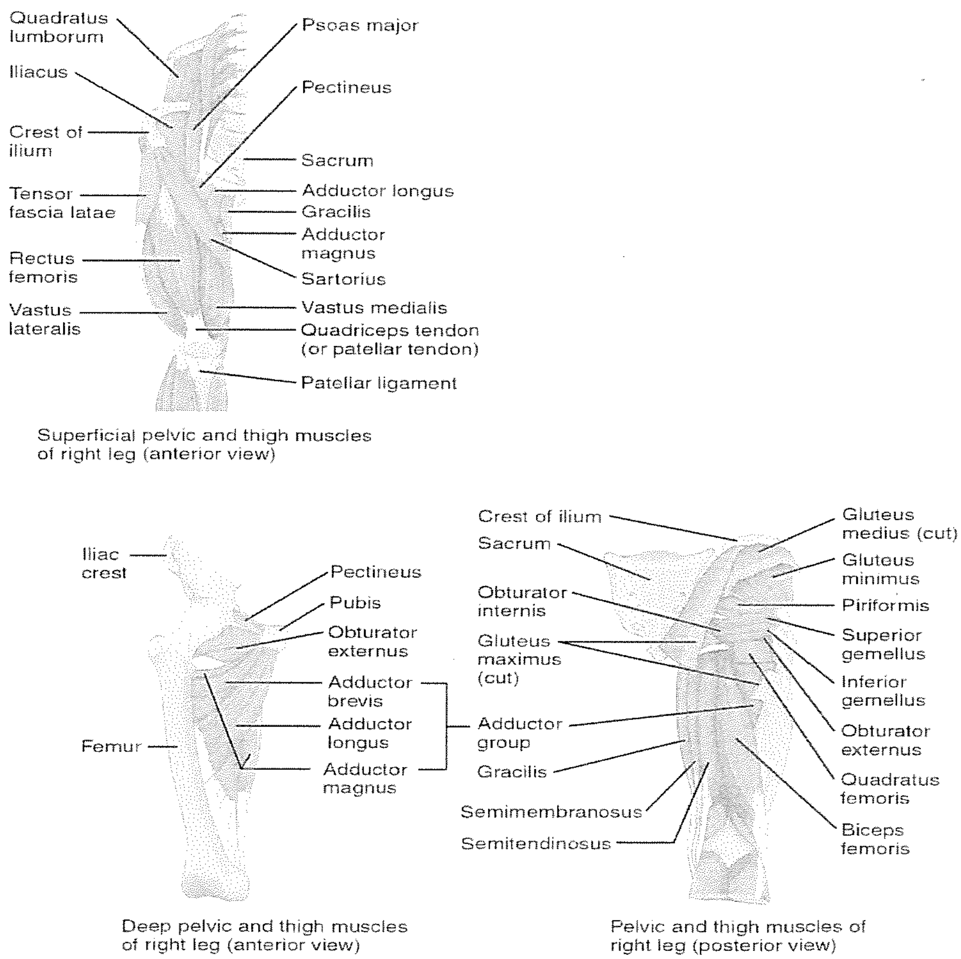

Figure 2. The large and powerful muscles of the hip that move the femur generally originate on the pelvic girdle and insert into the femur. The muscles that move the lower leg typically originate on the femur and insert into the bones of the knee joint. The anterior muscles of the femur extend the lower leg but also aid in flexing the thigh. The posterior muscles of the femur flex the lower leg but also aid in extending the thigh. A combination of gluteal and thigh muscles also adduct, abduct, and rotate the thigh and lower leg (CNX.org, 2014).

Hip Anatomy

The hip is the most proximal link to the knee in the kinetic chain. The hip also shares a common bone with the knee, the femur. It only makes sense that the knee could be affected by the actions of the hip. Reiman, Bolgla, & Lornz (2009) in a review, cited 51 articles providing some degree of evidence that proximal factors may influence knee loading through epidemiological, neuromuscular, or biomechanical factors and therefore contributing to injury. A study done by Lawrence, Kernozek, Miller, Torry, & Reuteman (2008) looking at hip strength in female athletes found stronger females exhibited reduced ground-reaction forces during landing and generated less external knee valgus movements. Both knee valgus movements and large ground reaction forces have been found to increase risk of ACL injury.

This basic understanding brings in the need to look at the hip anatomy. The hip has many muscles that act on its complex motions. Most of the muscles of the hip act in multi-movement actions. Refer to Appendix A to find an outline of the muscles of the hip, their actions, origins, and insertions. Figure 2 from CNX.org (2014) is a detailed image of the hip anatomy. The main muscles this study will be looking at are the gluteal group, the abductors, and adductors. OpenStax College of Rice University (2014) explains the gluteal group to be a very large and powerful muscle group in the body. The muscles of this group include: the gluteus maximus, gluteus minimus, gluteus medius, and tensor fascia lata. This group of muscles controls extension, abduction, flexion, and stabilization of the hip and knee joints. The gluteal muscles are the main abductors of the hip joint. The adductor group of muscles includes the adductor brevis, adductor longus, adductor magnus, and the pectineus. This muscle group controls the adduction, extension, and flexion of the hip joint.

The Core

According to Kibler, Press, & Sciascia (2006) a strong core reduces stress on ligaments and joints along with giving an athlete more power and efficiency in all aspects of sports. They explain the "core" as all muscles of the hip, pelvis, and spine. These muscles provide a rigid base for rotation, stabilization, and support the extremities by giving a rigid base to push off. A weak core will put more force on all ligaments and joints in the body (Kibler, Press, & Sciascia, 2006). A strong core will be able to stabilize the spine. This allows for the short muscles that connect to the extremities from the spine and pelvis to help support the longer muscles in their actions. The support will reduce the stress on the ligaments due to the body being stable in all three planes of motion. The facts presented by OpenStax College of Rice University (2014), and researched by Reiman, Bolgla, & Lornz (2009), and Kibler, Press, & Sciascia (2006) give evidence that strengthening of the core in a training setting will lead to not only reduction of injury but also an increase in performance. A list of the extrinsic abdominal muscles connecting to the spine can be found in Appendix B. The hip and pelvis muscles have been briefly examined. The abdominal muscles need to be examined to complete the explanation of the muscles that make up the core complex.

Akuthota, Scott, and Nadler (2004) explain the muscles of the core run in all directions helping to make a rigid stabilizing base for all body movements. The main abdominal muscles are animated in Figure 3. They include the transverse abdominis, whose muscles run horizontally around the abdomen the internal obliques, the external obliques, and the rectus abdominus. The transverse abdominus, external obliques, and internal obliques act together to increase the intra-abdominal pressure from the hoop created via the thoracolumbar fascia (TLF). The TLF has three layers: the anterior, middle, and posterior layers. The posterior layer plays the most important role in stabilization of the core. The transverse abdominus connects to the middle and posterior portion of the TLF. The TFL is explained as the connection between the lower and upper limbs and the connection of the core to the spine. Leetun, Ireland, Willson, Ballantyne, & Davis (2004) studied 80 female and 60 male collegiate athletes for a season looking to see if core stability affected back and lower extremity injuries. The authors found a reduction in hip and core strength led to more injuries of the back and lower extremities. Leetun et al. (2004) suggested that the higher rate of injury was due to the inability to stabilize the hips, making them more vulnerable to external forces experienced during athletic play, especially forces in the transverse and frontal plane. Exercises that strengthen the core could possible reduce the risk of lower extremity injuries, for example ACL injuries of the knee.

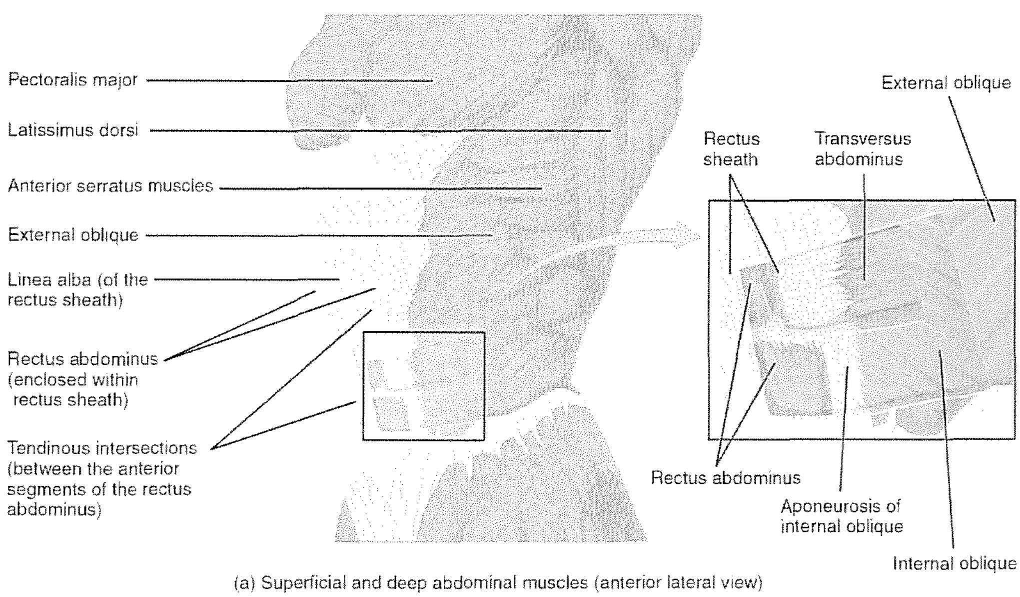

Figure 3. (a) The anterior abdominal muscles include the medially located rectus femoris, which is covered by a sheet of connective tissue called the linea alba. On the flanks of the body, medial to the rectus femoris, the abdominal wall is composed of three layers. The external oblique muscles form the outermost layer, while the internal oblique muscles form the middle layer, and the transverses abdominus forms the innermost layer (OpenStax College, 2014).

Knee Injuries in Sports

Knee injuries account for 15% of all injuries in high school sports (Ingram et al., 2008). Swenson et al. (2013) classified an injury as one that occurred as a result of participating in an organized practice, competition, or performance. The occurrence required medical attention by an athletic trainer or physician, and resulted in restriction of the athlete's participation for one or more days (Swenson et al., 2013). A study looked at 17,172,376 high school athletes from 20 sports using the National High School Sports Injury Surveillance System, High School RIO™, to gather the data. Knee injury rates, rate ratios, and injury proportion ratios were calculated. The occurrence of knee injuries was a rate of 2.98 per 10,000 athletes exposed, and it was noted that girls had a higher rate of injury than boys that required surgery (Swenson et al., 2013).

A study done Gianotti et al. (2009) looked at the occurrence of knee ligament injuries over a 5 year period. Injuries were categorized as non-surgical, anterior cruciate ligament (ACL) surgeries, and other knee ligament surgeries. Incidence per 100,000 persons per year were computed using population estimates. The incidence rate per 100,000 persons per year was 1147.1 for non-surgical, 36.9 for ACL surgical, and 9.1 for other knee ligament surgery. The average cost of an ACL surgery was $8574 and time missed from athletics was between 6 and 12 months (Gianotti et al., 2009). This study brings to light the fact that the ACL is the most commonly injured ligament that requires surgery in the knee by fourfold. Flanagan (2014) explains excessive motion at the hip can lead to a movement pattern referred to as a valgus collapse. Causes of a valgus collapse would be lack of strength/ power/ endurance of the subtalar invertors and hip external rotators as these groups control eccentric motion during lower extremity flexion. A valgus collapse places increased demands at the knee. These demands can result in injury including injuries to the anterior cruciate ligament (p.352).

Causes of Knee Injuries

Bahr and Krosshaug (2005) cite ten different sources explaining overall injury mechanisms and the characteristics involved. Injury mechanisms can be broken down into two major categories: player to player contact and non-contact (Bahr & Krosshaug, 2005). Non-contact mechanisms include: jumping, landing, decelerating, side stepping, and phantom foot mechanisms (Bahr & Krosshaug, 2005). Both player to player contact and non-contact mechanisms are then turned into biomechanical mechanisms. The occurrence of gross biomechanical mechanisms are what cause the body to put excess force on knee structures and cause injury (Bahr & Krosshaug, 2005). Biomechanical mechanisms of injury are anterior drawer, quadriceps drawer, and valgus collapse (Bahr & Krosshaug, 2005, p.3). Understanding how an injury occurs is vital to prevention of the injury. Other factors have also been attributed to the cause of injury including external and internal factors (Alentorn-Geli et al., 2009). Looking at the mechanisms to understand injuries will be explained below.

Mechanisms of Non-Contact Knee Injuries

Non-contact injuries are considered to be injuries with no physical contact with other players at the time of injury (Alentorn-Geli et al., 2009). For a non-contact ACL injury to occur a gross biomechanical mechanism must happen (Alentorn-Geli et al., 2009). When flexing or lowering the center of gravity the knee and hip flex and the ankle dorsal flexes while the femur and tibia rotate internally as the knee flexion angle decrease (Flanagan, 2014). Flanagan (2014) states a lower extremity flexion pattern is often used to decelerate the center of mass such as landing from a jump or the braking phase in running. When landing or stopping safely the body goes through the natural motion of dorsiflexion of the ankle, tibia internal rotation, lowering of the center of gravity, and flexion at the hip. Safe landing brings about minimal motion of the knee in the transverse plane. This minimal motion that does happen creates internal rotation and slight adduction of the femur. The dorsiflexion of the ankle and flexion of the knee and hip absorb the energy of the landing or stopping body (p.351). These natural motions are controlled by the muscles of the lower leg and ligaments in the knee. When the muscles are not able to control the motion, excess motion or a gross biomechanical mechanism occurs. This will put excess stress on the ligaments and other structures of the knee with the potential to lead to injury. In the goal to avoid injury, the muscles of the lower leg should be trained to keep this from happening. Bahr and Krosshaug (2005) explain there to be multiple biomechanical mechanisms that can lead to ACL injury.

The biomechanical mechanisms presented by Bahr and Krosshaug (2005) are an anterior drawer, quadriceps drawer, and valgus collapse. Examining these mechanisms will help to understand how the knee becomes injured. The biomechanical mechanism of injury the quadriceps drawer is explained by DeMorat, Weinhold, Blackburn, Chudik, and Garrett (2004) as the action of decelerating in the sagittal plane as the foot is planted, often on the fore foot; as the center of gravity lowers in an attempt to stop the forward motion, the quadriceps are activated. The quadriceps activation via the patella tendon to tibial shaft causes the tibia to translate anteriorly. Aggressive quadriceps loading, with the knee in slight flexion, produces significant anterior tibial translation stressing the ACL and potentially leading to ACL injury. The ability for the hamstrings and gluteal muscles to contract antagonistically could possibly help stop the forward motion and decrease anterior tibial translation reducing the risk of injury to the ACL.

The anterior drawer biomechanical mechanism of injury is explained by Geyer and Werth (1991) from video analysis of skiers as a minimal shift of the center of body mass backwards.

This leads to an acceleration of the thigh and body orientation forward and vertical. The foot will plantar flex pushing the tibia against the back of the boot. This acceleration produces a massive compensatory quadriceps contraction to prevent a backward fall, followed by an "anteroposterior shift" of the femur on the tibia in the sense of an anterior drawer, which in association with other factors leads to an ACL rupture. Senter and Hame (2006) discuss how ACL force increased as knee flexion decreased. The hyperextension of the knee to stop the body leads to a massive quadriceps contraction. Senter and Hame (2006) found that when the hamstrings were able to contract antagonistically the force on the ACL decreased. This emphasizes the need for the ability of the hamstrings to be strong to protect against excessive ACL force due to the event of an immense quadriceps contraction. The quadriceps drawer and anterior drawer are motions that only happen in the sagittal plane. Sports are played in all three planes and when decelerating the body often moves into the sagittal and transverse plane. Injuries that happen in all planes can be explained by the other mechanisms of injury that follow.

Koga et al. (2010) explains a valgus collapse as a biomechanical mechanism that happens when valgus loading is applied due to the natural motions of the knee. The valgus load occurs when the foot contacts the ground. The femur adducts and internally rotates as knee flexion increases. This loading causes the medial collateral ligament and ACL to stretch tight along with compression of the lateral meniscus. This compressive load, as well as the anterior motion along with internal rotation of the femur caused by quadriceps contraction, causes a displacement of the femur relative to the tibia. The lateral femoral condyle shifts posteriorly, the tibia translates anteriorly and rotates internally causing excessive stress on the ACL (Koga et al., 2010). Causes of a valgus collapse would be lack of strength/ power/ endurance of the subtalar invertors and hip external rotators as these groups control eccentric motion during lower extremity flexion. A valgus collapse places increased demands at the knee. These demands can result in injury including injuries to the anterior cruciate ligament (Flanagan, 2014, p.352).

How Flanagan (2014) and Koga et al. (2014) explain the cause of the valgus collapse shows how the kinetic chain can be a major player in the injury of the knee. A similar mechanism of an ACL deceleration injury is explained by Alentorn-Geli et al. (2009) as happening with knee extension and an internal torque combined with a valgus rotation, the body weight shifted over the injured leg and foot pronation on the playing surface. Berns, Hull, and Patterson (1992) found a combination of internal or external rotation and valgus or varus movements combined put more strain on the ACL than a single movement on its own (Berns, Hull, & Patterson, 1992). Boden et al. (2000) examined 71 non-contact knee injuries; of the 71, 38 happened during deceleration and 26 during landing. Both deceleration and landing cause the body to slow down the movement of the center of mass. The process to do both are multi-movement actions that could include all of the biomechanical mechanisms explained above. The multiple mechanisms of injury all relate to the ability of the hamstrings to antagonistically contract and the ability to control access valgus and varus motions. The ability to control these motions come from many different aspects.

Non-contact ACL injuries most likely have a multifactorial etiology (Alentorn-Geli et al., 2009). An article written by Meeuwisse (1994) examined risk factors and inciting events which have potential to lead to injury and he developed a model to assess the multiple risk factors that could lead to an athletic injury in general. Meeuwisse (1994) found that injuries can be caused by many different factors including internal and external factors. It is stated that intrinsic factors can predispose an individual to injury. Meeuwisse (1994) gives examples of internal risk factors, such as history of injury and body type. External factors act from outside the body, such as field conditions and rules. Bahr and Krosshaug (2005, p.327) examined the study by Meeuwisse (1994) and provided Figure 4 to help better understand all the factors that lead to injury. Since this study is looking at knee injuries and ACL injuries in particular, Figure 4 can help to find possible interventions leading to prevention.

Figure 4 (Bahr & Krosshaug, 2005, p.327) is broken down into two main categories: risk factors of injury and injury mechanisms that affect the injury prior to the injury happening. The main categories are then broken down into three more complex categories to explain causation of injury. Risk factors for injury have two sub-categories: internal risk factors and exposure to external risk factors. Injury mechanisms are broken down further to inciting events. This study will focus on the areas where a possible intervention could be used to help reduce the chance of injury.

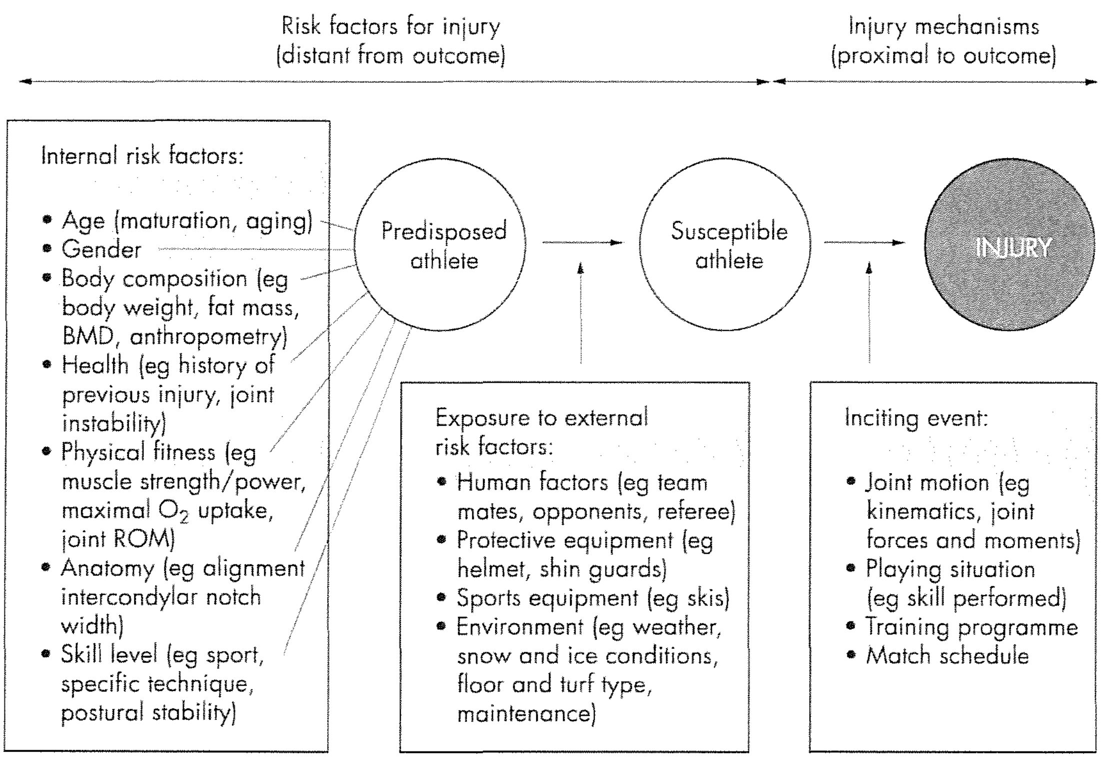

Figure 4. A more complete and understandable approach to the description of injury mechanisms (Bahr & Krosshaug, 2005, p.327).

Internal Risk factors

Alentorn-Geli et al. (2009) wrote a review that examined 204 articles with the goal of understanding how intervention could be taken to reduce ACL injury risk in soccer players. The review helps to break down and understand the risk factors (presented in Figure 4). An internal risk factor presented is gender. Multiple studies have reported females have a higher incidence of ACL injuries than males. Toth and Cordasco (2000) show females to have a risk of ACL injury eight times greater than males. Prodromos, Han, Rogowski, Joyce, and Shi (2007) did a meta-analysis study looking at which sports had the highest risk of ACL injury. The meta-analysis found that women's basketball and women's soccer athletes had the highest incidence of ACL injuries and this was 3 times greater than their male counterparts. Knee joint laxity is also identified as an internal risk factor (Bahr & Krosshaug, 2005, p.327). In conjunction with gender, recent research has been looking at hormonal effects on injury. Perrin (1999) explains some possible reasons for this are an increase in joint laxity in conjunction with an increase in hormonal release during menstrual cycles. This can be tied into gender and the difference in rates of injury. Liu et al. (2006) found that ACL cells have both estrogen and pro-estrogen receptors possibly making them susceptible to hormonal effects. Heitz, Eisenman, Beck, and Walker (1999) found that as estrogen and pro-estrogen levels rose, ACL laxity also did. An increase in hormones could increase laxity of the ACL, creating more laxity of the joint and therefore making it more susceptible to injury. In the meta-analysis done by Alentorn-Geli et al. (2009), nine studies reviewed found an increase in knee laxity during the ovulatory or post-ovulatory phases of the menstrual cycle. Hewett, Zazulak, and Myer (2007) found this phase of the menstrual cycle is consistent with estrogen surges. Arendt and Dick (1995) and Martineau, Al-Jassir, Lenczner, and Burman (2004) found the use of oral contraceptives decreased ligamentous laxity in female soccer players and lowered the rate of injury. These results suggest that lower levels of hormones found in oral contraceptives can potentially reduce injury in females (p.713).

Joint laxity was found to increase the risk of injury in both males and females (Alentorn-Geli et al., 2009). Knee joint laxity was found to increase valgus-varus and internal external rotation at the knee and an increase in valgus collapse while athletes played basketball and soccer (Alentorn-Geli et al., 2009, p.710). The increase in joint laxity and the excess movement that is associated with it will put unwanted stress on the ligaments of the knee increasing the risk of injury (Alentorn-Geli et al., 2009).

Alentorn-Geli et al. (2009) go on to explain how fatigued muscles are not able to absorb as much energy. Under fatigued conditions, it was found that knee flexion angle decreased along with an increase in tibial anterior shear force and knee varus movements when doing stop-jump tasks. Chappell, Herman, Knight, Kirkendall, Garrett, and Yu (2005) and Ryder, Johnson, Beynnon, and Ettlinger (1997) also found an increase in anterior tibal motion as fatigue increased. Fatigue of the core muscles or lower extremity muscles might increase the chance of a biomechanical mechanism leading to higher risk of injury.

Anatomical factors are reviewed in depth by Alentorn-Geli et al. (2009) and include: pelvic tilt, Q-anlge, intercondular notch width, and foot pronation. An increase in pelvic tilt was associated with an increase in ACL injury. An anterior pelvic tilt will lengthen and weaken the hamstrings and gluteal muscles. This leaves the athlete at risk for an increase in anterior tibial displacement and an increase in femur internal rotation and adduction. Q-angle is argued to be a risk factor though the exact role Q-angle has on the impact and risk factors for non-contact ACL injuries has not been found (p.711). Pantano, White, Gilchrist, and Leddy (2005) explain that pelvic width to femoral length ratios are to blame and not Q-angle. Looking at peak knee valgus during a squat and static knee valgus, no significant difference was found in college athletes with a higher Q-angle than a lower Q-angle. Participants with a larger Q-angle though did have a larger pelvic width to femoral length ratio. Pelvic width and femoral length ratios were related to static and dynamic knee valgus, and therefore could be the predisposing factor that has been hidden by Q-angles. Alentorn-Geli et al. (2009) concluded there is not enough evidence to suggest increased Q-angles as a risk for ACL injury.

A narrower intercondular notch width has been associated with a higher risk in ACL tears (Alentorn-Geli et al., 2009). It is suggested the narrow notch may cause an impingement of the ACL during tibial external rotation and abduction (p.711). Foot pronation and navicular drop have been found to correlate with an increased risk for ACL injury. Alentorn-Geli et al. (2009) explains other studies have found no statistical evidence that foot pronation and navicular drop were associated with ACL injury. The meta-analysis explains that foot pronation causes a tibial rotation at the knee as the leg extends. Tibial rotation only happens in the gait during contact phase of the gait. Pronation of the foot after the contact phase will leave the tibia internally rotated as the foot tries to supinate and the tibia tries to externally rotate in the mid-stance of the gait. This position translates force upward to the knee due to an increase in the tibial rotation. Forced movement of the body with the foot pronated and tibia internally rotated preloads the ACL placing excess stress on it potentially leading to a rupture. The increase in foot pronation and the tibia being internally rotated can also increase the internal rotation of the femur which will increase the valgus motion at the knee increasing the risk of ACL injury (Alentorn-Geli et al., 2009, p.712). Even though controversy exists, it is possible the biomechanical changes caused by foot pronation and navicular drop could increase injury.

External Risk Factors

Risk factors that fall under the category of external risk factors are human factors, equipment, and environment (Bahr & Krosshaug, 2005, p.327). Human factors would include contact injuries (Bahr & Krosshaug, 2005, p.327). It must be noted contact injuries are very hard to prevent. An example of a contact injury could be an athlete is hit on the lateral portion of the knee by another player, this contact causing a potential for the knee to be forced into a valgus collapse. This will put the knee at risk of injury. Gross valgus movements at the knee caused by external factors are not easy to prevent though attempts have been made through rule changes to reduce the risk (Anderson et al., 2009).

Environmental conditions have been found to have some effect on the rate of ACL injury. Alentorn-Geli et al.'s (2009) meta-analysis found artificial turf may place athletes at a higher risk of injury due to a harder surface increasing the ground reaction forces causing high energy impact forces when decelerating and landing. (p.723) Alentron-Geli et al. (2009) found an increased rate of ACL injury on dry natural grass compared to wet natural grass. It is thought an increase in friction and torsional resistance from the shoe on dry grass when compared to wet grass could be the cause of the increase in ACL injury rate (p.708).

Protective equipment such as a knee brace could be used to help reduce the risk of injury. Anderson et al. (2009) explains a brace can be prescribed to an individual with moderate to low instability issues and after ACL reconstruction. The goal of the brace is to control tibial translation and rotational stress of the femur. No consensus exists to explain the effectiveness of using a brace. The chance that a brace might not be effective leads to the need for better forms of prevention.

Inciting Events

Bahr and Krosshaug (2005) show in Figure 4, that internal risk factors and external risk factors have an effect on injury through inciting events. The inciting events are what lead to an injury and the main focus in preventing injury. Joint kinematics, joint forces, movements and skills can all be worked on within a training program. Finding an intervention to reduce the risk caused by predisposed factors can be done but is limited to a select few. Some can be changed with surgery, like the alignment of the intercondylar notch, but the goal is always to avoid surgery whenever possible (Bahr & Krosshaugh, 2005). Understanding the three areas of this model can help to indicate where intervention can take place to prevent injury from occurring. Intervention for potential of prevention will have to consider all of the above factors along with mechanisms of non-contact injuries to reduce inciting events. The researcher addressed joint motion, muscle actions, and training programs as potential interventions of prevention.

Chappell et al. (2005), Ryder et al. (1997), Meeuwisse (1994), and Alentorn-Geli et al. (2009) have shown knee injury to be caused by multiple factors including: decreased hamstring strength relative to quadriceps strength and decreased recruitment of muscle fibers, muscular fatigue by altering neuromuscular control, decreased "core" strength and proprioception, lateral trunk displacement and hip adduction combined with increased knee valgus movements, and increased hip internal rotation and tibial external rotation with or without foot pronation. This list can help to explain ACL injury etiology and help to answer the question of what can be done to help prevent ACL injuries from happening?

Of all the inciting factors examined above, all athletes can be worked with to increase physical fitness, strength, skill, and kinematics, through a training program. The motions that cause ACL injury have a potential to be reduced through training the glutes, gastrocnemius, quads, muscles connected to the TLF, and hamstrings. When strengthening these muscle groups a training program could work with skill and kinematics also. Risberg, Holm, Myklebust, and Engebretsen (2007) found training the muscle groups using perfect kinematic mechanics repetitively leads to proper form through correct repetitive neuromuscular activation. The repetition leads to improved proprioception of knee kinematics through athletic movements leading to a possible reduction in injury. Exercises that strengthen, increase stamina, and work repetitive motions similar to athletic motions could lead to a reduction in ACL injury.

ACL Rehabilitation

Understanding how an injured athlete will recover from an ACL injury can help a practitioner understand how one can be prevented. Following an ACL reconstruction a patient will go through a knee rehab protocol that is given by the orthopedic surgeon. According to Myer, Paterno, Ford, Quatman, and Hewett (2006), current ACL rehabilitation protocols are now emphasizing immediate motion, early weight bearing and accelerated return to sports participation for athletic patients. In the past protocols would immobilize the patient for a prolonged period of time and allow only non-weight bearing activity. Rehab protocols are commonly divided into early (immediate postoperative and subacute strengthening) and late rehabilitation phases (functional progression and return to sport). Phase progression is determined by specific goals and time since surgery.

Current protocols are more aggressive and advocate athletes to return to initial sports activity in as early as 8 weeks while some wait until week 12. An example of a current protocol from The Center for Orthopedics (2014) for an ACL reconstruction rehabilitation is in Appendix C. The Center for Orthopedics (2014) protocol sends the patient to a checkup with the orthopedic surgeon to check progress at week 8 (see page 3 of the protocol). If on schedule the protocol will move forward to a late rehabilitation stage. At this point lateral motion can be introduced into the rehabilitation protocol. The introduction to side movement in a protocol would allow for Myer et al.'s (2006) stage one work of late rehabilitation to begin (see Appendix D). On top of doctor release, Myer et al. (2006) recommend a patient meets a minimum baseline criteria to enter into the late rehabilitation phase. Criteria for phase advancement is laid out as having a minimum International Knee Documentation Committee (IKDC) Subjective Knee Form Score of 70 (IKDC, 2014) (see Appendix E). Irrgang et al. (2001) explain the IKDC Subjective Knee Form is a reliable and valid tool for determining a patient's rating of knee symptoms, function, and ability to participate in sport following knee injury- specifically, ACL injury. When the criteria is met, the Myer's four stage late rehabilitation process can begin. Goals and criteria for progression can be found in Appendix D (Myer et al., 2006). Using these guidelines a practitioner can make sure a patient is ready to move to late stage rehabilitation.

The mixture of the ideas in each of the protocols illuminates different philosophies on progressing an athlete back to full release. Goals that both the Myer et al. (2006) and The Center for Orthopedics (2014) want to accomplish include symmetric performance of surgical to non-surgical repaired leg, safe biomechanics, improved mental confidence with activity, and continued strengthening of the core and lower extremity. Accomplishing this is done through rehabilitation exercises.

Rehabilitation Exercises

Some variables that need to be considered when an athlete is going through an ACL rehab stint is the type of surgery performed. An ACL reconstruction can use many different types of grafts for the new ACL. This needs to be understood due to the fact the type of graft used will limit or delay some exercises in the rehabilitation process. For example looking at a patient that has had a hamstring graft, The Center of Orthopedics (2014) protocol (see Appendix C) allows no active hamstring exercises until 2 weeks and no open-chain resisted hamstring curls until 4 weeks post-op. The Center of Orthopedics protocol for a patella tendon graft, allows no resisted leg extension machine at any point. A meta-analysis review of 48 articles done by Ardern, Webster, Taylor, and Feller (2011) found patellar tendon grafts were used in 3967 patients (69%), while 1156 patients (20%) received hamstring tendon grafts. The remaining patients received iliotibial band grafts (2%), fascia lata and gracilis grafts (1%), fascia lata grafts (0.8%) or synthetic ligaments (0.3%) for their ACL reconstruction. Four studies did not report graft type (Arden et al., 2011).

Exercises used in each phase are specific to the goals of the phase. Exercises used in each phase of another commonly used ACL rehab protocol, the Brigham and Women's Hospital (2006) protocol are outlined in Appendix F, along with goals and criteria for advancement. Table 4 in Appendix F explains the goals of each phase of the Brigham and Women's Hospital (2006) protocol, and Table 5 shows specific exercises to go along with the goals of each phase. Phase one's goals are to protect the graft and increase range of motion while controlling swelling. Stretching along with minor strengthening activities are done. Phase two's goals are to restore normal gait, increase strength, and increase proprioception while still protecting the graft. Exercises to focus on these goals include continuing with flexibility and closed kinetic chain exercises. The patient will also begin working on climbing stairs and using the elliptical for conditioning. Phase three's goals are to gain full range of motion and gain normal running mechanics while protecting the graft. Exercises to reach goals are to continue flexibility, move to full weight bearing running at week 12, and lower extremity strength exercises. Phase four has the goals of basic agility drills and add quadriceps and hamstring strength. Strengthening exercises will continue and a plyometric program will be initiated. The patient will also progress to running increased distances and sport-specific drills (Brigham and Women's Hospital, 2006). This protocol lays out a basic idea of what a rehab protocol should involve to bring an athlete back to full participation. The Center of Orthopedics (2014), Myer et al. (2006), and Brigham and Women's Hospital (2006) are rehab protocols that were picked by the researcher, from many, because they give good examples of ACL protocols. They all address the same issues and are done by well-respected institutions.

A study done by Porucznik (2013) looked at 78 patients (59 female, 19 male) that had undergone ACL reconstruction. The patients were followed for 24 months after returning to play. They were then compared to a control group of 47 healthy individuals. The number of injuries sustained by the patients was investigated. Over the 24 month period the injury rate for the study group had 30% sustain a second ACL injury, 21% sustaining an opposite leg injury and 9% sustaining a graft re-tear. The study group also sustained 6 times more injuries than the control group. This study shows individuals returning to sport after an ACL injury have a high risk of sustaining another ACL injury on the same or opposite leg (Porucznik, 2013). Current standard rehab techniques must be examined with such a high rate of second ACL injury. When an individual tears an ACL there is a high chance they have predisposing factors that led to it. As talked about previously, a type of training must focus on eliminating gross non-contact biomechanical mechanisms through physical fitness, strength, skill, and kinematics. Doing this in a training setting and/or rehab setting could reduce the number of ACL injuries sustained each year.

Konrad (2005) explains for an exercise to be effective at strengthening the muscle used, the muscle must contract at 40-60% of its maximum voluntary contraction (MVC). Therefore a significant muscle contraction will be one greater than 40% MVC. Exercises done currently in a rehab setting were studied by Ekstrom, Donatelli, and Carp (2007) using EMG. Ekstrom, Donatelli, and Carp (2007) found a side bridge to have a significant percent of MVC to strengthen of the gluteus medius by measurement of amplitude as a % of MVC. Side bridges were done for 5 seconds. Prone bridges were found to activate the rectus abdominus significantly by measurement of amplitude as a % of MVC (Ekstrom, Donatelli, & Carp, 2007). Prone bridges were done for 5 seconds. A study done by Ekstrom, Donatelli, and Carp (2007) using EMG to measure muscle activation amplitude as a % of MVC found the hamstrings muscle group to be activated by a forward lunge. Dwyer, Boudreau, Mattacola, Uhl, and Lattermann (2010), using EMG to measure muscle activation amplitude as a % of MVC, found the rectus femoris to be activated by the lunge. A review by Reiman, Bolgla, and Loudon (2012) found the gluteus maximus to be most significantly activated on a forward step up exercise by measurement of amplitude of % of MVC. There is a lack of MVC studies on gastroc activation. Andrews, Harrelson, and Wilk (2004) found that during the push phase of the gait cycle, when the foot is maximally plantar flexed, the gastroc was activated. To mimic this a heel raise could be done at the top of a step up. Research found the previous exercises to significantly strengthen or activate and possibly strengthen the muscles involved in ACL injury mechanisms like the valgus collapse, and therefore they were used as the control exercises of the study (Figure 5).

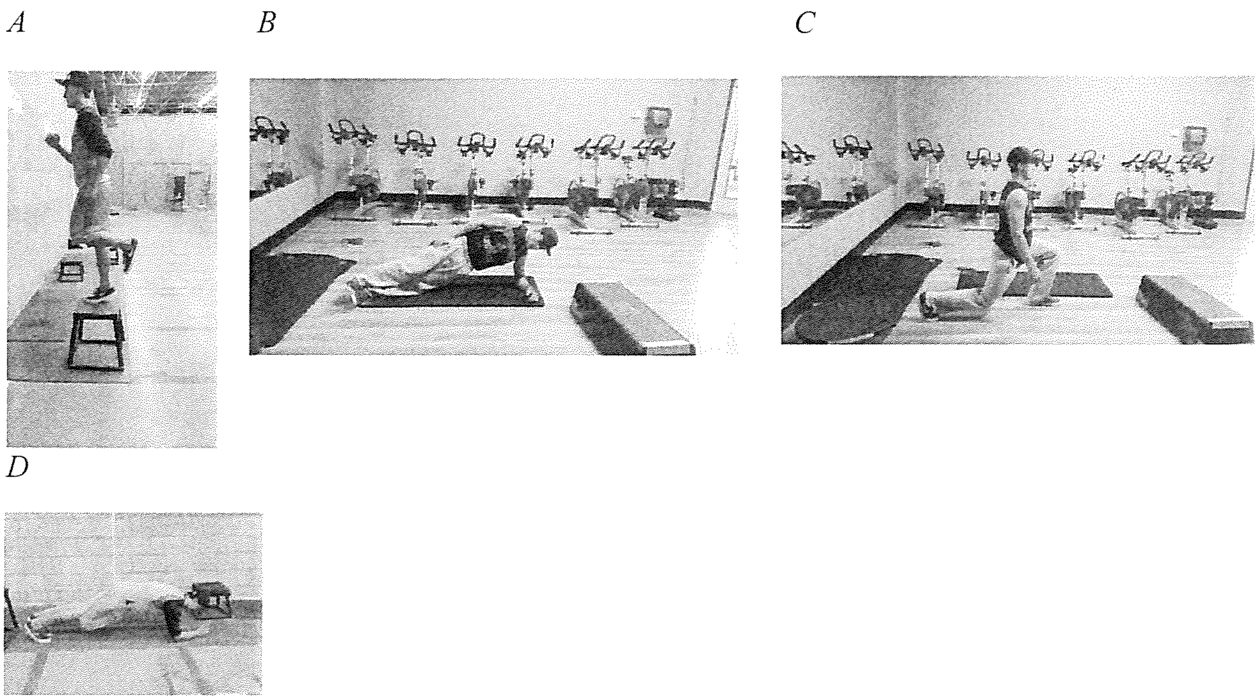

Figure 5. Pictures of the rehab exercises. (A) Forward step ups, (B) side bridge, (c) lunges, and (D) prone bridge.

Forward Lateral Retro Lateral Exercise

Reiman, Bolgla, and Lorenz (2009) stated that a program that emphasized a neutral (minimal knee valgus and knee varus) knee alignment during athletic maneuvers could reduce the risk of injury. The program should also focus on peak knee adduction and abduction movements in athletic motions (Reiman, Bolgla, & Lorenz, 2009, p.39). Hewett, Strope, Nance, and Noyes (1996) did a jump training program with female high school volleyball players. The program was split into three phases: the technique phase, the fundamental phase, and the performance phase. The technique phase concentrated on body alignment throughout the jump and emphasized the lack of valgus movement at the knees while jumping. The fundamental phase worked on building strength in the correct movement patterns, and the performance phase concentrated on achieving maximal vertical height (Hewett et al., 1996). The findings of this study were positive in the performance realm by increasing vertical jump numbers, which was a main goal of the program (Hewett et al., 1996). Hewett et al. (1996) also found the program decreased peak landing force, which has been found to be a cause of knee injury, ACL injury in particular (Powers, 2010, p.43). The study by Hewett et al. (1996) stated the reduction in peak landing force was solely due to the ability for the athletes to control the valgus and varus motions at the knee (p. 770). Research is pointing to the kinetic chain having a major impact on the cause of an ACL injury. The effect of the kinetic chain causing injury means the movement of the hip would have an effect on the knee, like Flanagan (2014) explains happens in a valgus collapse.

It is believed that training interventions can reduce the risk of knee injury. In order to help create a training regimen to reduce chance of injury in the knees, examination of the muscles that control the motions of the valgus collapse and affect stability of the hip may be necessary. Flanagan (2014) explains when looking at a valgus collapse causing injury to the knee, it needs to be understood that muscles acting in the eccentric contraction will be used to control this motion. The muscles that have control over hip abduction and external rotation of the femur are the gluteus maximus, gluteus medius, gluteus minimus, sartorius, and tensor fascia latae (Flanagan, 2014). The gastrocnemius and hamstrings play a major role in knee stabilization and the Quad strength dictates return to play (Myer et al., 2006). Strengthening these muscles could lead to less injury and faster return to play. A possible intervention that could be used to train these muscles would be FLRL exercises.

Forward Lateral Retro Lateral (FLRL) exercises are exercises the researcher has used in training programs in the past. The main reason for beginning the use of the FLRL exercise was to increase activation and strengthening of the muscles used in running and therefore increase running speed. FLRL exercises have shown great effects with rehab and performance training. In the rehab setting of an ACL reconstruction, an athlete using the FLRL exercise as the cornerstone of the rehab process was able to get a full release after five months. Five months is accelerated return when compared to a study done by Brophy et al. (2012) in which the authors followed 100 athletes and found the average return time was 12.2 ± 14.3 months post ACL surgery when using standard rehab protocols. The way the FLRL exercise is performed is based off of personal experiences of the researcher and the beneficial results the use of the exercise has produced in the training programs of over 250 athletes. A version of the exercise which has since been modified, was learned by the researcher when working at Rocky Mountain Performance in Trinidad, CO. The exercises, as shown in Figure 6, have the athlete work at various inclines, which progressively increase during the training program, on a treadmill to use overload training. The athletes work forward, lateral and retro (backwards). It is hypothesized the forward work primarily trains the hip extensors, the lateral primarily trains the hip abductors and adductors, and the retro primarily trains the knee extensors and hip flexors. This exercise works the athlete in all planes of motion in a functional manner. The ability of the treadmill to change speeds allows the athletes to work at game speed in a controlled environment with a trainer next to them making sure joint kinematics are correct; and the ability to change elevation can lead to a consistent overload when implemented in a training program.

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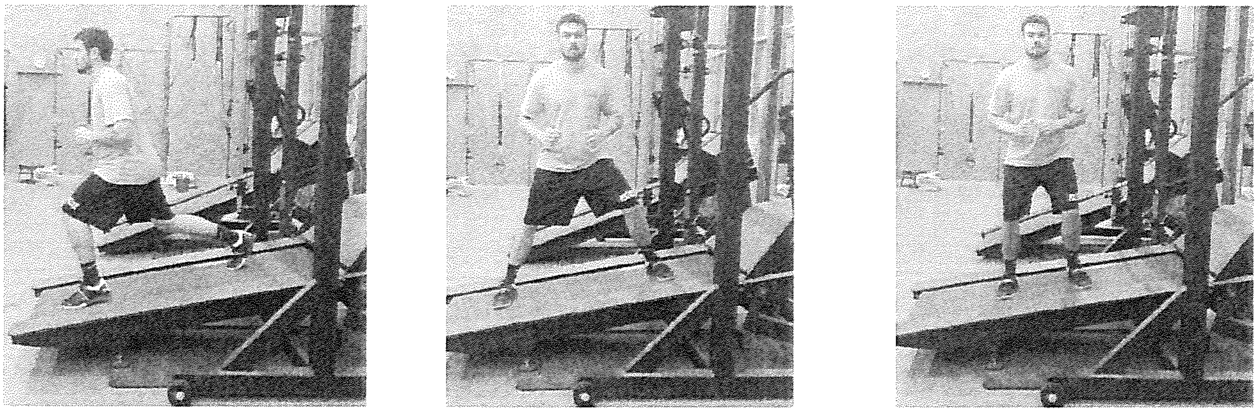


Figure 6. The actions involved in the FLRL exercises. (A) The retro walks, the athlete reaches back and pushes off through the toe to mimic athletic actions. (B,C) show the lateral portion of the exercise. The athlete will abduct and adduct the hips at incline.

The actions involved in the FLRL exercises are thought to be as follows: When the participant walks forward the hamstrings and gastrocnemiuss are used to walk up the incline. During the lateral walks the athlete will abduct and adduct the hips at incline. Sloniger, Cureton, Prior, & Evans (1997) state uphill training produces significantly more muscle activation than horizontal training. Training with the FLRL at incline should strengthen the gluteus maximus, gluteus medius, gluteus minimus, sartorius, and tensor fascia latae due to the actions being used. During the retro walks the athlete walks backwards reaching the leg to fully stretch the quads and pushes off through the toe using the gastrocnemius and quads to mimic athletic actions. As explained by Flanagan (2014), causes of a valgus collapse may be lack of strength/ power/ endurance of the subtalar invertors (gastrocnemius, hamstring muscle group) and hip external rotators (the gluteus maximus, gluteus medius, gluteus minimus, sartorius, and tensor fascia latae) as these groups control eccentric motion during lower extremity flexion (Flanagan, 2014, p.352).

The FLRL exercise is an exercise that is hypothesized to work the entire core and hip complex in one set. In the rehab exercises chosen for the study, the exercises are observed to only work the body in one plane of motion and do not mimic game situations (Myer et al., 2006). The introduction of the full body weight FLRL exercise would possibly occur in the late rehabilitation phase (Myer et al., 2006). Moving into this phase happens when an athlete demonstrates significant strength, is able to do lateral shuffling, full weight bearing exercises, and is able to perform exercises on a moving surface or a treadmill (Myer et al., 2006). All of these factors need to be obtained by the athlete for safety and lower risk of injury while doing the FLRL exercises.

The FLRL is an exercise that takes approximately one and a half minutes to complete. This puts demand on the working muscles to continue to contract through the duration of the exercise. The ability for the practitioner to stand next to the patient and check kinematic form through the duration of the exercise will insure the patient is working the muscles in their proper form as they are pushed to fatigue. As Alentorn-Geli et al. (2009), Chappell et al. (2005), Flanagan (2014), and Ryder et al. (1997) suggest, fatigue leads to the gross biomechanical mechanisms that cause ACL injuries. The hypothesized capability the FLRL exercises have to fatigue the muscles in a controlled environment could lead to adaptations that will ultimately reduce the amount of fatigue in a sport situation.

Surface Electromyography

Konrad (2005) explains EMG is a research and evaluation tool that reads the electrical signal the muscles produce when activated. EMG is an established tool for evaluation in applied research. It can be used in medical research, rehabilitation settings, and sports science settings (Konrad, 2005). This study will be using the EMG as a tool to analyze active training exercises. When looking at active training the EMG tool can answer five questions: (1) is the muscle active, (2) is the muscle more or less active than the control, (3) when is the muscle on/off, (4) how much is the muscle active, and (5) does the muscle fatigue (Konrad, 2005)? For this study, the EMG was used to analyze whether the muscle is active, if it is more or less active during the FLRL than the control, how much the muscle is active, and does the muscle fatigue?

The EMG signal produced is based upon action potentials at the muscle fiber membrane resulting from depolarization and repolarization process of the muscles (Konrad, 2005). At rest the muscle fibers of a given muscle have a difference in charge between the inner and outer surface. There is a negative intracellular charge compared to the external surface creating a resting potential at the muscle fiber membrane. In order for a muscle contract, the central nervous system activates the anterior motor neuron. This creates an action potential. The action potential spreads across the muscle plasma membrane opening voltage-gated sodium and potassium ion channels. This creates an increase flow of sodium into the cell and potassium out of the cell cutting off the positive charge. This flow depolarizes the cell allowing the muscle fiber to have the ability to contract. When the nerve impulse is cut off, the action potential is cut off, sodium flows out of the cell and potassium flows back in repolarizing the cell (Pollard, Earnshaw, & Lippincott-Schwartz, 2007; Powers & Howley, 2012). The electrodes pick up an electrical dipole or a depolarization wave that is produced by the depolarization – repolarization cycle (Konrad, 2005).

EMG answers the question if the muscle is active by observing any trace of EMG activity. It is answered on the nominal level with a yes/no (Konrad, 2005). To answer the question if a muscle is more active a comparison is needed. In this case the FLRL exercises were compared to the four standard rehab exercises. The question is answered on a scale level. The amplitudes were converted to an ensemble average mean expressed as a percentage of MVC and then compared. EMG amplitude ensemble average expressed as a percentage of MVC is the most useful way to analyze the comparison of the exercises (Konrad, 2005). The numbers given explained how much work or effort a particular muscle needs to give in a certain exercise. To answer the question of is the muscle active enough to produce hypertrophic effects, the ensemble average mean of EMG amplitudes expressed as a percentage of MVC was given a nominal value of above or equal to 40% or below 40% and then compared.. Efficient strength training exercises need an intervention level of at least 40-60% of max voluntary contraction (Konrad, 2005).

To answer the final question of does the muscle fatigue, the EMG analysis can use both amplitude and frequency measurements to show changes due to muscular fatigue. However Stulen and De Luca (1981) explain amplitude is known to vary with type of electrode used to detect the signal and therefore might be unsuitable for measuring the conduction velocity and the associated muscle fatigue. To monitor the decrease in conduction velocity Stulen and De Luca (1981) suggest it is only necessary to track the changes in a characteristic frequency of the spectrum (Stulen & De Luca, 1981). A test showing fatigue of the muscle will show a decrease in muscle firing frequency over contraction time (Konrad, 2005). Frequency declines because the conduction velocity of the motor unit action potentials on the muscle membrane decreases (Konrad, 2005). Fatigue is a very important measurement when looking at muscular training (Konrad, 2005). Short-term fatigue is the preliminary condition of muscle growth (Konrad, 2005). Bonato, Roy, Knaflitz, & De Luca (2001) explain the following: "The main phenomenon that influences the frequency scaling of the power spectrum of the myoelectric signal is the accumulation of biochemical byproducts within the muscle. The metabolite accumulation induces a progressive modification of the interstitial fluid pH, which in turn causes a reduction of the propagation velocity of the action potential along the muscle fibers. This complex of electrophysiological phenomena is referred to as localized muscle fatigue" (Bonato et al., 2001). The ability for an exercise to answer the four questions positively should lead to an increase in strength and endurance of the muscles being targeted by the exercise, due to the need for muscle recruitment and frequency of contractions.

Summary

The goal is to never have an ACL injury happen in sports but they do happen. Looking at the reasons they do happen has brought researchers to look for possible ways to prevent them from occurring. The use of FLRL exercises could be a possible exercise to help athletes prevent ACL injuries. The FLRL exercise has the potential to strengthen and increase endurance in the muscles that control the knee from gross biomechanical mechanisms that lead to injury. The use of the FLRL exercise could also teach proper joint kinematics to help reduce the risk of ACL injury. The FLRL exercise could also have potential to help in the rehab setting to speed recovery, along with reducing the chance for a second injury. Using EMG technology the researcher was able to test the effectiveness of the FLRL to see if the exercise has possible application in the performance training and rehabilitation settings.

Chapter 3: Procedures

Setting

The testing took place at Anytime Fitness, a fitness facility in Alamosa, Colorado, located at 7544 feet elevation, on a Noracmo High Speed Elite Treadmill in the isolated Sports Performance room.

Population

The participants were healthy well trained (at least 5 years of high level sport training) individuals who have had previous training of a minimum five sessions doing the FLRL exercises, and each session had a minimum of 3 sets of the FLRL done; therefore 15 sets of the exercise at minimum were done on an inclined treadmill by the participants. The training session familiarized the participants on proper form and increased their ability to give best effort. The researcher made the decision if the participants were good candidates by their ability to do the exercise correctly using proper muscle contractions. Twenty participants, both male and female (11 males, 9 females), ranging in age between 18 and 28 years, with a mean of 21.6 (± 2.6) years, participated in the study. The participants were recruited from Anytime Fitness in Alamosa, Colorado. All participants were in good health, fit/regularly trained for 5+ years, and were not recovering from any lower leg injuries. Participants were excluded if they had a previous lower extremity injury that required surgery. Participants signed an informed consent that was approved by ASU's IRB (Appendix G), a waiver of liability for the study, a waiver of liability for the facility, and a participant questionnaire (Appendix H).

Instrumentation

Analyzing software- BTS EMG-Analyzer was used to analyze the electromyography signals produced to measure muscle activation, muscle activity, and muscle fatigue.

EMG BTS FREEEMG 100 RT system- this was used to take the electromyography measurements of the rectus femoris, rectus abdominis, gluteus maximus, gluteus medius, hamstrings, and gastrocnemius muscles.

Electrodes- The surface electrodes used were made by Coviden Company; the model is the Kendall ECG Electrodes H12456, made of foam and hydrogel and have snaps to connect to the EMG. The electrodes monitor an area of 30mm x 24mm.

Mats- Mats with the dimensions 48"L x 20"W x 1/2" thick were used for the participants to lay on during side bridges, prone bridges, and MVC's.

Step-up box- An 18-inch box was used for the forward step-ups.

Treadmill- Noramco High Speed Elite treadmill was used to do the FLRL exercise.

Research Design

All procedures took place on the same day. Prior to any electrode placement for EMG, participants were briefed on the experimental procedures. Instruction on doing the MVC, FLRL exercises, and rehab exercises were given to insure proper form. All participants had done the exercises previously so they were familiar with the exercises. However to insure all participants were comfortable with the exercises, a familiarization session was given. The participants were asked to and wore loose workout attire, shorts being necessary and shoes that are low tops and used for running. In the event participants used orthotics in their shoes they were not allowed to participate in the study. Participants were informed about the use and placement procedure of electrodes. Electrode placement sites were prepared by abrading the skin and cleansing the area with rubbing alcohol swabs. Shaving of hair was performed if body hair was present because it can interfere with EMG signals.

Electrodes were then placed on the participants. The EMG placement was done on the dominate side of the participant's body. No evidence could be found that indicated a significant difference in muscle activity between dominate and non-dominate sides of healthy individuals. Ekstorm, Donatelli, and Carp (2007) explain electrode placement sites (Figure 7). For the rectus abdominus, the electrodes were placed 3cm lateral and 3cm superior to the umbilicus. For the gluteus medius, the placement was anterosuperior to the gluteus maximus muscle and just inferior to the iliac crest on the lateral side of the pelvis. For the gluteus maximus muscle, electrodes were placed in the center of the muscle belly between the lateral edge of the sacrum and the posterosuperior edge of the greater trochanter. A general electrode placement was used for the entire hamstring muscle group midway between the gluteal fold and the popliteal line on the posterior surface of the knee in the center of the posterior thigh. The gastrocnemius and rectus femoris electrode placement was over the center of the muscle's belly (Ekstorm et al., 2007). The sites chosen by the researcher measured the muscles found to be the most important when looking at ACL injuries in the review of literature.

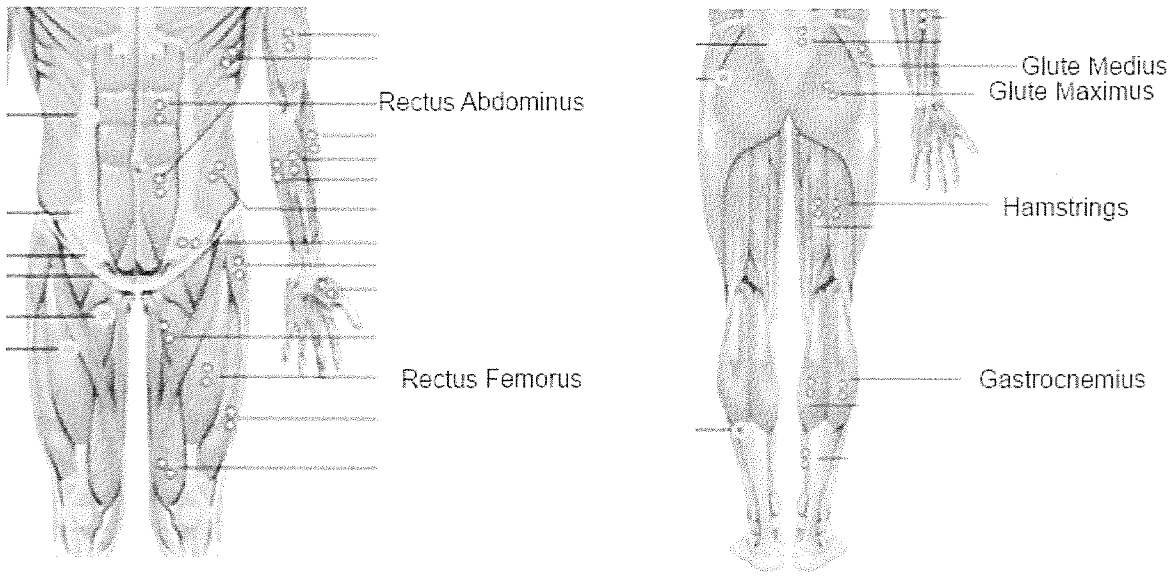


Figure 7. The placement sites for the rectus femoris, rectus abdominis, hamstrings, gluteus maximus, gluteus medius, hamstrings, and gastrocnemius (Konrad, 2005).

All participants walked on a treadmill at 3 mph to warm up for three minutes. Next the participants did maximum voluntary contractions (MVC) for the rectus abdominus, rectus femoris, gluteus maximus, gluteus medius, hamstrings muscle group and gastrocnemius. Figure 8 illustrates the positions and actions of the MVC for the rectus abdominus, rectus femoris, gluteus maximus, gluteus medius, hamstring muscle group, and gastrocnemius. The MVC tests were randomized for each participant by the participant randomly picking numbers to determine the order in which the tests were done. Each position was manually resisted to maximal amount then held for five seconds. The participants did not have any previous training on MVC testing. Each test was done twice on each muscle with a 30-sec rest period between. The participants were given a 30 second rest between each MVC (Konrad, 2005). The MVC tests gave confirmation of proper electrode placement by viewing EMG signal amplitude during an isolated muscle test (Ekstorm et al., 2007).

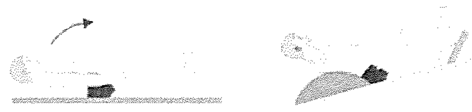
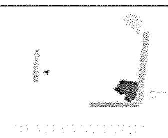
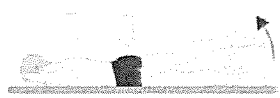
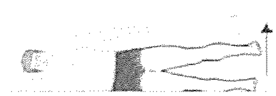
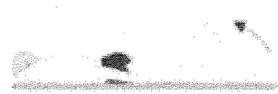
Rectus abdominis / Obliquus internus abdominis		A valid MVC test for the abdominals is difficult to arrange. Sit-up styled movements with the legs securely fastened work the best. Let the spine flex by around 30° and use a belt or manual restraint for that position. The obliques may fire more when an additional trunk rotation is added to the flexion
Rectus femoris		An easy and beneficial exercise for all quadriceps muscles is a single leg knee extension between 90 and 70° knee flexion position.
Gastrocnemius		Being one of the strongest human muscles, the triceps surae group requires a very rigid (machine) resistance against the restrained hip. Perform an unilateral plantar flexion at 90° ankle position
Glutaeus maximus		A control exercise for the gluteus maximus muscle. It should be performed both in extended and flexed knee position with slightly outward rotated legs. The hyperextension position (~20°) is important.
Glutaeus medius		The hip abduction can be performed in fixed side lying position or supine position. Some subjects show higher EMGs in standing position
Hamstring group		Isolated test for the hamstrings. Fasten the hip securely and perform a unilateral knee flexion at ~20-30 degrees knee flexion.

Figure 8. MVC positions (Konrad, 2005).

After MVC's all participants did both the FLRL exercise and rehab exercises on the same day. Participants randomly drew to decide if FLRL exercise or rehab exercises were done first. Due to the familiarity of the participants with the FLRL exercise, a middle of the program incline and reps were used for the exercise. The FLRL exercise was done on a Noramco High Speed Elite treadmill at an incline of 15% at 3 mph doing 10 forward steps, turning left for 10 lateral steps, turning reverse for 20 retro steps, turning left again for 20 lateral steps, turning backwards for 20 retro steps, turning right for 10 steps, and then forward for 10 steps (Figure 6). In the event the participant needed spotting or did the exercise wrong the test was vetoed, a five-minute rest was given, and the participant repeated the exercise. The participants were given a five-minute break between the rehab and FLRL exercises. Baechle (2000) states full recovery from an exercise takes 3-5 minutes.

For the rehab exercises (refer to Figure 5), participants drew numbers to randomize the order the exercises were done. Forward step-ups were performed on an 18-inch box slowly through full range of motion and coming to the toe at the top, for ten reps continuously on one leg then switching to the other leg immediately for ten reps. A side bridge was performed on each side holding for 30 seconds and a 30 second rest between reps. Standing lunges with each leg forward were done starting with legs fully extended then slowly going through full range of motion to the point of maximal knee flexion and back to the top. The lunges were done for ten repetitions continuously on one leg then switching to the other leg immediately for ten reps. The last randomized exercise of the rehab exercises was a prone bridge that was performed for 30 seconds. The participants were given a one-min rest between each rehab exercise.

EMG Signal Processing

The electromyographic signal was detected via bipolar surface electrodes throughout the duration of the study. The signal was obtained with a sampling rate of 1000 Hz using a differential amplifier with variable gain. All of the raw sEMG signals were processed using the sEMG Analyzer Software (BTS Bioengineering, Italy). The root mean square over a time interval of 500 ms was computed for the raw MVC data, rehab exercises, and FLRL exercise; for all muscles analyzed in this study.

Looking at amplitude, the ensemble average was then computed for all muscles, except the rectus abdominus, in all conditions by picking 9-10 consecutive repetitions that were observed to be the highest amplitude of the exercise to analyze. The rectus abdominus mean average was analyzed from the full duration of the exercises. Analysis of the rectus abdominus was done from the full duration of the exercises to be consistent due to the comparison to the prone bridge, which is a stabilization exercise. The stabilization exercises could not be compared to independent repetitions of the other exercises. All data were then normalized to the MVC's and expressed as a percentage of the respective MVC for each of the muscles in all conditions.

Reliability

To the researcher's knowledge there is no research on the FLRL exercise. The personal experience of the researcher and use of the FLRL exercise on others has shaped how the exercise is done and used. The researcher standardized the protocol to improve reliability. The wireless surface electromyography (sEMG) electrodes, like used in this study, were proved reliable by multiple studies including ones done by Dwyer, Kennedy, Lamontagne, and Roth (2011), and Konrad (2005). Cram (1986) reported a mean reliability coefficient of 0.83 for EMG. The rehab exercises done in the study were done previously by Ekstorm et al. (2007) and Reiman, Bolgla, and Loudon (2012), and were confirmed to produce significant EMG activation for the muscles being tested. The electrodes were placed on every subject only by the researcher. The researcher was the only one interpreting the data. The electrode placement sites have been confirmed reliable by Ekstorm et al. (2007) and Konrad (2005).

Validity

Wireless EMG was proven to be a valid for measuring electromyography signals in muscles (Dwyer et al., 2011). The rehab exercises chosen are currently used as standard rehab exercises (Myer et al., 2006). The FLRL exercise was based off the researcher's personal experiences and its previous use with others in rehabilitation and performance training settings of more than 250 participants. This study was done to validate the use of the FLRL exercise and the way the researcher practices the exercise in training programs and for injury rehab.

Treatment of Data

The independent variables of the study were the FLRL exercise and the rehab exercises. The dependent variables of the study were the EMG signals produced measured in amplitude, frequency, and activation for the rectus femoris, rectus abdominis, gluteus maximus, gluteus medius, hamstrings, and gastrocnemius. Data was recorded in the BTS EMG- Analyzer. The data was filtered via Smart Analyzer software and averages of the data were used. The data was analyzed using SPSS v.22, 2013. To analyze if the muscle is active, the observation of any EMG activity was given a yes or no answer. To answer the question if the exercise activated the muscles the researcher observed the raw sEMG data for any trace of activity. A value of yes or no was assigned to the muscles.

To answer the question which exercise activated the muscles to a greater amplitude, a repeated measures ANOVA was run. Field (2013) explains the use of a univariate test is more powerful than a multivariate test in small sample sizes (p.549). In all tests done, Mauchly's test for sphericity was significant ($p<.05$), therefore a violation of sphericity was committed. When this happens the degrees of freedom need to be adjusted for any F-ratios affected by the violation (Field, 2013, p.548). The degrees of freedom can be adjusted by using the Greenhouse-Geisser when its estimate is between .25 and .75, which was true for this study (Field, 2013). A pairwise comparison using the Bonferroni method was run to determine which exercises had significantly different degrees of muscle activity (as a percentage of the MVC) of each muscle analyzed. The

Bonferroni method was chosen to control for type I error, due to violation of Mauchly's tests for sphericity (Field, 2013, p.547). Data output files can be found in Appendix I.

To answer the question which exercise activated the muscles in question at a value high enough to possibly cause hypertrophic effects, a nominal value was assigned to each ensemble average (expressed as a percentage of MVC) as above or below the 40% threshold. A nonparametric related samples McNeamer's test was run on the muscles comparing the rehab exercises to the FLRL exercise. Data output files can be found in Appendix J.

To answer the question which exercise created significantly greater amounts of fatigue in the muscles in question, a repeated measures ANOVA was run. A pairwise comparison using the Bonferroni method was run to determine which exercises had significantly different changes in frequency. Statistical significance for all tests was set at $p<0.05$.

Chapter 4: Results

Subjects

Twenty participants (11 males and 9 females) volunteered to be in the study. The mean age of the participants was 21.65 ± 2.62 years, and the mean weight 158.6 ± 31.29 lbs. All participants were healthy well trained (at least 5 years of high-level sport training) physically active individuals who were currently participating in aerobic and anaerobic training a mean of 5.2 ±1.11 days a week.

Findings

FLRL Muscle Activation

Trace EMG was observed by the researcher on all EMG data for the Rectus Femoris (RF), Gluteus Maximus (GMA), Gluteus Medius (GME), Abdominals (ABS), hamstring group (HAM), and Gastrocnemius (GA) except for the Gluteus Maximums on one of the participants. Excluding the GMA in the one participant, all muscles were active for the complete duration of the FLRL exercise (≈90 seconds).

Muscle Activation Levels

Rectus Femoris

Mauchly's test indicated that the assumption of sphericity had been violated $X^2(9)=118.56$, $p=<.001$, therefore degrees of freedom was corrected using the Greenhouse-Geisser test estimate of sphericity ($\varepsilon= .295$), $F(1.18, 22.4)=20.107$, $p<.001$. These results suggest there were significantly different amounts of activation in the RF between exercises. The observed power was .995. The comparison between the rehab exercises and the FLRL exercise for the RF found the ensemble means of percentage of MVC for the bridges (BR) was 16.89% ± 10.89%, side bridges (SB) was 7.65% ±9.9%, lunges (LU) was 49.55% ±20.64%, step ups (SU) was 50.5% ±41.5% and the FLRL was 91% ±78.03%. The FLRL significantly activated the RF better than the BR ($p<.05$), the SB ($p<.05$), and SU ($p<.05$). The FLRL did not significantly activate the RF more than the LU ($p>.05$). Table 1 shows the amplitude expressed as a percentage of MVC for all exercises. The p value represents the comparison of the exercise to the FLRL exercise.

Table 1. RF MVC%

Rectus Femoris		
Exercise	**MVC%**	**p**
Prone Bridge	6.89 ± 10.89	<.05
Side Bridge	7.65 ± 9.9	<.05
Lunges	49.55 ± 20.64	<.05
Step ups	50.5 ± 41.5	>.05
FLRL	91 ± 78.03	

Note. Shaded p values designate FLRL exercise activates the RF more significantly.

Gluteus Maximus

Mauchly's test indicated that the assumption of sphericity had been violated $X^2(9)=162.35$, $p=<.001$, therefore degrees of freedom were corrected using the Greenhouse-Geisser test estimate of sphericity ($\varepsilon= .261$), $F(1.05, 18.82)=13.371$, $p<.05$. These results suggest there were significantly different amounts of activation in the GMA between exercises. The observed power was .940. The comparison between the rehab exercises and the FLRL exercise for GMA found the ensemble means of percentage of MVC for the BR was 3.58% ± 16.4%, SB was 13% ±7.8%, LU was 20.3% ±7.9%, SU was 20.5% ±13.8% and the FLRL was 61.5% ±63.5%. The FLRL significantly activated the GMA better than the BR ($p<.05$), the SB ($p<.05$), and SU ($p<.05$). The FLRL did not significantly activate the GMA more than the LU but was very close and trending towards significance ($p=.06$). Table 2 shows the amplitude expressed as a percentage of MVC for all exercises. The p value represents the comparison of the exercise to the FLRL exercise.

Table 2. GMA MVC%

	Gluteus Maximus	
Exercise	**MVC%**	**p**
Prone Bridge	3.58 ± 16.4	<.05
Side Bridge	13 ± 7.8	<.05
Lunges	20.3 ± 7.9	=.06
Step ups	20.5 ± 13.8	<.05
FLRL	61.5 ± 63.5	

Note. Shaded p values designate FLRL exercise activates the GMA more significantly.

Gluteus Medius

Mauchly's test indicated that the assumption of sphericity had been violated $X^2(9)=147.66$, $p=<.001$, therefore degrees of freedom were corrected using the Greenhouse-Geisser test estimate of sphericity ($\varepsilon= .275$), $F(1.1, 20.92)=8.27$, $p<.05$. These results suggest there were significantly different amounts of activation in GME between exercises. The observed power was .827. The comparison between the Rehab exercises and the FLRL exercise for Gluteus GME found the ensemble means of percentage of MVC for the BR was 21.2% ± 15.3%, SB was 24.1% ±10.9%, LU was 14.95% ±7%, SU was 28.9% ±14.1%, and the FLRL was 69.8% ±77.3%. The FLRL significantly activated the GME better than the LU ($p<.05$). The FLRL did not significantly activate the GME better than the SB ($p>.05$), SU ($p>.05$) and the BR, although the BR was close to significant ($p=.06$). Table 3 shows the amplitude expressed as a percentage of MVC for all exercises. The p value represents the comparison of the exercise to the FLRL exercise.

Table 3. GME MVC%

	Gluteus Medius	
Exercise	**MVC%**	**P**
Prone Bridge	21.2 ± 15.3	=.06
Side Bridge	24.1 ± 10.9	>.05
Lunges	14.95 ± 7.0	<.05
Step ups	28.9 ± 14.1	>.05
FLRL	69.8 ± 77.3	

Note. Shaded p values designate FLRL exercise activates the GME more significantly.

Rectus Abdominus

Mauchly's test indicated that the assumption of sphericity had been violated $X^2(9)=47.69$, p=<.001, therefore degrees of freedom were corrected using the Greenhouse-Geisser test estimate of sphericity ($\mathcal{E}= .574$), $F(2.29, 43.54)=17.76$, $p<.001$. These results suggest there were significantly different amounts of activation in the ABS between exercises. The observed power were 1.000. The comparison between the Rehab exercises and the FLRL exercise for ABS found the ensemble means of percentage of MVC for the BR was 21.2% ± 15.3%, SB was 15.3% ±10.3%, LU was 4.3% ±2.2%, SU was 6.7% ±5.3% and the FLRL was 11.8% ±9.8%. The FLRL significantly activated the ABS better than the LU (p<.05), the SU (p <.05), and the BR (p<.05). The FLRL did not significantly activate the ABS more than the SB (p>.05). Table 4 shows the amplitude expressed as a percentage of MVC for all exercises. The p value represents the comparison of the exercise to the FLRL exercise.

Table 4. ABS MVC%

	Rectus Abdominus	
Exercise	**MVC%**	**p**
Prone Bridge	21.2 ± 15.3	<.05
Side Bridge	15.3 ± 10.3	>.05
Lunges	4.3 ± 2.2	<.05
Step ups	6.7 ± 5.3	<.05
FLRL	11.8 ± 9.8	

Note. Shaded p values designate FLRL exercise activates the ABS more significantly.

Hamstring Group

Mauchly's test indicated that the assumption of sphericity had been violated $X^2(9)=86.13$, p=<.001, therefore degrees of freedom were corrected using the Greenhouse-Geisser test estimate of sphericity (Ɛ= .342), $F(1.37, 25.98)=24.94$, p<.001. These results suggest there were significantly different amounts of activation in the HAM between exercises. The observed power was 1.000. The comparison between the Rehab exercises and the FLRL exercise for the HAM found the ensemble means of percentage of MVC for the BR was 5.8% ± 11.3%, SB was 11.5% ±10.3%, LU was 13.3% ±7.1%, SU was 36.9% ±28.9% and the FLRL was 65.1% ±46.1%.. The FLRL significantly activated the HAM better than the BR (p<.001), the SB (p<.001), SU (p<.05), and LU (p<.001). Table 5 shows the amplitude expressed as a percentage of MVC for all exercises. The p value represents the comparison of the exercise to the FLRL exercise.

Table 5. HAM MVC%

Hamstring Group		
Exercise	**MVC%**	**p**
Prone Bridge	5.8 ± 11.3	<.001
Side Bridge	11.5 ± 10.3	<.001
Lunges	13.3 ± 7.1	<.001
Step ups	36.9 ± 28.9	<.05
FLRL	65.1 ± 46.1	

Note. Shaded p values designate FLRL exercise activates the HAM more significantly.

Gastrocnemius

Mauchly's test indicated that the assumption of sphericity had been violated $X^2(9)=148.85$, p=<.001, therefore degrees of freedom were corrected using the Greenhouse-Geisser test estimate of sphericity (Ɛ= .281), F(1.12, 21.33)=32.731, p<.001. These results suggest there were significantly different amounts of activation in the GA between exercises. The comparison between the Rehab exercises and the FLRL exercise for the GA found the ensemble means of percentage of MVC for the BR was 4.9% ± 2.1%, SB was 7.95% ±5.4%, LU was 28.5% ±15.9%, SU was 62.5% ±28.9% and the FLRL was 127.3% ±92.5%. The observed power was 1.000. The FLRL significantly activated the GA better than the BR (p<.001), the SB (p<.001), SU (p<.05), and LU (p<.001). Table 6 shows the amplitude expressed as a percentage of MVC for all exercises. The p value represents the comparison of the exercise to the FLRL exercise.

Table 6. GA MVC%

Gastrocnemius		
Exercise	**MVC%**	**p**
Prone Bridge	4.9 ± 2.1	<.001
Side Bridge	7.95 ± 5.4	<.001
Lunges	28.5 ± 15.9	<.001
Step ups	62.5 ± 28.9	<.05
FLRL	127.3 ± 92.5	

Note. Shaded p values designate FLRL exercise activates the HAM more significantly

Activity Level for Hypertrophy

The FLRL exercise, when compared to the BR, SB, LU, and SU exercises, activated the RF above 40% of the MVC significantly more (p=<.05). The FLRL exercise did not activate the ABS more significantly above 40% of the MVC than any of the other exercises (p>.05). The FLRL exercise activated the GMA more significantly above 40% of the MVC than the BR, SB, LU, and SU exercises (p<.05). The FLRL exercise activated the GME more significantly above 40% of the MVC than the BR, SB, LU, and SU exercises (p<.05). The FLRL exercise activated the HAM more significantly above 40% of the MVC than the BR, SB, and LU (p<.05) but did not activate the HAM significantly above 40% of the MVC more than the SU (p=.375). The FLRL exercise activated the GA more significantly above 40% of the MVC than the BR, SB, LU, and SU exercises (p<.05). Table 7 shows the results of McNeamer's test comparing the ability of the FLRL exercise to create the effects of hypertrophy on the muscle (i.e., >40% of MVC).

Table 7. Results of McNeamer's. Comparison of Exercises to Create the Effects of Hypertrophy

Prone Bridges VS FLRL			
Potential to Strengthen			
Muscle	Degree of Freedom	X^2	p
Rectus Femoris	1	16.05	<.001
Rectus Abdominus	1	5.818	>.05
Gluteus Maximus	1	12.071	<.05
Gluteus Medius	1	1.333	<.001
Hamstring Group	1	5.818	<.05
Gastrocnemius	1	18.05	<.001

Side Bridges VS FLRL			
Potential to Strengthen			
Muscle	Degree of Freedom	X^2	p
Rectus Femoris	1	15.059	<.001
Rectus Abdominus	1	0	1.000
Gluteus Maximus	1	9.091	<.05
Gluteus Medius	1	11.077	<.001
Hamstring Group	1	5.818	<.05
Gastrocnemius	1	18.05	<.001

Lunges VS FLRL			
Potential to Strengthen			
Muscle	Degree of Freedom	X^2	p
Rectus Femoris	1	8.1	<.05
Rectus Abdominus	1		UC
Gluteus Maximus	1	8.1	<.05
Gluteus Medius	1	12.071	<.001
Hamstring Group	1	8.1	<.05
Gastrocnemius	1	13.067	<.001

Step Ups VS FLRL			
Potential to Strengthen			
Muscle	Degree of Freedom	X^2	p
Rectus Femoris	1	6.125	<.05
Rectus Abdominus	1		UC
Gluteus Maximus	1	7.111	<.05
Gluteus Medius	1	9.091	<.05
Hamstring Group	1	0.8	>.05
Gastrocnemius	1	5.143	<.05

Note. p= significance of test, highlighted boxes represent significant difference between the exercises. X^2= McNeamer's test. UC= Not able to test due to no values in either exercise being >40% of the MVC.

Frequency change

The change in frequency allows the researcher to determine the amount of fatigue in a muscle during the exercises (Konrad, 2005). The values expressed in Hz show the change in firing frequency of the muscles through the duration of the exercises. Positive numbers indicate the muscle's firing frequency decreased through the exercise representing fatigue of the muscles (Konrad, 2005). Negative numbers indicate the muscle's firing frequency increased through the duration of the exercise meaning no fatigue of the muscle was observed during the exercise (Konrad, 2005).

Rectus Femoris

Mauchly's Test of Sphericity indicated that the assumption of sphericity had not been violated, $X^2(9)=8.09$, $p>.05$. This indicates the RF was fatigued significantly different when comparing the exercises, $F(4,19)=7.939$, $p=<.001$. Table 8 shows the change in frequency for all exercises. The negative numbers represent an increase in frequency throughout the exercise indicating a no fatigue of the muscle was observed during the exercise. The p value represents the comparison of the exercise to the FLRL exercise. The observed power was .997. The comparison between the rehab exercises and the FLRL exercise for the RF found the mean in change of frequency in prone bridges (BR) was .85Hz ± 1.65Hz, side bridges (SB) was .48Hz ± 2.06Hz, lunges (LU) was -.2Hz, ±2.33Hz, step ups (SU) was .24Hz ± 2.19Hz and the FLRL was -2.14Hz ± 1.72Hz. The negative values represent an increase in frequency indicating no fatigue in the muscles during the LU and FLRL exercises. The FLRL created significantly less amounts of fatigue for the RF compared to the BR ($p<.05$), the SB ($p<.05$), and SU ($p=.05$). The FLRL did not significantly create different amounts of fatigue the RF when compared to the LU ($p>.05$).

Table 8. RF Frequency Change

Rectus Femoris		
Exercise	**Change**	**p**
Prone Bridge	.85Hz ± 1.65Hz	<.05
Side Bridge	.48Hz ± 2.06Hz	<.05
Lunges	-.2Hz, ±2.33Hz	>.05
Step ups	.24Hz ± 2.19Hz	=.05
FLRL	-2.14Hz ± 1.72Hz	

Note. p= significance of test, highlighted boxes represent significant difference

Gluteus Maximus

Mauchly's Test of Sphericity indicated that the assumption of sphericity had not been violated, $X^2(9)=11.39$, $p>.05$. This indicates the GMA was fatigued significantly different when comparing the exercises, $F(4,19)=7.939$, $p=<.001$. The observed power was .996. Table 9 shows the change in frequency for all exercises.. The p value represents the comparison of the exercise to the FLRL exercise. The comparison between the rehab exercises and the FLRL exercise for the GMA found the mean in change of frequency for BR was -.19Hz ± 1.06Hz, SB was -.257Hz ± 2.63Hz, LU was 1.26Hz ±2.59Hz, SU was .4Hz ± 2.97Hz and the FLRL was 2.9Hz ± 2.22Hz. The negative numbers represent an increase in frequency throughout the exercise, thus no fatigue of the muscle was observed during the BR and SB exercise The FLRL created significantly greater amounts of fatigue for the GMA compared to the BR ($p<.05$), the SB ($p<.05$), and SU ($p<.05$). The FLRL did not significantly fatigue the GMA more than the LU ($p>.05$).

Table 9. GMA Frequency Change

Gluteus Maximus		
Exercise	**Change**	**p**
Prone Bridge	-.19Hz ± 1.06Hz	<.05
Side Bridge	-.257Hz ± 2.63Hz	<.05
Lunges	1.26Hz ±2.59Hz	>.05
Step ups	.4Hz ± 2.97Hz	<.05
FLRL	2.9Hz ± 2.22Hz	

Note. p= significance of test, highlighted boxes represent significant difference

Gluteus Medius

Mauchly's Test of Sphericity indicated that the assumption of sphericity had not been violated, $X^2(9)=13.39$, $p>.05$. This indicates the GMA was fatigued significantly different when comparing the exercises, $F(4,19)=6.718$, $p=<.001$. The observed power was .990. Table 10 shows the change in frequency for all exercises. The p value represents the comparison of the exercise to the FLRL exercise. The comparison between the rehab exercises and the FLRL exercise for the GME found the mean in change of frequency for BR was -.04Hz ± 1.59Hz, SB was .15Hz ± 1.58Hz, LU was .74Hz, ±2.51Hz, SU was -.62Hz ± 2.97Hz and the FLRL was 2.36Hz ± 1.44Hz. The negative numbers represent an increase in frequency throughout the exercise thus no fatigue of the muscle was observed during the BR and SU exercises. The FLRL created significantly greater amounts of fatigue for the GME compared to the BR ($p<.001$), the SB ($p<.05$), and SU ($p<.05$). The FLRL did not significantly fatigue the GME more than the LU ($p>.05$).

Table 10. GME Frequency Change

Gluteus Medius		
Exercise	**Change**	**p**
Prone Bridge	-.04Hz ± 1.59Hz	<.05
Side Bridge	.15Hz ± 1.58Hz	<.05
Lunges	.74Hz, ±2.51Hz	>.05
Step ups	-.62Hz ± 2.97Hz	<.05
FLRL	2.36Hz ± 1.44Hz	

Note. p= significance of test, highlighted boxes represent significant difference

Rectus Abdominus

Mauchly's Test of Sphericity indicated that the assumption of sphericity had not been violated, X2(9)=8.834, p>.05. This indicates the ABS was fatigued significantly different when comparing the exercises F(4,19)=3.68, p=<.001. The observed power was .862. Table 11 shows the change in frequency for all exercises. The p value represents the comparison of the exercise to the FLRL exercise. The comparison between the rehab exercises and the FLRL exercise for the ABS found the mean in change of frequency for BR was .22Hz ± 1.69Hz, SB was .99Hz ± 1.98Hz, LU was .61Hz ± 1.85Hz, SU was 1.05Hz ± 2.24Hz and the FLRL was 2.40Hz ± 1.63Hz. All values were positive, indicating some degree of fatigue in the ABS. The FLRL created significantly greater amounts of fatigue for the ABS compared to the BR (p<.05). The FLRL did not significantly fatigue the ABS more than the LU (p>.05), the SB (p>.05), and SU (p>.05).

Table 11. ABS Frequency Change

	Rectus Abdominus	
Exercise	**Change**	**p**
Prone Bridge	.22Hz ± 1.69Hz	<.05
Side Bridge	.99Hz ± 1.98Hz	>.05
Lunges	.61Hz, ± 1.85Hz	>.05
Step ups	.05Hz ± 2.24Hz	>.05
FLRL	2.40Hz ± 1.63Hz	

Note. p= significance of test, highlighted boxes represent significant difference

Hamstring Group

Mauchly's test indicated that the assumption of sphericity had been violated $X^2(9)=23.07$, p=<.05, therefore degrees of freedom were corrected using the Greenhouse-Geisser test estimate of sphericity (Ɛ= .597), F(2.38, 45.38)=4.32, p<.05. This indicates the HAM was fatigued significantly different when comparing the exercises. Table 12 shows the change in frequency for all exercises. The p value represents the comparison of the exercise to the FLRL exercise. The comparison between the rehab exercises and the FLRL exercise for the HAM found the mean in change of frequency for BR was .53Hz ± 1.14Hz, SB was .45Hz ± 1.79Hz, LU was .97Hz ± 2.18Hz, SU was .47Hz ± 2.35Hz and the FLRL was 2.54Hz ± 1.47Hz. All values were positive, indicating some degree of fatigue in the HAM. The FLRL significantly created greater amounts of fatigue for the HAM compared to the BR (p<.05), the LU (p<.05), and the SB (p<.05). The FLRL did not significantly fatigue the HAM more than the SU (p>.05).

Table 12. HAM Frequency Change

Hamstring Group		
Exercise	**Change**	**p**
Prone Bridge	.53Hz ± 1.14Hz	<.05
Side Bridge	.45Hz ± 1.79Hz	<.05
Lunges	.97Hz, ± 2.18Hz	<.05
Step ups	.47Hz ± 2.35Hz	>.05
FLRL	2.54Hz ± 1.47Hz	

Note. p= significance of test, highlighted boxes represent significant difference

Gastrocnemius

Mauchly's test indicated that the assumption of sphericity had been violated $X^2(9)=18.89$, p=<.05, therefore degrees of freedom were corrected using the Greenhouse-Geisser test estimate of sphericity (Ɛ= .717), F(2.87, 54.46)=2.88, p<.05. This indicates the GA was fatigued significantly different when comparing the exercises. Table 13 shows the change in frequency for all exercises. The p value represents the comparison of the exercise to the FLRL exercise. The comparison between the rehab exercises and the FLRL exercise for the GA found the mean in change of frequency for BR was .76Hz ± 1.25Hz, SB was .26Hz ± 1.47Hz, LU was .6Hz ± 1.58Hz, SU was .84Hz ± 2.28Hz and the FLRL was 1.8Hz ± 1.24Hz. All values were positive, indicating some degree of fatigue in the GA. The FLRL significantly created greater amounts of fatigue for the GA compared to the BR (p<.05) and the SB (p<.05). The FLRL did not significantly fatigue the GA more than the SU (p>.05) and the LU (p>.05).

Table 13. GA Frequency Change

Gastrocnemius		
Exercise	**Change**	**p**
Prone Bridge	.76Hz ± 1.25Hz	<.05
Side Bridge	.26Hz ± 1.47Hz	<.05
Lunges	.6Hz, ± 1.58Hz	>.05
Step ups	.84Hz ± 2.28Hz	>.05
FLRL	1.8Hz ± 1.24Hz	

Note. p= significance of test, highlighted boxes represent significant difference

Chapter 5: Discussion

Discussion of Results

The purpose of this study was to determine if forward lateral retro lateral incline (FLRL) exercises on an inclined treadmill are more effective at activating and fatiguing the rectus femoris, rectus abdominis, gluteus maximus, gluteus medius, hamstrings, and gastrocnemius than current standard rehab exercises used for strengthening the core, hip complex and calf muscles, therefore having the potential to better strengthen and train these muscles and prevent or reduce the risk of ACL injury.

RQ 1: Are the rectus femoris (RF), rectus abdominis (ABS), gluteus maximus (GMA), gluteus medius (GME), hamstrings (HAM), and gastrocnemius (GA) activated during the FLRL exercise?

The observation of EMG signals by the researcher on the RF, ABS, GMA, GME, HAM, and GA show that the FLRL activated all the muscles in the study for the full duration of the exercise. The one participant in which the GMA was not found to have trace activity was most likely due to failure of equipment during the exercise. The ability for the exercise to activate all of the muscles in question will lead to the possibility for the exercise to strengthen the muscles. The activation of the muscles along with the nature of the exercise can potentially work to train the body along the guidelines of Reiman, Bolgla, and Lorenz (2009), who explain a program that emphasized a neutral (minimal knee valgus and knee varus) knee alignment during athletic maneuvers could reduce the risk of injury. The program should also focus on peak hip adduction and abduction movements in athletic motions (Reiman et al., 2009, p.39). The nature of the lateral motions of the FLRL exercise have the athletes abduct the lower extremities as the athletes push with the downhill leg abducting to keep up with the treadmill and push the body up the incline. The uphill leg will also fully abduct as the athlete reaches up the treadmill. Both legs will recover by adducting and getting in position to take another lateral step. The nature of the FLRL exercise along with the coach/clinician reminding the athletes of correct form can create an environment in which the athlete will be able to use peak hip abduction and adduction in a movement that simulates athletic motions.

RQ 2: Does the FLRL exercise require greater muscle activity of the RF, ABS, GMA, GME, HAM, and GA than the current rehab exercises when expressed as a percentage of the maximum voluntary contraction?

This section is a discussion of the main muscles activated during the rehab exercise compared to the FLRL exercise. The prone bridge (BR) exercise was previously found to activate the ABS significantly at 42% ± 24% of MVC (Ekstrom, Donatelli, & Carp, 2007). The current study found the BR to not activate the ABS to the same level (21.2% ± 15.3%). The reason for this could be the current study took the mean of the data of the stabilization exercise for the full duration (30 seconds) of the exercise, while Ekstrom et al. (2007) calculated the amplitude from a one-second window centered about the peak activity for each of the MVC's and exercises. The current study chose to use more than just a one-second window due to variability in human movement (Konrad, 2005). The BR did not activate the ABS more significantly than the FLRL exercise ($p = < .05$). The ABS were activated by the BR at 21.2% ± 15.3% MVC, and this was more than any other exercise when looking at the mean averages of percentage of MVC, including the FLRL exercise at 11.8% ± 9.8%. This rejects the researcher's original hypothesis that the FLRL would be able to activate the ABS more significantly. Table 14 shows the difference in ensemble means expressed as a % of MVC between the BR and FLRL for all muscles. The FLRL exercise was not able to activate the ABS in the current study more significantly than the BR, though the FLRL exercise activated all other muscles significantly greater when compared to the BR. The current study did not find any of the exercises to produce amplitudes above 40% MVC for the ABS. The FLRL exercise therefore could be assumed to be a capable exercise to train the ABS.

Table 14. Ensemble Mean % of MVC BR vs FLRL

Prone Bridges vs FLRL			
Activation % of MVC			
	Prone Bridge	FLRL	p Value
Rectus Femoris	16.89% ±10.89%	91% ±78.03%	<.05
Rectus Abdominus	21.2% ± 15.3%	11.8% ± 9.8%	<.05
Gluteus Maximus	3.58% ±16.4%	61.5% ± 63.5%	<.05
Gluteus Medius	21.2% ±15.3%	69.8% ±77.3%	<.05
Hamstring Group	5.8% ±11.3%	65.1% ± 46.1%	<.001
Gastrocnemius	4.9% ± 2.1%	127.3%± 92.5%	<.001

Note. Shaded boxes represent significantly greater means.

The side bridge (SB) exercise was previously found to activate the Gluteus Medius (GME) significantly, 74% ± 30% of MVC and more than any other exercise in the study (Ekstrom et al., 2007). The current study also found the SB to activate the GME to the highest level of the muscles being studied however the ensemble average % of MVC mean for this exercise was only 24.1% ± 10.9% MVC. The reasoning for the difference in the current study could be the current study took the mean of the data of the stabilization exercise for the full duration (30 seconds) of the exercise, while Ekstrom et al. (2007) calculated the amplitude from a one-second window centered about the peak activity for each of the MVC's and exercises. The FLRL exercise did not significantly activate the GME greater than the SB. Though the findings are not significant, the mean percentage of MVC activation of ensemble averages for the FLRL show the GME to be activated at 69.8% ± 77.3% MVC compared to the SB in which the GME was activated at 24.1% ± 10.9% MVC. The difference in mean averages leads to the theory that even though the difference wasn't significant (p=.06) the FLRL could be a better choice of exercise when looking to train the GME due to the mean being greater than 40% MVC. This idea goes along with Reiman et al.'s (2011) theory that the ability for an exercise to require greater EMG activity will result in strength gains. The large standard deviation of the mean (69.8% ± 77.3%) was most likely due to the inability of some of the participants to perform a true MVC. Table 15 shows the difference in ensemble means expressed as a % of MVC between the SB and FLRL for all muscles. The ABS were significantly more activated by the SB than the FLRL exercise. The FLRL exercise significantly activated the RF, GMA, HAM, and GA greater than the SB. The means of the SB (15.3% ± 10.3%) and FLRL (11.8% ±9.8%) for the ABS were very similar though. During the processing of the raw EMG data the researcher observed spikes in the ABS data during portions of the FLRL exercise. The highest activity for all but one participant was during the lateral motions of the 10-step phases. When analysis of just this portion of the exercise was run, a mean amplitude expressed as a % of MVC was 17.5% ± 20.5%. This portion of the FLRL exercise had a higher mean for the ABS than the SB, therefore possibly making the FLRL exercise more effective than the SB at strengthening the ABS.

Table 15. Ensemble Mean % of MVC SB vs FLRL

Side Bridges vs FLRL			
Activation % of MVC			
	Side Bridge	FLRL	p Value
Rectus Femoris	7.65% ± 9.9%	91% ±78.03%	<.05
Rectus Abdominus	15.3% ± 10.3%	11.8% ±9.8%	>.05
Gluteus Maximus	13% ± 7.8%	61.5% ±63.5%	<.05
Gluteus Medius	24.1% ± 10.9%	69.8% ±77.3%	=.06
Hamstring Group	11.5% ± 10.3%	65.1% ±46.1%	<.001
Gastrocnemius	7.95% ± 5.4%	127.3%±92.5%	<.001

Note. Shaded boxes represent greater means.

The lunge (LU) exercise was previously found to be the exercise to activate the hamstring group (HAM) (Ekstrom et al., 2000). The current study found the LU to be an exercise that was not able to activate the HAM more than the other rehab exercises. The rectus femoris (RF) was found by Dwyer et al. (2010) to be activated by the LU. The current study found the RF to not be most activated by the LU. In both of the studies looking at the HAM and RF the current study found higher values of MVC% during the LU. The FLRL exercise was found to not significantly activate the RF more than the LU. Though there was not a significant difference, the difference in means could make the FLRL (91% ± 78.03% MVC) a better choice than the LU (49.55% ±20.6% MVC). The FLRL exercise was found to significantly activate the HAM better than the LU (p=<.05). Table 16 shows the difference in ensemble means expressed as a % of MVC between the LU and FLRL for all muscles. The ABS and gluteus maximus (GMA) were not significantly activated differently by the FLRL compared to the LU. The GMA though was very close to being significantly different (p=.06). The GMA also had a high SD possibly due to the inability for participants to perform a true MVC. The high SD could have caused the GMA not to statistically be significantly greater. Both the GMA and ABS did have higher mean values during the FLRL than during the lunge. The GMA mean value was above 40% during the lunge possibly making it an exercise that has potential to create hypertrophic effects in the GMA (Konrad, 2005). The GA and GME were significantly activated greater by the FLRL compared to the LU.

Table 16. Ensemble Mean % of MVC LU vs FLRL

Lunges vs FLRL			
Activation % of MVC			
	Lunges	FLRL	p Value
Rectus Femoris	49.55% ±20.6%	91% ±78.03%	>.05
Rectus Abdominus	4.3% ± 2.2%	11.8% ±9.8%	>.05
Gluteus Maximus	20.3% ± 7.9%	61.5% ±63.5%	=.06
Gluteus Medius	14.95% ± 7%	69.8% ±77.3%	<.05
Hamstring Group	13.3% ± 7.1%	65.1% ±46.1%.	<.05
Gastrocnemius	28.5% ± 15.9%	127.3% ±92.5%	<.05

Note. Shaded boxes represent greater means.

The step up (SU) exercise was previously found to activate the gluteus maximus (Reiman, Bolgla, & Loudon, 2012). The current study found this to be consistent. The toe raise done during the step up was to mimic the push off phase of the running gait which was found to activate the gastrocnemius (GA) (Andrews et al., 2004). If the assumption that the heel raise was sufficient to mimic the push off phase, the current study agrees with the findings of Andrews et al. (2004). The FLRL exercise though was able to activate the GMA more significantly than the SU (p=<.05). The FLRL exercise could therefore be the exercise of choice when looking to work the GMA. Table 17 shows the difference in ensemble means expressed as a % of MVC between the SU and FLRL for all muscles. The FLRL exercise was able to significantly activate every muscle more than the SU except the GME. This is possibly due to the high SD which was possibly caused to lack of ability for some participants to complete a true MVC. When excluding the FLRL exercise the SU exercise had the highest MVC % values for all muscle except the ABS.

Table 17. Ensemble Mean % of MVC SU vs FLRL

Step Ups VS FLRL			
Activation % of MVC			
	Step ups	FLRL	p Value
Rectus Femoris	50.5% ± 41.5%	91% ±78.03%	<.05
Rectus Abdominus	6.7% ± 5.3%,	11.8% ±9.8%	<.05
Gluteus Maximus	20.5% ± 13.8%	61.5% ±63.5%	<.05
Gluteus Medius	28.9% ± 14.1%	69.8% ±77.3%	>.05
Hamstring Group	36.9% ± 28.9%,	65.1% ±46.1%.	<.001
Gastrocnemius	62.5% ± 28.9%	127.3%±92.5%	<.001

Note. Shaded boxes represent greater means.

Based on the comparison above (refer back to Tables 14-17), the conclusion could be drawn that the FLRL exercise is the superior exercise of the study when looking at all muscles in the current study except the ABS. However the bridge was not found to significantly activate the ABS greater than the FLRL exercise and when looking at portions of the FLRL the mean expressed as a percentage of MVC was greater than the SB. Therefore this possibly makes the FLRL exercise the best exercise in the study to train all the muscles in question.

The results from the current study can lead to the following assumptions: The FLRL exercise was found to activate the HAM and GA more significantly than any of the other exercises. In conjunction with the goal to prevent ACL injuries previous studies have found the following: The HAM muscle group was found to protect the ACL over most of the flexion range, except near full extension; the GA can protect the posterior cruciate over the entire range of motion of the knee (O'Conner, 1993, p.47). Weakness in the HAM group during the eccentric phase has been attributed to injury in the lower extremity (Reiman et al., 2009, p.36). The ability for the FLRL exercise to activate the HAM and GA more significantly than the other exercises suggests the use of the FLRL to train the muscles to be stronger in all actions, therefore being able to protect the knee, leading to a possible reduction in ACL injuries.

The FLRL exercise was not found to activate the RF more significantly than the LU but produced a higher percentage of MVC. These results along with Reiman et al.'s (2011) theory that the ability for an exercise to require greater EMG activity will result in greater strength gains would suggest that the FLRL exercise would still be the better choice for exercising the RF. Training the RF to the best potential is important because quadriceps weakness is a limiting factor in rehabilitative progression and failure to achieve adequate strength can potentially result in increased risk of future injury, including acute and overuse injuries such as anterior knee pain (Myer et al., 2006, p.391). The original use of the FLRL exercise was to increase strength and stabilization of the hip complex to result in an increased running speed. The role the FLRL exercise plays on strengthening the RF makes the FLRL a great exercise to possibly improve strength of the RF and therefore possibly increase strength of the knee drive in the running gait.

The FLRL exercise was not found to activate the GMA more significantly than the LU but was very close to a significant value (p=.06). The ensemble average mean % of MVC was greater in the FLRL exercise (61.5%± 63.5% MVC) compared to the LU (20.3%±7.9% MVC).

The FLRL exercise was not found to activate the GME more significantly than the LU, but was found to activate the GME more significant than the BR, SU, and SB and produced a higher mean of percentage of MVC on all the exercises. The higher values suggest higher amplitude activation of the GMA and GME in the FLRL exercise. The GMA and GME muscles have control over hip abduction and external rotation of the femur in the concentric motion; they also control hip adduction and internal rotation through the eccentric motion (Flanagan, 2014).

How Flanagan (2014) and Koga et al. (2014) explain the cause of the valgus collapse shows how the kinetic chain can be a major player in the injury of the knee and therefore the movement of the hip would have an effect on the knee. Training the GMA and GME using the FLRL exercise could lead to control over motions that cause ACL injury, such as the valgus collapse.

The lack of ability for the FLRL exercise, compared to the BR and SB, to be significantly higher or produce greater ensemble average of % MVC means for the ABS, suggests the need of other exercises being supplemented in to train the ABS. The ability though for the FLRL exercise (11.8% ±9.8% MVC) to produce higher ensemble average of % MVC means than he SU (6.7% ± 5.3% MVC) and LU (4.3% ± 2.2% MVC) would lead to the assumption that when training the ABS in an active exercise the FLRL exercise could be the better choice. Akuthota and Nadler (2004) recommend that in a rehabilitation setting which is leading an athlete that has had a lower-extremity injury back to play, functional progression core training is needed. During functional progression training patients should be given exercises in a standing position (Akuthota & Nadler 2004). Core strengthening for sports should involve movements in the three cardinal planes: sagittal, frontal, and transverse (Akuthota & Nadler 2004). Training the domain balance is important for functional activities and progression to a labile surface may improve balance and proprioception (Akuthota & Nadler, 2004). Akuthota and Nadle (2004) explain exercises that do this can potentially lead to lower risk of injury and performance enhancement. The FLRL exercise is an exercise that is done standing, brings the need for stabilization on a labile surface in all three planes, and therefore can potentially train balance, improve proprioception, reduce injury risk, and enhance performance (Akuthota & Nadler, 2004).

RQ 3: When compared to the current rehab exercises, does the FLRL exercise reach at least 40% of the MVC, to cause hypertrophic effects, of the rectus femoris (RF), rectus abdominis (ABS), gluteus maximus (GMA), gluteus medius (GME), hamstrings (HAM), and gastrocnemius GA)?

Konrad (2005) explains that for a muscle to have strength gains 40-60% of the MVC must be reached by the muscle during the exercise. Comparison was done of the percentage of muscle activation that was found to be over 40% of rehab exercises to the FLRL exercise.

The FLRL exercise was found to significantly produce muscle activation to an amplitude greater than 40% of the MVC for the RF, GMA, GME, and GA, more so than the BR, SB, LU, and SU ($p<.05$). Research is pointing to the kinetic chain being a factor that has a major impact on ACL injuries and non-contact mechanisms of injury such as the valgus collapse (Flanagn, 2014). The GMA and GME must be considered important muscles due to their role in the kinetic chain and how they control hip abduction and external rotation (Flanagan, 2014). The GMA is also active during cutting maneuvers to the opposite side, and the GME accounts for 60% of the total hip abductor area and initiates hip abduction (Reiman et al., 2012). The motions explained above are all motions described in the valgus collapse. The ability for the GMA and GME to control hip abduction could be increased by strengthening the muscles. The FLRL exercise was found to be the best exercise in the current study for increasing strength of the GME and GMA.

The FLRL exercise was found to produce muscle activation to an amplitude greater than 40% of the MVC for the HAM when compared to the BR, SB, and LU ($p<.05$). The SU and FLRL were found to produce similar results for HAM activation to an amplitude greater than 40% MVC. The ensemble average MVC% mean for the HAM for FLRL was 65.1% ±46.1% MVC. The average is above the 40% mark and suggests the FLRL can sufficiently activate the muscle to levels that would create muscle hypertrophy. The anterior drawer mechanism of injury is described as aggressive quadriceps loading, with the knee in slight flexion, producing significant anterior tibial translation stressing the ACL and potentially leading to ACL injury (DeMorat et al., 2004). The ability for the hamstrings, GA, and gluteal muscles to contract antagonistically could possibly help stop the forward motion and decrease anterior tibial translation reducing the risk of injury to the ACL (DeMorat et al., 2004). The ability for the FLRL to possibly strengthen the HAM may reduce the risk of decreased hamstring strength relative to quadriceps strength and decreased recruitment of muscle fibers, therefore possibly leading to reduction in the risk of injury.

The FLRL was not found to significantly produce muscle activation to an amplitude greater than 40% of the MVC for ABS when compared to the BR or SB ($p>.05$). When comparing the LU and SU to FLRL exercise, none of the three exercises were able to produce significant amplitude MVC% to create hypertrophic effects in the ABS for any of the participants. For the BR exercise only three participants had a mean that was above 40% and for the SB only one participant had a mean above 40% MVC. A possible reasoning for the lack of results in the ABS above 40%MVC could be the population used was very physically active and training consistently. Baechle and Earle (2008) explain that the regulation of exercise intensity is critical to the success of the exercise and if not overloaded to a point greater than the participant is accustomed to, the exercise might not produce the desired physiological effects. The BR and SB could have not been challenging enough for the participants to be able to produce amplitudes at 40% and above of MVC.

When compared to all four rehab exercises the FLRL exercises was found to be able significantly produce muscle activation to an amplitude greater than 40% for the RF ($p<.05$). During the FLRL exercise the RF was activated to an ensemble average of MVC (91% ±78.03%

MVC). The high numbers could lead to accelerated strength gains for the quadriceps muscle groups. Training the RF to the best potential is important because quadriceps weakness is a limiting factor in rehabilitative progression and failure to achieve adequate strength can potentially result in increased risk of future injury, including acute and overuse injuries such as anterior knee pain (Myer et al., 2006, p.391). This study suggests the FLRL exercise is the best exercise for training the RF.

The FLRL exercise was found to produce muscle activation to an amplitude greater than 40% of the MVC for the GA when compared to all four rehab exercises ($p<.05$). The GA produced the highest of all means 127.3%±92.5% MVC of any of the muscles during any of the exercises done. The role the GA plays in knee stabilization can possibly lead to ACL injury prevention (Myer et al., 2006). However the ensemble average mean being over 100% should not happen. This potentially could be due to the technique used in gathering MVC's in the current study. The use of manual resistance is not the best choice due to chance for human error (Morrow, 2011). Also, while all the participants were trained on how to do the exercises of the study, they were never trained on how to do the MVC's. Konrad (2005) explains practicing the MVC's prior to testing can help participants feel what it is like to create a true maximum contraction and be comfortable with the positions.

RQ 4: Does the FLRL exercise produce more fatigue in the RF, ABS, GMA, GME, HAM, and GA than current rehab exercises?

A test showing fatigue of the muscle will show a decrease in frequency of EMG sginal over contraction time (Konrad, 2005) and is represented by a positive value in the current study. Fatigue is a very important aspect of strength because short-term fatigue is the preliminary condition of muscle growth (Konrad, 2005).

When comparing the rehab and FLRL exercises the current study found the FLRL exercise to significantly fatigue all muscles in question except the RF more than the BR and SB ($p<.05$). The findings of Kay, Gibson, Mitchell, Lambert, and Noakes (2000) found concentric contractions to create a greater reduction in frequency when compared to an isometric contraction. The results of the Kay et al. (2000) study can help explain why the FLRL exercise was able to create greater amounts of fatigue than the isometric exercises: BR and SB. The FLRL exercise could have created greater amounts of fatigue also due to the time of the exercise. The FLRL exercise lasted approximately 1.5 minutes while the SB and BR were only performed for 30 seconds.

When comparing the FLRL exercise to the LU, the FLRL exercise was found to create significantly greater amounts of fatigue in the HAM group ($p<.05$). The FLRL exercise was not found to create fatigue in the RF during the exercise. Though the FLRL exercise was not found to create statistically significantly greater amounts of fatigue in the four other muscles, the FLRL exercise produced greater means in decreased frequency in all of them; FLRL vs. LU: ABS (2.40Hz ± 1.63Hz vs. .61Hz, ± 1.85Hz), GMA (2.9Hz ± 2.22Hz vs. 1.26Hz ±2.59Hz), GME (2.36Hz ± 1.44Hz vs. .74Hz, ±2.51Hz), and GA (1.8Hz ± 1.24Hz vs. .6Hz, ± 1.58Hz). Thus in a practical sense the greater amounts of fatigue change possibly makes the FLRL exercise a better option to create fatigue in the muscles of question excluding the RF, compared to the LU.

When comparing the FLRL exercise to the SU exercise, the FLRL exercise was found to create significantly greater amounts of fatigue in the ABS, GMA, and GME ($p<.05$). Though the FLRL exercise was not found to create statistically significantly greater amounts of fatigue in the HAM and GA muscles, the FLRL exercise produced greater means in decreased frequency change in both of them. The FLRL exercise was not able to produce a change in frequency to indicate fatigue in the RF; FLRL vs. SU: RF (-2.14Hz ± 1.72Hz. vs. 24Hz ± 2.19Hz), HAM (2.54Hz ± 1.47Hz vs. .47Hz ± 2.35Hz), and GA (1.8Hz ± 1.24Hz vs. .84Hz ± 2.28Hz). The ability for the FLRL exercise to create significantly greater amounts of fatigue in the GMA and GME could be due in part to the nature of the FLRL exercise and how doing the exercise correctly forces the GMA and GME to be used in their full range of motion throughout the whole exercise. This goes along with Kay et al. (2000), who explain fatigue is a decrease in force production or an inability to regenerate the original force in the presence of an increased perception of effort. Baechle and Earle (2008) enforce the idea by explaining "when the entire range of motion is covered during an exercise, the value of the exercise is maximized (p.327)."

As Konrad (2005) explains short-term fatigue is the preliminary condition of muscle growth. The ability for the FLRL exercise to produce greater amounts of fatigue in all the muscles tested could possibly make this exercise the best candidate for inducing muscle fatigue, and thus potentially enhancing training outcomes. Alentorn-Geli et al. (2009) go on to explain how fatigued muscles are not able to absorb as much energy. Under fatigued conditions, it was found that knee flexion angle decreased along with an increase in tibial anterior shear force and knee varus movements when doing stop-jump tasks. Chappell et al. (2005) and Ryder et al. (1997) also found an increase in anterior tibal motion as fatigue increased. The ability for an exercise to train and improve tolerance to fatigue can lead to adaptations to fatigue (Baechle & Earle, 2008). Also the ability for the FLRL exercise to create fatigue while training athletic motions can possibly increase resistance to fatigue in all planes of motion (Baechle & Earle, 2008).

From the research presented in the current study it is possible to draw the conclusion that an exercise with the ability to activate the muscles in question, create amounts of amplitude greater than 40% of MVC in the muscles, and create fatigue in the muscles possibly has the ability to strengthen the muscles. The muscles presented in the current study have been found by many researchers (Akuthota & Nadler 2004; Flanagan, 2014; and Koga et al., 2014) to play a major role in ACL injury etiology. The FLRL exercise was found in the current study to activate all the muscles (RF, ABS, GMA, GME, HAM, and GA) in question for the duration of the exercise. With all the muscles meeting the question of activation, a discussion of each muscle and the ability of the FLRL exercise to create a situation in which the 40% MVC activation and a decrease in firing frequency are met is needed.

Rectus Femoris

The FLRL exercise was not able to produce fatigue in the RF (-2.14Hz ± 1.72Hz) while doing the exercise. The negative number indicates an increased rate of firing frequency during the exercises meaning no fatigue was observed. Possible reasoning for the FLRL not producing fatigue could be explained by the fact the participants were currently training on average 5 days a week and were considered well trained. As Bishop, Jones, and Woods (2008) explain during the immediate recovery phase, the leg muscles must regenerate ATP and remove byproducts of bioenergetics. The better trained an athlete is, the more productive they will be at immediate recovery (Bishop et al., 2008). The action of the RF is hip flexion and knee extension, which is only in the sagittal plane of motion (Starkey et al., 2009). During the lateral portion of the FLRL exercise the main motions are hip abduction and adduction in the frontal plane. The minimal use of knee extension and hip flexion could possibly have allowed for the RF to recover. The other five muscles in question act on the body in all planes of motion (Starkey et al., 2009) and possibly were continuously working through the exercise and therefore not able to use immediate recover (Bishop et al., 2008).

The FLRL exercise was able to produce an amplitude above 40% of the MVC (91% ±78.03%). The ability for the FLRL exercise to produce activation above 40% MVC shows the exercise has potential to create strength gains and hypertrophic effects in the muscle (Konrad, 2005). Training the RF to the best potential is important because quadriceps weakness is a limiting factor in rehabilitative progression and failure to achieve adequate strength can potentially result in increased risk of future injury, including acute and overuse injuries such as anterior knee pain (Myer et al., 2006, p.391). When doing the FLRL exercise the trainee is instructed to reach up the treadmill in the lateral and retro motions creating maximal range of motion while not compromising mechanics. Full range of motion along with meeting the parameters of activation, activation above 40% MVC, during the exercise makes the argument the FLRL has great potential to increase hypertrophy and strength in the RF (Konrad, 2005). This can lead to a reduction in future acute and overuse injury risk, and keep progression of the rehabilitation on track (Myer et al., 2006).

Hamstring Group

The FLRL exercise was able to produce fatigue in the HAM (2.54Hz ± 1.47Hz) while doing the exercise. The positive number indicates a decrease in firing frequency of the muscle during the exercise representing fatigue of the muscle. The FLRL exercise was also able to produce an amplitude above 40% of the MVC (65.1% ± 46.1%). The ability for the FLRL exercise to produce fatigue and activation above 40% MVC shows the exercise has potential to create strength gains and hypertrophic effects in the muscle (Konrad, 2005). The ability for the hamstrings muscles to contract antagonistically to the quadriceps muscle group, could possibly help stop the gross forward motion and decrease gross anterior tibial translation which occurs during injury mechanisms, therefore reducing the risk of injury to the ACL (DeMorat et al.,

2004) The HAM muscle group was found to protect the ACL over most of the flexion range, except near full extension (O'Conner, 1993, p.47), and weakness in the HAM group during the eccentric phase has been attributed to injury in the lower extremity (Reiman et al., 2009, p.36). Konrad (2005) explains the ability for an exercise to produce fatigue and activation above 40% MVC shows the exercise has potential to create strength gains and hypertrophic effects in the muscle, which the FLRL exercise did. Producing these effects can decrease possible chance of injury by reducing fatigue and increasing the strength of the HAM to protect the ACL. Alentorn-Geli et al. (2009) explains decreased hamstring strength relative to quadriceps strength leads to an increased risk of injury. From the combined findings of this study, the ability for the FLRL exercise to possibly fatigue the HAM greater than the RF (-2.14Hz ± 1.72Hz vs. 2.54Hz ± 1.47Hz) and increase strength of the HAM leads to the idea the HAM can possibly be trained effectively and reduce the risk of injury due to muscle imbalance that a stronger RF would create.

Gluteus Maximus

The FLRL exercise was able to produce fatigue in the GMA (2.9Hz ± 2.22Hz) while doing the exercise. The positive number indicates a decrease in firing frequency of the muscle during the exercise representing fatigue of the muscle. The FLRL exercise was also able to produce an amplitude above 40% of the MVC (61.5% ± 63.5%). The ability for the FLRL exercise to produce fatigue and activation above 40% MVC shows the exercise has potential to create strength gains and hypertrophic effects in the muscle (Konrad, 2005). The GMA muscles have control over hip abduction and external rotation of the femur in the concentric motion, along with controlling hip adduction and internal rotation through the eccentric motion (Flanagan, 2014).). How Flanagan (2014) and Koga et al. (2014) explain the cause of the valgus collapse, a cause of ACL injury, shows how the kinetic chain can be a major player in the injury of the knee since the movement of the hip would have an effect on the knee. The role the GMA plays in the kinetic chain, by controlling hip abduction and adduction, along with internal and external rotation, gives evidence that strengthening the GMA can reduce the chance of gross biomechanical mechanisms causing injury (Flanagan, 2014).

Gluteus Medius

The FLRL exercise was able to produce fatigue in the GME (2.36Hz ± 1.44Hz) while doing the exercise. The positive number indicates a decrease in firing frequency of the muscle during the exercise representing fatigue of the muscle. The FLRL exercise was also able to produce an amplitude above 40% of the MVC (69.8% ±77.3%). The ability for the FLRL exercise to produce fatigue and activation above 40% MVC shows the exercise has potential to create strength gains and hypertrophic effects in the muscle (Konrad, 2005). The GME also plays a role in controlling hip abduction and external rotation of the femur in the concentric motion, along with controlling hip adduction and internal rotation through the eccentric motion (Flanagan, 2014). This means the GME will also be part of the influence of injury from the kinetic chain and its effect on the knee (Flanagan, 2014). By increasing hypertrophy, strength, and an increased resistance to fatigue, the FLRL exercise can possibly lead to a reduction of gross biomechanical mechanisms causing injury by increasing the ability of the GME to play its part in controlling the motions (Flanagan, 2014).

Causes of a valgus collapse would be lack of strength/ power/ endurance of the subtalar invertors and hip external rotators (Flanagan, 2014). The HAM, GMA and GME are included in this group of muscles which control eccentric motion during lower extremity flexion. A valgus collapse places increased demands at the knee. These demands can result in injury including injuries to the anterior cruciate ligament (Flanagan, 2014, p.352). The ability for the FLRL exercise to train these muscles to be resistant to fatigue and increase strength, power, and endurance can possibly lead to a reduction of injury (Alentorn-Geli et al., 2009; Baechle & Earle, 2008; DeMorat et al., 2004; Flanagan, 2014; Reiman et al., 2009).

Alentorn-Geli et al. (2009) explain an anterior pelvic tilt will lengthen and weaken the hamstrings and gluteal muscles. This leaves the athlete at risk for an increase in anterior tibial displacement and an increase in femur internal rotation and adduction. Athletes that have an increased pelvic tilt can possibly use the FLRL exercise and reduce injury risk by strengthening the hamstrings and gluteal muscles (Alentorn-Geli et al., 2009). Strengthening the muscles of the posterior chain can possibly give these muscles a better chance to resist the lengthening and weakening caused by the anterior pelvic tilt.

Gastrocnemius

The FLRL exercise was able to produce fatigue in the GA (2.36Hz ± 1.44Hz) while doing the exercise. The positive number indicates a decrease in firing frequency of the muscle during the exercise representing fatigue of the muscle. The FLRL exercise was also able to produce an amplitude above 40% of the MVC. The ability for the FLRL exercise to produce fatigue and activation above 40% MVC shows the exercise has potential to create strength gains and hypertrophic effects in the muscle (Konrad, 2005). The gastrocnemius plays a major role in knee stabilization (Myer et al., 2006). In this role the GA can protect the posterior cruciate over the entire range of motion of the knee that might occur with gross biomechanical mechanisms (O'Conner, 1993, p.47). The ability for GA to contract antagonistically to the quadriceps muscle group during gross biomechanical mechanisms could possibly help stop the forward motion and decrease anterior tibial translation reducing the risk of injury to the ACL as well (DeMorat et al., 2004). The findings of DeMorat et al. (2004) and O'Conner (1993) show the important role a strong GA plays in protecting the knee from injury. By increasing hypertrophy, strength, and an increased resistance to fatigue, the FLRL exercise can possibly increase the ability of the GA to protect the knee (Flanagan, 2014).

Rectus Abdominus

The FLRL exercise was able to produce fatigue in the ABS (2.40Hz ± 1.63Hz) while doing the exercise. The positive number indicates a decrease in firing frequency of the muscle during the exercise representing fatigue of the muscle. The FLRL exercise though was not able to produce an amplitude above 40% of the MVC (11.8% ± 9.8%). The FLRL exercise was able to produce greater amounts of amplitude than the SU and LU exercises therefore possibly making it a better exercise. The ability for the FLRL exercise to produce fatigue shows the exercise has potential to create strength gains and hypertrophic effects in the muscle (Konrad, 2005). The ability of the FLRL exercise to create fatigue along with training the ABS in a standing position, involving movements in the three cardinal planes: sagittal, frontal, and transverse, and training the domain balance on a labile surface may improve balance and proprioception (Akuthota & Nadler, 2004). This leads to potentially training balance, improving proprioception, reducing injury risk, and enhancing performance (Akuthota & Nadler, 2004). The lack of ability for the FLRL exercise to activate the ABS above 40% MVC leads to the need for other exercises to be added to help increase strength and hypertrophy of the ABS muscles such as the BR and SB based on the findings of this study.

During the study of the exercise the researcher observed that the participants did not seem to be as physically stressed during the four rehab exercises as they were during the FLRL exercise. The participants of the study were very physically active and currently training consistently at high levels. The exercise intensity of the rehab exercises were potentially not an overload to what they were accustomed to, therefore being too low to produce the desired physiological effects (Baechle and Earle, 2008). The intensity of the FLRL exercise (15% incline, 3 MPH) chosen for the current study was at a mid-program level. The participants when finished with the FLRL exercise showed signs of being physically stressed and in need of time to recover. The participants had had some training on the FLRL exercise previously, however the intensity chosen for the current study could have potentially been the correct amount of overload to produce the desired physiological effects. Though it is hard to quantify the volume of the rehab exercises and FLRL exercises, there is a possibility the rehab exercises were not a sufficient overload for the participants while the FLRL exercise was.

The high values of SD in the study could possibly be due to the nature of the MVC tests. The lack of practice for the participants possibly led to a small number not being able to give a true MVC. Therefore the amplitude values of some of their tests were above 100% of the MVC with large variability. This creates a high SD making the results look like they were more spread out and lowering the significance (Field, 2013). As Morrow (2011) explains the use of manual resistance testing to acquire MVC values leads to a high variability in the resistance given due to human error.

Prevention of Injury

The multifactorial risks, including internal and external risks, that potentially lead to injury can be reduced through inciting events (Bahr & Krosshaugh, 2005). The inciting events the current study was investigating, with the hope of using the FLRL exercise to prevent injury, are joint motion, muscle actions, and training programs. The FLRL exercise has the potential to be an effective exercise as a cornerstone exercise in a preseason training program. Reiman et al.

(2009) stated that a program that emphasized a neutral (minimal knee valgus and knee varus) knee alignment during athletic maneuvers could reduce the risk of injury. The program should also focus on peak hip adduction and abduction movements in athletic motions (Reiman et al., 2009, p.39). The basic nature of the FLRL exercise, if done correctly, will have a coach or trainer observe and verbally interact with the trainee. The coach or trainer needs to make sure the trainee is focusing on correct knee alignment while continuously reaching up the treadmill and pushing off as they reach up the incline to focus on peak hip adduction and abduction in the lateral positions of the exercise. Also correct knee alignment and continuous reaching to full range of motion while not compromising mechanics should be done while in the retro position. Exercises involving full range of motion leads to the value of the exercise being maximized (Baechle & Earle 2008). The coach/trainer should always make sure the trainee is using good kinematic mechanics. Risberg et al. (2007) found training the muscle groups using proper kinematic mechanics repetitively leads to proper form through correct repetitive neuromuscular activation. The repetition leads to improved proprioception of knee kinematics through athletic movements leading to a possible reduction in injury (Risberg et al., 2007).

The FLRL exercise was found to create an increase in fatigue in all the muscles of this study. Alentorn-Geli et al. (2009) explain as muscles become more fatigued they are not able to absorb as much energy. Under fatigued conditions, it was found that knee flexion angle decreased along with an increase in tibial anterior shear force and knee varus movements when doing stop-jump tasks. Chappell et al. (2005) and Ryder et al. (1997) also found an increase in anterior tibal motion as fatigue increased. Fatigue of the core muscles or lower extremity muscles might increase the chance of a biomechanical mechanism leading to higher risk of injury due to the spine being unstable (Kibler et al., 2006). The ability for an exercise to induce muscle fatigue can lead to adaptations to the fatigue (Baechle & Earle, 2008). Also the ability for the FLRL exercise to create fatigue while training athletic motions can possibly increase resistance to fatigue in the specific motions (Baechle & Earle, 2008).

Exercises that strengthen, increase stamina, and work repetitive motions similar to athletic motions could lead to a reduction in ACL injury (Risberg et al., 2007). The ability for the FLRL exercise to possibly strengthen the muscles that have control over hip abduction and external rotation of the femur, along with the knee stabilizers, through multi-plane athletic motions, could lead to a reduction of injury. Strengthening these muscles can possibly lead to the ability of the athlete to control muscle actions and joint motions which if not in control can lead to injury. Having control over the natural motion of deceleration as explained by Flanagan (2014), due to stronger muscles, can help prevent excess motion or gross biomechanical mechanisms which can lead to ACL injury. The activation of the HAM group during the FLRL exercise and its potential to strengthen the muscle addresses the issue; the ability of the hamstrings to be strong can help to prevent against excess ACL force due to the events of an immense quadriceps contraction (Boden et al., 2002; Senter & Hame, 2006).

The findings of this study support the FLRL exercise causing fatigue of the ABS. The ability for the exercise to produce fatigue can lead to adaptations to fatigue (Baechle & Earle, 2008) and possibly reducing instability of the spine (Kibler, 2006). The lack of ability for the FLRL exercise to create amplitudes great enough to cause hypertrophic effects leads to the need for other exercises to be included in a training program focusing on the muscles of the current study.

Use in the Rehabilitation Setting

Current ACL rehabilitation protocols emphasize immediate motion, early weight-bearing, and an accelerated return to sport. The FLRL exercise has the potential, in its current form, to be used at certain points of the rehabilitation process. The use of a treadmill with adjustable incline and speed gives the clinician the ability to change the intensity of the exercise to meet the needs of the rehabilitation setting and create overload to continue with progression.

The Center for Orthopedics (2014) ACL rehab protocol (Appendix C) at 6-8 weeks post-op allows for the start of lateral movement if the patient demonstrates good mechanics and adequate strength. The lateral movement needs to be carefully monitored by a clinician. If the patient shows no signs of diminished eccentric control, poor stability, and is able to control against varus/ valgus motion, the lateral motion can be continued (The Center for Orthopedics, 2014). This is a point when the FLRL could possibly be introduced. A clinician might choose to start the patient on the ground doing the exercise. If the patient has complete control over the exercise, progression to a very slow moving treadmill and low incline might be done. The FLRL could possibly be used to strengthen the muscles of the lower extremity continuously due to the ability to overload the exercise by increasing elevation and speed of the treadmill. The FLRL exercise's potential to strengthen the GA, HAM and RF can address the fact that the GA and HAM play a major role in knee stabilization and the quad strength dictates return to play (Myer et al., 2006). Strengthening these muscles could lead to less injury and faster return to play. The results of the current study show the use of the FLRL exercise could potentially accomplish this.

The FLRL exercise is not the perfect exercise. The possible inability for it to train the ABS and the core is one of it possible downfalls. However the ability for the FLRL exercise to significantly train muscles at amplitudes above 40% MVC shows it has the potential to be effective if used correctly in the performance and rehabilitation settings.

Recommendations

This study opens the doors for many possible future studies and also brings to light some changes that need to be addressed. Knowing the FLRL exercise activates all the muscles of the study and has the ability to possibly strengthen and create fatigue of them in healthy individuals, a future study might look at the use in an injured ACL population. A study in an injured population could look at the potential to decrease the amount of time a muscle takes to re-gain neuromuscular control after being damaged and repaired by surgery. A study looking at the ability of a training program, with the FLRL as the cornerstone, to prevent injury could be done in a pre-season athletic population. Future studies could also look at different athletes and the effects on their sports. For example if the FLRL exercise has any effect on an athlete's 40-yard dash time. Gender differences and age differences could also be looked at in future studies. A study could look at one gender possibly being more affected by the FLRL exercises. Age differences could look at benefits for adolescents to prevent injury or the use in a rehab setting for any age group.

In future studies, MVC testing of the extremity muscles should be done using a machine such as a Biodex to keep the resistance consistent and the angle of testing exact (Morrow, 2011). Participants should also practice doing the MVC's when they come in to practice the other exercises of the study.

More electrodes could be used to study the potential for the FLRL exercise to activate more muscles of the lower extremity and core due to the role the kinetic chain plays in injury.

Testing could look at the individual muscles of the hamstring group, other quadriceps muscles and the other core muscles to help understand the abilities of the FLRL exercise.

Rehab exercises could be overloaded with the goal of creating an equal training intensity between the FLRL and rehab exercises. The study could use weights in the hands of the participants to overload the exercises to create equal volume and intensity of the exercises. The study could also look at different levels of rehab exercises and how they compare to the FLRL exercise. This could possibly create a more uniform volume and intensity between the FLRL exercise and the control exercises.

A future study could use the unweighting system the Noramco treadmills offer to look at potential use at an earlier time in the rehabilitation setting. Since surgery can affect neural function a study using the unweighting system could look at the potential of the FLRL exercise to re-afferentate or stimulate neural function and sensory input to the affected area by using correct kinetic motions. A future study could look at the parts of the FLRL exercise that create the highest amplitude and fatigue for each muscle group. Understanding this could possibly lead to correcting imbalances in an athlete's gait by strengthening muscle imbalances.

Chapter 6: Summary and Conclusion

Summary

The FLRL exercise was found to activate all the muscles in question in the current study. The FLRL exercise significantly activated all the muscles of the study more than the prone bridge ($p<.05$). The FLRL exercise significantly activated all muscles except the ABS above 40% MVC ($p<.05$) compared to the prone bridge and caused a significantly greater change in frequency indicating greater fatigue in all the muscles ($p<.05$).

The FLRL exercise significantly activated the RF, GMA, HAM, and GA more than the side bridge ($p<.05$). The GME was not statistically activated more by the FLRL, however was very close to being more significantly activated ($p=.06$) and produced a higher ensemble mean, 24.1% ± 10.9% vs 69.8% ±77.3% for the SB and FLRL exercises respectively. The FLRL exercise significantly activated all muscles except the ABS above 40% MVC ($p<.05$) and to a greater extent when compared to the side bridge and caused a significantly greater change in frequency indicating in fatigue in all the muscles ($p<.05$).

The FLRL exercise significantly activated all the muscles of the study except the GMA more than the lunge ($p<.05$). The FLRL exercise was not able to significantly activate the GMA more than the lunge ($p=.06$), however was very close to being statistically significant and produced a higher ensemble mean, 20.3% ± 7.9% vs 61.5% ± 63.5%. The FLRL exercise significantly activated all muscles except the ABS above 40% MVC ($p<.05$) compared to the lunge indicating no observable fatigue and caused a significantly greater change in frequency indicating fatigue in the RF and HAM ($p<.05$). The FLRL did not cause a significant change in frequency in the GMA, GME, ABS, and GA when compared to the lunge. However the FLRL exercise created a greater change in firing frequency mean in all muscles when compared to the lunge indicating more fatigue even though this was not statistically significant.

The FLRL exercise significantly activated the GMA, ABS, HAM, and GA more than the step up ($p<.05$). The RF and GME were not found to be significantly activated greater than the step up by the FLRL exercise but the FLRL exercise did produce a higher ensemble mean in all the muscles. The FLRL exercise significantly activated all muscles accept the ABS and HAM above 40% MVC ($p<.05$) compared to the step ups and caused a significantly greater change in frequency indicating fatigue in the GMA, GME, and ABS ($p<.05$). The FLRL did not cause a significant change in firing frequency in the RF, HAM, and GA when compared to the step ups, however the FLRL exercise created a greater change in firing frequency mean than the step ups in all the muscles.

The findings of this study indicate the FLRL exercise has potential to increase strength, hypertrophy, and resistance to fatigue in the RF, ABS, GMA, GME, HAM, and GA. The findings indicate the FLRL exercise potentially can increase strength, hypertrophy, and resistance to fatigue in the RF, ABS, GMA, GME, HAM, and GA better than the standard rehab exercises. The FLRL exercise therefore has the potential to be used effectively as a cornerstone exercise for rehabbing a knee injury and as part of a preseason training program to prevent injury and possibly improve performance.

Conclusion

The FLRL exercise has the potential to be an exercise used in the rehabilitation setting of a knee injury and preseason training to prevent injury due to its ability to activate and fatigue the muscles of the hip complex to levels that can produce strength and hypertrophy. The FLRL exercise combined with other exercises used in a training or rehab setting can potentially lead to performance gains, reduced chance of injury, and accelerated recovery. The FLRL exercise needs to be studied further and compared to other rehab and performance exercises.

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Appendix A: *Muscles of the Hip*

Table 18. Muscles of the Hip

Muscle of the Hip	Action	Origin	Insertion
Adductor Brevis	Hip adduction (ADD) Hip internal rotation(IR)	Pubic ramus	Pectineal line Medial lip of linea aspera
Adductor Longus	Hip ADD, Hip IR	Pubic symphysis	Middle on third of medial linea aspera
Adductor Magnus	Hip ADD, Hip IR	Inferior pubic ramus Ramus of ischium Ischial tuberosity	Line spanning from the gluteal tuberosity to the adductor tunercle of the medial femoral condyle
Biceps Femoris	Hip extension(EXT), Hip external rotation(ER), Knee Flexion (FLX), External rotation (ER) of the tibia	**Long Head** -Ischial tuberosity -Sacrotuberous ligament **Short Head** -lateral lip of the linea aspera -upper two thirds of the supracondylar line	Lateral fibular head Lateral tibial head
Gemellus Inferior	Hip ER	Tuberosity of ischium	Greater trochanter of femur via the obturator internus tendon
Gemellus Superior	Hip ER	Spine of ischium	Greater trochanter of femur via obturator internus tendon
Gluteus Maximus	Hip EXT, Hip ER, Hip ADD	Posterior gluteal line of ilium Posterior sacrum Posterior coccyx	Gluteal tunerosity of femur Through fibrous band to the iliotibial tract
Gluteus Medius	Hip Abduction (ABD), Hip FLX, Hip IR, Hip EXT, Hip ER	External surface of superior ilium Anterior gluteal line Gluteal aponeurosis	Greater trochanter of femur
Gluteus Minimus	Hip ABD, Hip IR, Hip FLX	Lower portion of ilium Margin of greater sciatic notch	Greater trochanter of femur
Gracillis	Hip ADD, Knee FLX	Symphysis pubis Inferior pubic ramus	Medial tibial flare
Iliacus	Hip FLX	Superior surface of the iliac fosa Internal iliac crest	Lateral to the psoas major, distal to the lesser trochanter

		Sacral ala	
Obturator Externus	Hip ER	Pubis ramus	Trochanteric fossa of femur
Obturator Internus	Hip ER	Obturator membrane Margin of obturator foramen Pelvic surface of ischium	Greater trochanter of femur
Pectineus	Hip ADD	Superior symphysis pubis	Pectineal line of femur
Piriformis	Hip ER	Pelvic surface of sacrum Rim of greater sciatic foramen	Greater trochanter of femur
Psoas Major and Minor	Hip FLX	Transverse process of T12 and all lumbar vertebrae	Lesser trochanter of femur
Quadartus Femoris	Hip ER	Tuberosity of ischium	Introchanteric crest of femur
Rectus Femoris	Hip FLX, Knee EXT	Anterior inferior iliac spine Groove located superior to the acetabulum	To the tibial tuberosity via the patella and patellar ligament
Sartorius	Hip FLX, Hip ABD, Hip ER, Knee FLX, Internal tibial rotation(ITR)	Anterior superior iliac spine	Proximal portion of the anteromedial tibial flare
Semimembranosus	Hip EXT, Hip IR, Knee FLX, ITR	Ischial tuberosity	Posteromedial portion of the medial condyle of the tibia
Semitendinosus	Hip EXT, Hip IR, Knee FLX, ITR	Ischial tuberosity	Medial portion of the tibial flare
Tensor Fasciae Latae	Hip FLX, Hip IR, Hip ABD	Anterior iliac spine External lip of the iliac crest	Illiotibial tract

(Starkey et al., 2009)

Appendix B: *Muscles Connecting to the Spine*

Table 19. Muscles Connecting to the Spine

Muscles off the spine	Actions	Origin	Insertion
Rectus Abdominis	Flexion of the lumbar spine against gravity Posterior rotation of the pelvis	Pubic Crest Pubis Symphysis	Costal cartilage of the 5^{th}-7^{th} ribs Xiphoid process of sternum
External Oblique	Bilateral contraction: Flexsion of the lumbar spine Posterior rotation of the pelvis Unilateral contraction: Rotation of the lumbar spine to the opposite side Lateral bending of the lumbar spine to the same side	5^{th}-8^{th} ribs 9^{th}-12^{th} ribs	Via an aponeurosis to the linea alba Anterior superior iliac spine, pubic tubercal, and the anterior portion of the iliac crest
Internal Oblique	Bilateral contraction: Support of the abdominal viscera Posterior rotation of the pelvis Flexion of the lumbar spine Unilateral contraction: Rotation of the lumbar spine to the same side	Lateral two thirds of the inguinal ligament (lower fibers) - Anterior one third of the iliac crest - Middle one third of the iliac crest	Crest of pubis, pectinial line 10^{th}-12^{th} ribs Linea alba

	Lateral bending of the lumbar spine to the same side		
Latissimus Dorsi	Extension of the spine Anterior rotation of the pelvis Stabilization of the lumbar spine via the thoracodorsal fascia	Spinous process of T6-T12 and the lumbar vertebrae via thoracodorsal fascia Posterior iliac crest	Intertubercular groove of the humerus
Trapezius(Middle Third)	Retraction of scapula Fixation of thoracic spine	Lower portion of the ligamentum nuchae Spinous process of the 7^{th} cervical vertebra and T1-T5	Acromion process Spine of the scapula
Trapezius (Lower Third)	Depression of scapula Retraction of scapula Upward rotation of the scapula Fixation of thoracic spine	Spinous processes and supraspinal ligaments of T8-T12	Spine of the scapula
Rhomboid Major	Retraction of scapula Elevation of scapula Downward rotation of scapula Fixation of thoracic spine	Spinous prcesses of T2-T5	Vertebral border of scapula

Rhomboid Minor	Retraction of scapula Elevation of scapula Downward rotation of scapula Fixation of thoracic spine	Inferior portion of the ligamentum nuchae Spinous processes C7 and T1	Vertebral border of scapula

(Starkey et al., 2009)

Appendix C: *Center for Orthopedics Protocol*

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Anterior Cruciate Ligament Reconstruction Rehabilitation Protocol

GENERAL CONSIDERATIONS

* This handout serves as a general outline for you as a patient to better understand guidelines and time frames associated with your ACL reconstruction rehabilitation.

* Please keep in mind that these time frames are to be considered approximate and may not be met by all patients at the specific timeline. This is due to differences in healing, tolerance, and subtle differences with the surgical procedure.

* The rehabilitation process is an ongoing process of re-evaluation, with specific changes in your program based on your progression. You will undergo a functional evaluation at 14 weeks, 6 months, and 1 year post-operatively to objectively assess what specific strengths and weaknesses exist.

* ***It is important to recognize that your symptoms do not necessarily reflect your ability to perform activities.*** Due to healing, incorporation of your ACL graft, weakness of the leg and compensation, it is best to check with your physical therapist or your physician before engaging in any activity you are unsure of.

* You will be scheduled for a pre-operative visit with a physical therapist.

The purpose of this visit is to:
-introduce you to the rehabilitation department who will be helping guide you through your post-operative rehabilitation
-instruct you on specific pre-operative and post-operative home exercises
-familiarize you with the rehabilitation protocol and specific goals

* Post-operatively, you will follow-up with the physical therapy center at your 1 and 2 week appointment. This corresponds with your physician appointment. After that, the following is the schedule for physical therapy appointments:

- 2-10 weeks post-op—3 times per week
- 10-12 weeks post-op—2 times per week
- 12+ weeks post-op—1 time per week or as needed

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- 14 week functional test
- 24 week functional test

Anterior Cruciate Ligament Reconstruction Rehabilitation Protocol

PROGRESSION OF PROGRAM

Pre-operative visit:

-Evaluation and home program review of pre-op and post-op exercises, brace and crutch use, and post-op guidelines and precautions. Questions on the surgical procedure, post-op expectations and time frames will also be addressed.

Post-operatively:

Week 1-2:

-Re-evaluation and review of home program.
-Begin increasing weight bearing and wean from crutches as able to demonstrate good mechanics. Brace is to be used until 1-2 weeks post-op depending on ability to control the leg with ambulation.
-ROM should be 0-75 degrees and the patient should be able to straight leg raise.
-Early emphasis on achieving full extension with active VMO recruitment.
-Soft tissue treatments to patella, patella tendon, incisions, and posterior musculature to improve range of motion and decrease fibrosis.

Weeks 2-4:

-Range of motion exercises (i.e. wall/heel slides, passive stretching), pain control, gait training, and continue with soft tissue treatments.
-ROM should be 0-110 degrees by 2 weeks post-op.
-Incorporate functional, closed-chain focused exercises (i.e. mini-squats, modified lunges, leg press, calf exercises.). Emphasis on VMO control, core stability, and avoidance of varus / valgus moment with exercises.
-*If hamstring graft,* no active hamstring exercises until 2 weeks and no open-chain resisted hamstring curls until 4 weeks post-op.
-*If patella tendon graft,* no resisted leg extension machine at any point.
-Stationary bike, pool workouts and upper body conditioning.
-Balance and proprioception exercises.

Weeks 4-6:

-Continue with ROM focus if patient cannot actively move knee from 0-115. Soft tissue and scar mobilization for ROM and patella / tendon mobility.
-Increase intensity of functional exercises (i.e. add weight or resistance with exercises, incorporate stretch cord exercises, increase intensity with aerobic machines).
-Single-leg/unilateral workouts (i.e. on weight machines, squats, side and forward step-downs, increase depth of balance exercises).
-Aggressive core stabilization program (i.e. physioball, foam roller exercises).

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-Extensive balance/proprioception program focusing on weak positions.
-Add Stairmaster, VersaClimber, Elliptical Trainer.

Weeks 6-8: *M.D. follow-up at 6 or 8 weeks. Will reduce number of visits to 1x/week.
-Introduce lateral training as able to demonstrate good mechanics and adequate strength..
-Carefully monitor exercises for signs of diminished eccentric control, weakness, or poor ability to stabilize against varus / valgus moment with loading exercises.

Weeks 8-10:
-Continued supervised care 1 x / week with particular emphasis on strengthening in the lower ranges of motion (i.e. from 30-80 degrees of knee flexion).

Weeks 10-12:
-1 visit at 10 weeks and one visit at 12 weeks to review home program, increase intensity as indicated and monitor for guarding or compensation.

Weeks 12-14:
-Patients can begin jogging at 14 weeks assuming they have adequate quadriceps control and no complications. Their first few sessions of running should be monitored by the clinician for proper mechanics.
-At 14 weeks, the patient will have a follow-up appointment with the M.D. and a functional test. The functional test consists of:
-Ground clock / timed
-Unilateral squat / timed / to 70 degrees of flexion
-Lateral shuffle / leaping
-Carioca
-Two-legged leap / distance
-Jogging
-Unilateral balance
-Other functional test specific to patient's activity

(The Center for Orthopedics, 2014)

Appendix D: *Late Stage Rehab Criteria*

Table 20. Late Stage Rehab Criteria According to Myer et al. (2006)

Stage	Goals	Criteria for Progression to Next Stage
ONE	1. Improve single-limb weight-bearing strength at increasingly greater knee flexion angles 2. Improve side-to-side symmetry in lower extremity running mechanics 3. Improve weight baring single limb postural balance	1. Single-limb squats and hold symmetry (minimum 60^0 knee flexion with 5 second hold). 2. Audibly rhythmic foot strike patterns without gross asymmetries in visual kinematics when running 3. Acceptable single-limb balance scores on stabilometer (females < 2.2^0 of deflection; males < 3.0^0 of deflection
TWO	1. Improve lower extremity non-weight-bearing strength 2. Improve force contribution symmetry during activities in bipedal stance 3. Improve single-limb landing force attenuation strategies.	1. Side-to-side symmetry in peak torque knee flexion and extension and hip abduction peak torque knee flexion and extension (within 15% non-surgical). 2. Plantar force total-loading symmetry measured during bipedal squat to 90^0 knee flexion (< 20% discrepancy). 3. Single-limb peak-landing-force symmetry on a 50-cm hop (within 10% non-surgical).
THREE	1. Improve single-limb power production 2. Improve lower extremity muscular endurance 3. Improve lower extremity biomechanics during plyometric activates	1. Single-limb hop for distance (within 15% non-surgical) 2. Single-limb triple hop crossover for distance (within 15% non-surgical) 3. Single limb timed hop over 6m distance (within 15% non-surgical) 4. Single-limb vertical power hop (within 15% non-surgical)
FOUR	1. Equalizing ground reaction force attenuation strategies between limbs 2. Improve confidence and stability with high intensity change of direction activates	1. Drop vertical jump landing force bilateral symmetry (within 15%) 2. Modified agility T-test, test time (within 15%). 3. Single-limb average peak power test for 10 seconds (within 15%).

3. Improve and equalize power endurance between limbs
4. Use safe biomechanics

Myers et al. (2006)

Appendix E: IKDC Subjective Knee Evaluation

IKDC Subjective Knee Evaluation

SYMPTOMS*:

*Grade symptoms at the highest activity level at which you think you could function without significant symptoms, even if you are not actually performing activities at this level.

1. What is the highest level of activity that you can perform without significant knee pain?
   - 4 ☐ Very strenuous activities like jumping or pivoting as in gymnastics or football
   - 3 ☐ Strenuous activities like heavy physical work, skiing or tennis
   - 2 ☐ Moderate activities like moderate physical work, running or jogging
   - 1 ☐ Light activities like walking, housework or gardening
   - 0 ☐ Unable to perform any of the above activities due to knee pain

2. During the past 4 weeks, or since your injury, how often have you had pain?

	0	1	2	3	4	5	6	7	8	9	10	
Never	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Constant

3. If you have pain, how severe is it?

	0	1	2	3	4	5	6	7	8	9	10	
No pain	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Worst pain imaginable

4. During the past 4 weeks, or since your injury, how stiff or swollen has your knee been?
   - 4 ☐ Not at all
   - 3 ☐ Mildly
   - 2 ☐ Moderately
   - 1 ☐ Very
   - 0 ☐ Extremely

5. What is the highest level of activity you can perform without significant swelling in your knee?
   - 4 ☐ Very strenuous activities like jumping or pivoting as in gymnastics or football
   - 3 ☐ Strenuous activities like heavy physical work, skiing or tennis
   - 2 ☐ Moderate activities like moderate physical work, running or jogging
   - 1 ☐ Light activities like walking, housework or gardening
   - 0 ☐ Unable to perform any of the above activities due to knee swelling

6. During the past 4 weeks, or since your injury, has your knee locked or caught?

   0 ☐ Yes   1 ☐ No

7. What is the highest level of activity you can perform without significant giving way in your knee?
   - 4 ☐ Very strenuous activities like jumping or pivoting as in gymnastics or football
   - 3 ☐ Strenuous activities like heavy physical work, skiing or tennis
   - 2 ☐ Moderate activities like moderate physical work, running or jogging
   - 1 ☐ Light activities like walking, housework or gardening
   - 0 ☐ Unable to perform any of the above activities due to giving way of the knee

SPORT ACTIVITIES:

8. What is the highest level of activity you can participate in on a regular basis?

- 4☐ Very strenuous activities like jumping or pivoting as in gymnastics or football
- 3☐ Strenuous activities like heavy physical work, skiing or tennis
- 2☐ Moderate activities like moderate physical work, running or jogging
- 1☐ Light activities like walking, housework or gardening
- 0☐ Unable to perform any of the above activities due to knee

9. How does your knee affect your ability to:

		Not difficult at all	Minimally difficult	Moderately Difficult	Extremely difficult	Unable to do
a.	Go up stairs	4☐	3☐	2☐	1☐	0☐
b.	Go down stairs	4☐	3☐	2☐	1☐	0☐
c.	Kneel on the front of your knee	4☐	3☐	2☐	1☐	0☐
d.	Squat	4☐	3☐	2☐	1☐	0☐
e.	Sit with your knee bent	4☐	3☐	2☐	1☐	0☐
f.	Rise from a chair	4☐	3☐	2☐	1☐	0☐
g.	Run straight ahead	4☐	3☐	2☐	1☐	0☐
h.	Jump and land on your involved leg	4☐	3☐	2☐	1☐	0☐
i.	Stop and start quickly	4☐	3☐	2☐	1☐	0☐

FUNCTION:

10. How would you rate the function of your knee on a scale of 0 to 10 with 10 being normal, excellent function and 0 being the inability to perform any of your usual daily activities which may include sport?

FUNCTION PRIOR TO YOUR KNEE INJURY:

	0	1	2	3	4	5	6	7	8	9	10	
Couldn't perform daily activities	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	No limitation in daily activities

CURRENT FUNCTION OF YOUR KNEE:

	0	1	2	3	4	5	6	7	8	9	10	
Cannot perform daily activities	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	No limitation in daily activities

(IKDC, 2014)

Appendix F: *Brigham and Women's Hospital ACL Rehab Protocol*

Table 21. Brigham and Women's Hospital ACL Rehab Protocol

Phase	Goals	Criteria for Phase Advancement
One: Immediately Postoperative to week 4	1. Protect graft and graft fixation 2. Minimize effects of immobilization 3. Control inflammation/swelling 4. Full active and passive extension/hyperextension range of motion. Caution: avoid hyperextension greater than 10 degrees. 5. Educate patient on rehabilitation progression 6. Restore normal gait on level surfaces	1. Full extension/hyperextension 2. Good quad set, SLR without extension lag 3. Minimum of 90° of flexion 4. Minimal swelling/inflammation 5. Normal gait on level surfaces

Two: Post-operative weeks 4 to 10	1. Restore normal gait with stair climbing 2. Maintain full extension, progress toward full flexion range of motion 3. Protect graft and graft fixation 4. Increase hip, quadriceps, hamstring and calf strength 5. Increase proprioception	1. No patellofemoral pain 2. Minimum of 120 degrees of flexion 3. Sufficient strength and proprioception to initiate running. 4. Minimal swelling/inflammation
Three: Post-operative weeks 10 to 16	1. Full range of motion 2. Improve strength, endurance and proprioception of the lower extremity to prepare for sport activities 3. Avoid overstressing the graft	1. No significant swelling/inflammation. 2. Full, pain-free ROM 3. No evidence of patellofemoral joint irritation 4. Strength approximately 70% of uninvolved lower extremity per isokinetic evaluation

	4. Protect the patellofemoral joint 5. Normal running mechanics 6. Strength approximately 70% of the uninvolved lower extremity per isokinetic evaluation (if available)	5. Sufficient strength and proprioception to initiate agility activities 6. Normal running gait
Four: Post-operative week months 4 through 6	1. Symmetric performance of basic and sport specific agility drills 2. Single hop and 3 hop tests 85% of uninvolved lower extremity 3. Quadriceps and hamstring strength at least 85% of uninvolved lower extremity per isokinetic strength test	1. No patellofemoral or soft tissue complaint 2. Necessary joint ROM, strength, endurance, and proprioception to safely return to work or athletics 3. Physician clearance to resume partial or full activity

Five: Beginning at approximately 6 months post-op	1. Safe return to athletics/work 2. Maintenance of strength, endurance, proprioception 3. Patient education with regards to any possible limitations

Brigham and Women's Hospital (2006)

Table 22. Exercises in Brigham and Women's Hospital ACL Rehab

Phase	Exercises
One:	1. Patellar mobilization/scar mobilization to reduce scare tissue build up. 2. Heel slides, hamstring curls adding weight as tolerated for hamstring strength 3. Quad contractions (consider electrical stimulation for poor quad contractions), straight leg raises in all planes, with brace in full extension until quadriceps strength is sufficient to prevent extension lag. 4. Gastrocnemius/soleus, and hamstring stretches for flexibility training 5. Gastrocnemius/soleus strengthening 6. Weight can be added as tolerated to hip abduction, adduction and extension. 7. Closed Kinetic Chain Quadriceps strengthening activities can be done (wall sit, step ups, mini squats, leg press 90-30 degrees) along with quadriceps isometric contractions at 60° and 90°, and 8. Single leg balance proprioception exercises as tolerated by the patient.

Two:	1. Flexibility exercises, continue Closed chain strengthening as in phase one, 2. Stairs avoiding hyperextension, 3. Elliptical for conditioning, stationary bike with increased resistance, 4. continue proprioception activities, 5. hip hamstring and calf strengthening, 6. In week 8 pool or unweighted treadmill running can be started
Three	1. Range of motion and flexibility exercises, 2. Knee extensions 90^0-30^0 and progressing to eccentric motions, 3. Progress to full weightbearing running at 12 weeks, 4. Progressive hip, quadriceps, hamstring, and calf strengthening, 5. Cardiovascular endurance training via stairmaster, elliptical, and bike, 6. Advance proprioceptive activities.
Four:	1. Continues strength training of the hips, quadriceps, hamstrings, and gastrocnemius, 2. Imitation of a plyometric program, 3. Agility progression with cutting, acceleration, deceleration, 4. Progress running distance

5. Imitate sport-specific drills.

Five:	1. Safe return to athletics/work
	2. Maintenance of strength, endurance, proprioception
	3. Patient education with regards to any possible limitations

Brigham and Women's Hospital (2006)

Appendix G: IRB Forms

IRB Form
Adams State University
Academic Department: HPPE
Request to obtain approval for the use of human participants
Project: Electromyography analysis of Forward Lateral Retro Lateral Incline Exercises and Their Potential to Reduce ACL Injury (Master's Thesis project)
Principal Investigator: Kevin Feldman
Masters Student Researcher: Kevin Feldman
E-mail: feldmankl@grizzlies.adams.edu
Phone number: 505-819-8642
Chair of Thesis Committee: Tracey Robinson, Ph.D.
Email: tlrobins@adams.edu
Phone: 719-587-7663

Purpose of Research: Knee injuries account for approximately 30% of all injuries in athletics and the ACL requires surgery four times more often than any other structure in the knee. The purpose of this study is to determine if forward lateral retro lateral incline (FLRL) exercises on an inclined treadmill are more effective at training the muscles than current rehab exercises used for strengthening the core, hip complex and calf muscles, therefore having the potential to decrease the occurrence of ACL injury.
This study will measure muscle activity in a number of different exercises via electromyography (EMG), a non-invasive (minimal risk) procedure that consists of applying electrodes to the surface of the skin and attaching a wireless probe to the electrode that will capture the electrical activity of the muscle. All procedures will take place at Anytime Fitness in Alamosa, Colorado.

Research Design
All procedures will take place on the same day. Prior to any electrode placement for EMG, participants will be briefed on the experimental procedures. Instruction on doing the MVC, FLRL exercises, and rehab exercises will be given to insure proper form. All participants will have done the exercises previously so they should be familiar with the exercises. However to ensure all participants are comfortable with the exercises, a familiarization session will be given. The participants will be asked to wear loose workout attire, shorts being necessary and shoes that are low tops and used for running. In the event participants use orthotics in their shoes they will

not be allowed to use them during the procedures. Participants will be informed about the use and placement procedure of electrodes.

Setting

The testing will take place at Anytime Fitness, a fitness facility in Alamosa, Colorado, located at 7544 feet elevation, on a Noracmo High Speed Elite Treadmill in the isolated Sports Performance room.

Participants

The participants will be healthy individuals that have had previous training of a minimum five times doing the FLRL exercises on an inclined treadmill, so they are familiar with proper form and able to give best effort. No deception will be involved in this study. Twenty-five participants, both male and female, ranging in age between 16 and 45 years, will be asked to participate in the study. The participants will be recruited from the sports performance training program at Anytime Fitness in Alamosa, Colorado. All will be in good health and not recovering from any lower leg injuries. A participant will be excluded if they have had a previous lower extremity injury that required surgery. Participants will not be compensated for their participation.

Pre-test: Participants will be asked to fill out a consent form and a questionnaire about their physical activity routine and injury history (attached).

Methods of Procedure:

1. Electrode placement sites on the skin will be prepared on the participant's dominant side by abrading the skin and cleansing the area with rubbing alcohol swabs. Shaving of hair will be performed if it is present, as it will interfere with the EMG signals.
2. Electrodes will then be placed on the skin of the participants. Electrodes will be placed on the belly of the following muscles: rectus femorus, gluteus maximus, gluteus medius, rectus abdominus, hamstring group, and gastrocnemius. The sites chosen by the researcher will measure the muscles found to be the most important when looking at ACL injuries in the review of literature.
3. All participants will walk on a treadmill at 3 mph to warm up for three minutes.
4. Participants will do randomized maximum voluntary contractions (MVC) for the rectus abdominus, rectus femorus, gluteus maximus, gluteus medius, hamstrings

muscle group and gastrocnemius. Each position will be manually resisted gradually to maximal amount then held for five seconds. Each test will be done twice on each muscle with a 30-sec rest period between. The participants will have a 30second rest between each MVC (Konrad, 2005). This will give conformation of proper electrode placement by viewing EMG signal amplitude during an isolated muscle test (Ekstorm et al., 2007).

5. After MVC's all participants will do both FLRL exercise and rehab exercises on the same day. Participants will randomly draw to decide if FLRL exercise or rehab exercises are done first.
6. Due to the familiarity of the participants with the FLRL exercise, a middle of the program incline and reps will be used for the exercise. The FLRL exercise will be done on a treadmill at an incline of 15% at 3 mph doing
    a. 10 forward steps
    b. turning left for 10 lateral steps
    c. turning backwards for 20 retro steps in reverse
    d. turning left again, which will be opposite the first lateral direction, for 20 lateral steps,
    e. turning backwards for 20 retro steps
    f. turning right for 10 steps.
        i. In the event to participants grab on to the safety bar or need a spot the test will be vetoed, a five-minuet rest will be given, and the participant will repeat the exercise.

7. The participants will have a five-minuet brake between the rehab and FLRL exercises.
8. Rehab exercises will be done in a randomized order drawn by the participants.
    a. participants will do forward step-ups to an 18 in box performed slowly through full range of motion and coming to the toe at the top, for ten reps continuously on one leg then switching to the other leg immediately for ten reps.
9. The participants will then get a one-minute rest.
10. A side bridge will be performed on each side holding for 30 seconds and a 30 sec rest between reps.
11. The participants will get a one-minute rest
12. Standing lunges with each leg forward will be done starting with legs fully extended then slowly going through full range of motion to the point of maximal knee flexion and back to the top.
13. The participants will get a one-minute rest
14. The lunges will be done for ten repetitions continuously on one leg then switching to the other leg immediately for ten reps.
15. The participants will get a one-minuet rest
16. The prone bridge will be done for 30 sec.

Duration of Participation: One session, total time will be approximately 2 hours. EMG prep will take about 10 minutes, MVC's can take up to 1 hour, and the actual data collection should take no longer than 1 hour.

Risks to the Individual: The testing presents a chance of falling on the slow moving treadmill while doing the exercises. The risk will be minimized by using young healthy participants with past experience on the treadmill doing the FLRL exercise. There will be a spotter next to them during all exercises. The electrode placement could cause some light skin irritation. Minor muscle discomfort is possible while doing the exercises, but the risks are equivalent to those that participants would encounter in everyday life.

Benefits: Participating in the study can help advance the sports rehab and performance fields. Participation can help to identify specific exercises that will contract specific muscles. The participants will have the chance to learn a new exercise and how to do it correctly, which could provide health benefits if added to their own workout routine.

Confidentiality: Participation is voluntary and will be held confidential. Participants may choose not to do any of the exercises/tests they do not want to participate in and/or they may withdraw from participation at any time without penalty. Names will not be used in the study. Data will be locked under a password protected computer for five years in which the researcher only has the password. Hard copies of data will be kept in a locked file cabinet in the researcher's office. Adams State University reserves the right to use the results of this study for future research and/or presentation of results. If research is used in a public forum, data will be reported as a group without individual or school identification.

Consent: Participants will be asked to read over and sign the consent form before any testing commences. The informed consent is attached separately.

Changes: If any changes are made to the research I will contact the IRB immediately and fill out

the needed paperwork.

Tracey L Robinson 2-10-2015

Signature of Department Chair or Appropriate Person Date

[illegible] 2-6-15

Signature of IRB Chair Date

RESEARCH PARTICIPANT CONSENT FORM

EMG analysis of Forward Lateral Retro Lateral Incline Exercises and Their Potential to Reduce ACL Injury

Kevin Feldman
Adams State University
Department of Human Performance and Physical Education

INFORMED CONSENT FOR PARTICIPATION IN RESEARCH

Knee injuries account for approximately 30% of all injuries in athletics and the ACL requires surgery four times more often than any other structure in the knee. The purpose of this study is to determine if forward lateral retro lateral incline (FLRL) exercises on an inclined treadmill are more effective at training the muscles than current rehab exercises used for strengthening the core, hip complex and calf muscles, therefore having the potential to decrease the occurrence of ACL injury.

This study will measure muscle activity in a number of different exercises via electromyography (EMG), a non-invasive procedure that consists of applying electrodes to the surface of the skin and attaching a wireless probe to the electrode that will capture the electrical activity of the muscle. All procedures will take place at Anytime Fitness in Alamosa, Colorado.

PROCEDURES

All procedures will take place on the same day.

1. Participants will be asked to complete a short questionnaire about their physical activity routine and injury history.
2. Electrode placement sites on the skin will be prepared on the participant's dominant side by abrading the skin and cleansing the area with rubbing alcohol swabs. Shaving of hair will be performed if body hair is present, as it will interfere with the EMG signals. Electrodes will then be placed on the belly of the following muscles: rectus femorus, gluteus maximus, gluteus medius, rectus abdominus, hamstring group, and gastrocnemius.
3. All participants will walk on a treadmill at 3 mph to warm up for three minutes.
4. Participants will do randomized maximum voluntary contractions (MVC) for the muscles with electrodes.
5. Participants will randomly draw to decide if they will perform the FLRL exercise or rehab exercises first.

6. The FLRL exercise will be done on a treadmill at an incline of 15% at 3 mph.
7. The participants will have a five-minute break between the rehab and FLRL exercises.
8. Rehab exercises will be done in a randomized order drawn by the participants. Rehab exercises to be performed include: step-ups onto an 10 inch box, side and prone bridges, and lunges.

DURATION OF PARTICIPATION

Data collection will take place throughout the spring semester at Adams State University. All procedures mentioned above will take place in one session, which will likely take anywhere from one (1) to two (2) hours. EMG prep usually takes around 10 minutes; the MVC's and data collection can take up to 2 hours.

RISKS AND DISCOMFORTS OR EXCLUSION FROM TESTING

Every effort will be made to conduct the testing procedures in such a way to minimize any risk. You have been asked to participate in this study because you have fulfilled all criteria as an individual with no prior history of knee injury, and have previous experience performing the FLRL exercise. Due to the FLRL exercise taking place on a slow moving motorized treadmill, the potential risks include a chance of falling while performing the exercises. Additionally to minimize risk of this occurrence, the researcher will assume the role of a spotter next to the participants during all exercises. The placement of electrodes could cause some light skin irritation due to the electrode gel on the underside of the electrode coming in contact with the skin. Minor muscle discomfort is possible while doing the exercises, but the risks are equivalent to those that participants would encounter in everyday life. Lastly, participants may experience soreness in the active musculature after the conclusion of the experiment, which is a potential side effect with any exercise.

BENEFITS

Participating in the study can help advance the sports rehab and performance fields. Participation can help to identify specific exercises that will contract specific muscles. The participants will have the chance to learn a new exercise and how to do it correctly, which could provide health benefits if added to their own workout routine.

CONFIDENTIALITY

Participation is voluntary and will be held confidential. Your privacy is always the number one concern. You may choose not to answer any question you do not want to answer, and/or you may withdraw from participation at any time, without penalty. All data files will be stored in a locked filing cabinet in the Adams State Athletic Training Room. Only the primary researcher will have access to the files. Names/identities will never be revealed even at the conclusion of the study. Any written or oral publication and/or presentation of this research will only show group data; you as an individual subject will not be identified.

INQUIRIES

Principal Researcher: Kevin Feldman, Masters Student, Department of Human Performance and Physical Education, feldmankl@grizzlies.adams.edu, 505-819-8642.

Thesis Advisor: Dr. Tracey Robinson, Professor, Department of Human Performance and Physical Education, (719) 587-7663, tlrobins@adams.edu.

IRB Chair: Dr. Rob Demski, chair of the IRB committee, rmdemski@adams.edu, or by phone at (719) 587-7216.

PLEASE READ THE FOLLOWING STATEMENTS, AND SIGN IN THE SPACES PROVIDED TO INDICATE YOUR CONSENT:

You are being asked to participate in a research study. This form provides you with information about the study. The researcher and/or a qualified representative will also describe this study to you and answer any questions you may have. Please read the information below and ask for clarification for any parts on which you have questions. Your participation in this study is completely confidential and voluntary. You may refuse to participate or withdraw at any time without penalty.

I have read the entirety of this form and understand the purpose of the study, procedures, discomforts and inconvenience of this study, as well as the benefits and risks. I have been given the opportunity to ask any questions before signing, and know that I am able to ask questions at any time during the study. By signing this form, I agree to voluntarily participate in this research study. I understand that I may later refuse to participate, and that I may withdraw from the study at any time. I have received a copy of this consent form for my own records. By signing this form, I am not waiving any of my legal rights.

____

Printed Name of Subject Date

____

Signature of Subject Date

____

Signature of Principal Researcher Date

Appendix H: Participant Questionnaire

Please take a few minutes to answer the questions to your best ability. You may skip any question you are not comfortable answering. Please do not put your name on the paper to keep your confidentiality.

Gender M F

Age ____

Weight _____

How many days a week do you work out? ________

Normal Duration of Workouts? <30min 30-45min 45min-1hr 1hr-1.5hr >1.5hr

Type of exercise? (*Circle all that apply*) Resistance training, Aerobic training, Flexibility Training, High Intensity Training FLRL

How many years have you been working out this way? ________

Have you had any previous knee injuries that required surgery? Y N

Appendix I: Output File Amplitude

Within-Subjects Factors

Measure: MEASURE_1

Exercise_RF	Dependent Variable
1	Bridge_RF_PER
2	SB_RF_PER
3	L_RF_PER
4	SU_RF_PER
5	FLRL_RF_PER

Descriptive Statistics

	Mean	Std. Deviation	N
Bridge_RF_PER	.1685	.10893	20
SB_RF_PER	.0765	.09901	20
L_RF_PER	.4955	.20649	20
SU_RF_PER	.5055	.41548	20
FLRL_RF_PER	.9100	.78031	20

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Exercise_RF	.001	118.557	9	.000	.295	.303	.250

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept
Within Subjects Design: Exercise_RF

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
Exercise_RF	Sphericity Assumed	8.675	4	2.169	20.107	.000	80.427	1.000
	Greenhouse-Geisser	8.675	1.179	7.357	20.107	.000	23.709	.995
	Huynh-Feldt	8.675	1.211	7.162	20.107	.000	24.352	.996
	Lower-bound	8.675	1.000	8.675	20.107	.000	20.107	.989
Error(Exercise_RF)	Sphericity Assumed	8.197	76	.108				
	Greenhouse-Geisser	8.197	22.404	.366				
	Huynh-Feldt	8.197	23.011	.356				
	Lower-bound	8.197	19.000	.431				

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
Intercept	18.593	1	18.593	44.869	.000	44.869	1.000
Error	7.873	19	.414				

a. Computed using alpha = .05

Pairwise Comparisons

Measure: MEASURE_1

(I) Exercise_RF	(J) Exercise_RF	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
1	2	.092*	.017	.000	.038	.146
	3	-.327*	.029	.000	-.420	-.234
	4	-.337*	.079	.004	-.588	-.086
	5	-.742*	.162	.002	-1.256	-.227
2	1	-.092*	.017	.000	-.146	-.038
	3	-.419*	.037	.000	-.538	-.300
	4	-.429*	.088	.001	-.710	-.148
	5	-.834*	.170	.001	-1.374	-.293
3	1	.327*	.029	.000	.234	.420
	2	.419*	.037	.000	.300	.538
	4	-.010	.065	1.000	-.217	.197
	5	-.414	.146	.103	-.877	.048
4	1	.337*	.079	.004	.086	.588
	2	.429*	.088	.001	.148	.710
	3	.010	.065	1.000	-.197	.217
	5	-.405*	.102	.008	-.729	-.080
5	1	.742*	.162	.002	.227	1.256
	2	.834*	.170	.001	.293	1.374
	3	.414	.146	.103	-.048	.877
	4	.405*	.102	.008	.080	.729

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

Within-Subjects Factors

Measure: MEASURE_1

Exercise_GMA	Dependent Variable
1	Bridge_GMAX_PER
2	SB_GMAX_PER
3	L_GMAX_PER
4	SU_GMAX_PER
5	FLRL_GMAX_PER

Descriptive Statistics

	Mean	Std. Deviation	N
Bridge_GMAX_PER	.0358	.01644	19
SB_GMAX_PER	.1300	.07888	19
L_GMAX_PER	.2026	.07915	19
SU_GMAX_PER	.2047	.13870	19
FLRL_GMAX_PER	.6153	.63598	19

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Exercise_GMA	.000	162.349	9	.000	.261	.263	.250

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept
Within Subjects Design: Exercise_GMA

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Exercise_GMA	Sphericity Assumed	3.748	4	.937	13.371	.000	.426	53.485	1.000
	Greenhouse-Geisser	3.748	1.045	3.585	13.371	.002	.426	13.977	.940
	Huynh-Feldt	3.748	1.053	3.557	13.371	.001	.426	14.086	.942
	Lower-bound	3.748	1.000	3.748	13.371	.002	.426	13.371	.933
Error(Exercise_GMA)	Sphericity Assumed	5.045	72	.070					
	Greenhouse-Geisser	5.045	18.816	.268					
	Huynh-Feldt	5.045	18.962	.266					
	Lower-bound	5.045	18.000	.280					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	5.367	1	5.367	34.359	.000	.656	34.359	1.000
Error	2.812	18	.156					

a. Computed using alpha = .05

Pairwise Comparisons

Measure: MEASURE_1

(I) Exercise_GMA	(J) Exercise_GMA	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	-.094*	.017	.000	-.150	-.039
	3	-.167*	.016	.000	-.219	-.114
	4	-.169*	.030	.000	-.265	-.073
	5	-.579*	.144	.008	-1.041	-.118
2	1	.094*	.017	.000	.039	.150
	3	-.073*	.019	.013	-.134	-.012
	4	-.075	.027	.139	-.162	.013
	5	-.485*	.137	.023	-.923	-.047
3	1	.167*	.016	.000	.114	.219
	2	.073*	.019	.013	.012	.134
	4	-.002	.019	1.000	-.063	.059
	5	-.413	.133	.060	-.836	.011
4	1	.169*	.030	.000	.073	.265
	2	.075	.027	.139	-.013	.162
	3	.002	.019	1.000	-.059	.063
	5	-.411*	.117	.025	-.784	-.037
5	1	.579*	.144	.008	.118	1.041
	2	.485*	.137	.023	.047	.923
	3	.413	.133	.060	-.011	.836
	4	.411*	.117	.025	.037	.784

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

Within-Subjects Factors

Measure: MEASURE_1

Exercise_GMED	Dependent Variable
1	Bridge_GMED_PER
2	SB_GMED_PER
3	L_GMED_PER
4	SU_GMED_PER
5	FLRL_GMED_PER

Descriptive Statistics

	Mean	Std. Deviation	N
Bridge_GMED_PER	.2115	.15267	20
SB_GMED_PER	.2405	.10860	20
L_GMED_PER	.1495	.07000	20
SU_GMED_PER	.2885	.14065	20
FLRL_GMED_PER	.6980	.77369	20

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Exercise_GMED	.000	147.661	9	.000	.275	.280	.250

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept
Within Subjects Design: Exercise_GMED

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Exercise_GMED	Sphericity Assumed	3.820	4	.955	8.719	.000	.315	34.875	.999
	Greenhouse-Geisser	3.820	1.101	3.470	8.719	.006	.315	9.598	.827
	Huynh-Feldt	3.820	1.118	3.416	8.719	.006	.315	9.750	.832
	Lower-bound	3.820	1.000	3.820	8.719	.008	.315	8.719	.800
Error(Exercise_GMED)	Sphericity Assumed	8.325	76	.110					
	Greenhouse-Geisser	8.325	20.916	.398					
	Huynh-Feldt	8.325	21.248	.392					
	Lower-bound	8.325	19.000	.438					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	10.087	1	10.087	45.805	.000	.707	45.805	1.000
Error	4.184	19	.220					

a. Computed using alpha = .05

Pairwise Comparisons

Measure: MEASURE_1

(I) Exercise_GMED	(J) Exercise_GMED	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	-.029	.042	1.000	-.163	.105
	3	.062	.030	.519	-.033	.157
	4	-.077	.034	.356	-.185	.031
	5	-.486	.158	.060	-.986	.013
2	1	.029	.042	1.000	-.105	.163
	3	.091*	.026	.024	.009	.173
	4	-.048	.035	1.000	-.160	.064
	5	-.457	.177	.181	-1.019	.104
3	1	-.062	.030	.519	-.157	.033
	2	-.091*	.026	.024	-.173	-.009
	4	-.139*	.018	.000	-.198	-.080
	5	-.549*	.161	.029	-1.059	-.038
4	1	.077	.034	.356	-.031	.185
	2	.048	.035	1.000	-.064	.160
	3	.139*	.018	.000	.080	.198
	5	-.409	.146	.115	-.874	.055
5	1	.486	.158	.060	-.013	.986
	2	.457	.177	.181	-.104	1.019
	3	.549*	.161	.029	.038	1.059
	4	.409	.146	.115	-.055	.874

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

Within-Subjects Factors

Measure: MEASURE_1

Exercise_ABS	Dependent Variable
1	Bridge_ABS_PER
2	SB_ABS_PER
3	L_ABS_PER
4	SU_ABS_PER
5	FLRL_ABS_PER

Descriptive Statistics

	Mean	Std. Deviation	N
Bridge_ABS_PER	.2115	.15267	20
SB_ABS_PER	.1525	.10315	20
L_ABS_PER	.0430	.02227	20
SU_ABS_PER	.0670	.05332	20
FLRL_ABS_PER	.1175	.09765	20

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Exercise_ABS	.065	47.688	9	.000	.574	.657	.250

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept
Within Subjects Design: Exercise_ABS

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Exercise_ABS	Sphericity Assumed	.363	4	.091	17.760	.000	.483	71.041	1.000
	Greenhouse-Geisser	.363	2.294	.158	17.760	.000	.483	40.750	1.000
	Huynh-Feldt	.363	2.627	.138	17.760	.000	.483	46.659	1.000
	Lower-bound	.363	1.000	.363	17.760	.000	.483	17.760	.979
Error(Exercise_ABS)	Sphericity Assumed	.389	76	.005					
	Greenhouse-Geisser	.389	43.594	.009					
	Huynh-Feldt	.389	49.916	.008					
	Lower-bound	.389	19.000	.020					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	1.399	1	1.399	53.061	.000	.736	53.061	1.000
Error	.501	19	.026					

a. Computed using alpha = .05

Pairwise Comparisons

Measure: MEASURE_1

(I) Exercise_ABS	(J) Exercise_ABS	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	.059	.024	.261	-.019	.137
	3	.169*	.031	.000	.069	.268
	4	.145*	.028	.001	.056	.233
	5	.094*	.027	.024	.009	.179
2	1	-.059	.024	.261	-.137	.019
	3	.109*	.021	.001	.042	.177
	4	.085*	.022	.009	.016	.155
	5	.035	.023	1.000	-.039	.109
3	1	-.169*	.031	.000	-.268	-.069
	2	-.109*	.021	.001	-.177	-.042
	4	-.024	.008	.097	-.050	.002
	5	-.075*	.018	.007	-.133	-.016
4	1	-.145*	.028	.001	-.233	-.056
	2	-.085*	.022	.009	-.155	-.016
	3	.024	.008	.097	-.002	.050
	5	-.050*	.013	.009	-.091	-.010
5	1	-.094*	.027	.024	-.179	-.009
	2	-.035	.023	1.000	-.109	.039
	3	.075*	.018	.007	.016	.133
	4	.050*	.013	.009	.010	.091

Within-Subjects Factors

Measure: MEASURE_1

Exercise_HAM	Dependent Variable
1	Bridge_HAM_PER
2	SB_HAM_PER
3	L_HAM_PER
4	SU_HAM_PER
5	FLRL_HAM_PER

Descriptive Statistics

	Mean	Std. Deviation	N
Bridge_HAM_PER	.0575	.11336	20
SB_HAM_PER	.1145	.10329	20
L_HAM_PER	.1325	.07144	20
SU_HAM_PER	.3685	.28880	20
FLRL_HAM_PER	.6510	.46114	20

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[c]
Exercise_HAM	Pillai's Trace	.646	7.305[b]	4.000	16.000	.002	.646	29.221	.975
	Wilks' Lambda	.354	7.305[b]	4.000	16.000	.002	.646	29.221	.975
	Hotelling's Trace	1.826	7.305[b]	4.000	16.000	.002	.646	29.221	.975
	Roy's Largest Root	1.826	7.305[b]	4.000	16.000	.002	.646	29.221	.975

a. Design: Intercept
Within Subjects Design: Exercise_HAM

b. Exact statistic

c. Computed using alpha = .05

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Exercise_HAM	.007	86.127	9	.000	.342	.359	.250

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept
Within Subjects Design: Exercise_HAM

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Exercise_HAM	Sphericity Assumed	4.859	4	1.215	24.944	.000	.568	99.776	1.000
	Greenhouse-Geisser	4.859	1.367	3.554	24.944	.000	.568	34.108	1.000
	Huynh-Feldt	4.859	1.438	3.380	24.944	.000	.568	35.858	1.000
	Lower-bound	4.859	1.000	4.859	24.944	.000	.568	24.944	.997
Error(Exercise_HAM)	Sphericity Assumed	3.701	76	.049					
	Greenhouse-Geisser	3.701	25.980	.142					
	Huynh-Feldt	3.701	27.314	.136					
	Lower-bound	3.701	19.000	.195					

a. Computed using alpha = .05

Pairwise Comparisons

Measure: MEASURE_1

(I) Exercise_HAM	(J) Exercise_HAM	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	-.057*	.016	.025	-.109	-.005
	3	-.075	.028	.134	-.162	.012
	4	-.311*	.069	.002	-.530	-.092
	5	-.594*	.107	.000	-.934	-.253
2	1	.057*	.016	.025	.005	.109
	3	-.018	.023	1.000	-.090	.054
	4	-.254*	.061	.005	-.446	-.062
	5	-.537*	.102	.000	-.861	-.212
3	1	.075	.028	.134	-.012	.162
	2	.018	.023	1.000	-.054	.090
	4	-.236*	.058	.007	-.420	-.052
	5	-.519*	.096	.000	-.823	-.214
4	1	.311*	.069	.002	.092	.530
	2	.254*	.061	.005	.062	.446
	3	.236*	.058	.007	.052	.420
	5	-.283*	.065	.003	-.487	-.078
5	1	.594*	.107	.000	.253	.934
	2	.537*	.102	.000	.212	.861
	3	.519*	.096	.000	.214	.823
	4	.283*	.065	.003	.078	.487

Within-Subjects Factors

Measure: MEASURE_1

Exercise_GAS	Dependent Variable
1	Bridge_Gas_per
2	SB_GAS_PER
3	L_GAS_PER
4	SU_GAS_PER
5	FLRL_GAS_PER

Descriptive Statistics

	Mean	Std. Deviation	N
Bridge_Gas_per	.0485	.02134	20
SB_GAS_PER	.0795	.05443	20
L_GAS_PER	.2850	.15932	20
SU_GAS_PER	.6255	.32997	20
FLRL_GAS_PER	1.2725	.92596	20

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[c]
Exercise_GAS	Pillai's Trace	.809	16.920[b]	4.000	16.000	.000	.809	67.681	1.000
	Wilks' Lambda	.191	16.920[b]	4.000	16.000	.000	.809	67.681	1.000
	Hotelling's Trace	4.230	16.920[b]	4.000	16.000	.000	.809	67.681	1.000
	Roy's Largest Root	4.230	16.920[b]	4.000	16.000	.000	.809	67.681	1.000

a. Design: Intercept
Within Subjects Design: Exercise_GAS

b. Exact statistic

c. Computed using alpha = .05

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Exercise_GAS	.000	148.851	9	.000	.281	.286	.250

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept
Within Subjects Design: Exercise_GAS

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Exercise_GAS	Sphericity Assumed	20.645	4	5.161	32.731	.000	.633	130.926	1.000
	Greenhouse-Geisser	20.645	1.122	18.395	32.731	.000	.633	36.736	1.000
	Huynh-Feldt	20.645	1.144	18.051	32.731	.000	.633	37.435	1.000
	Lower-bound	20.645	1.000	20.645	32.731	.000	.633	32.731	1.000
Error(Exercise_GAS)	Sphericity Assumed	11.984	76	.158					
	Greenhouse-Geisser	11.984	21.325	.562					
	Huynh-Feldt	11.984	21.731	.551					
	Lower-bound	11.984	19.000	.631					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	21.363	1	21.363	58.635	.000	.755	58.635	1.000
Error	6.922	19	.364					

a. Computed using alpha = .05

	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	1	.577*	.070	.000	.355	.799
	2	.546*	.072	.000	.318	.774
	3	.341*	.054	.000	.169	.512
	5	-.647*	.155	.005	-1.137	-.157
5	1	1.224*	.203	.000	.578	1.870
	2	1.193*	.206	.000	.539	1.847
	3	.988*	.187	.000	.395	1.580
	4	.647*	.155	.005	.157	1.137

Based on estimated marginal means

Appendix J: Output File McNeamer's

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distributions of different values across Strength_RF and Strength_FLRL_RF are equally likely.	Related-Samples McNemar Test	.000[1]	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

[1] Exact significance is displayed for this test.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distributions of different values across Strength_GMAX and ST_GMAX_FLRL are equally likely.	Related-Samples McNemar Test	.001[1]	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

[1] Exact significance is displayed for this test.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distributions of different values across ST_GMED_BRIDGE and ST_GMED_FLRL are equally likely.	Related-Samples McNemar Test	.000[1]	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

[1] Exact significance is displayed for this test.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distributions of different values across ST_ABS_BRIDGE and ST_ABS_FLRL are equally likely.	Related-Samples McNemar Test	.250[1]	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

[1] Exact significance is displayed for this test.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distributions of different values across ST_HAM_BRIDGE and ST_HAM_FLRL are equally likely.	Related-Samples McNemar Test	.012[1]	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

[1]Exact significance is displayed for this test.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distributions of different values across ST_GAS_BRIDGE and ST_GAS_FLRL are equally likely.	Related-Samples McNemar Test	.000[1]	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

[1]Exact significance is displayed for this test.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distributions of different values across ST_RF_SB and Strength_FLRL_RF are equally likely.	Related-Samples McNemar Test	.000[1]	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

[1]Exact significance is displayed for this test.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distributions of different values across ST_GMAX_SB and ST_GMAX_FLRL are equally likely.	Related-Samples McNemar Test	.001[1]	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

[1]Exact significance is displayed for this test.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distributions of different values across ST_GMED_SB and ST_GMED_FLRL are equally likely.	Related-Samples McNemar Test	.000[1]	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

[1] Exact significance is displayed for this test.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distributions of different values across ST_ABS_SB and ST_ABS_FLRL are equally likely.	Related-Samples McNemar Test	1.000[1]	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

[1] Exact significance is displayed for this test.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distributions of different values across ST_HAM_SB and ST_HAM_FLRL are equally likely.	Related-Samples McNemar Test	.012[1]	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

[1] Exact significance is displayed for this test.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distributions of different values across ST_GAS_SB and ST_GAS_FLRL are equally likely.	Related-Samples McNemar Test	.000[1]	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

[1] Exact significance is displayed for this test.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distributions of different values across ST_RF_L and Strength_FLRL_RF are equally likely.	Related-Samples McNemar Test	.002[1]	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

[1]Exact significance is displayed for this test.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distributions of different values across ST_GMAX_L and ST_GMAX_FLRL are equally likely.	Related-Samples McNemar Test	.002[1]	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

[1]Exact significance is displayed for this test.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distributions of different values across ST_GMED_L and ST_GMED_FLRL are equally likely.	Related-Samples McNemar Test	.000[1]	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

[1]Exact significance is displayed for this test.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distributions of different values across ST_ABS_L and ST_ABS_FLRL are equally likely.	Related-Samples McNemar Test	.	Unable to compute .

Asymptotic significances are displayed. The significance level is .05.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distributions of different values across ST_HAM_L and ST_HAM_FLRL are equally likely.	Related-Samples McNemar Test	.002[1]	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

[1]Exact significance is displayed for this test.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distributions of different values across ST_GAS_L and ST_GAS_FLRL are equally likely.	Related-Samples McNemar Test	.000[1]	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

[1]Exact significance is displayed for this test.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distributions of different values across Strength_FLRL_RF and ST_RF_SU are equally likely.	Related-Samples McNemar Test	.008[1]	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

[1]Exact significance is displayed for this test.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distributions of different values across ST_GMAX_SU and ST_GMAX_FLRL are equally likely.	Related-Samples McNemar Test	.004[1]	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

[1]Exact significance is displayed for this test.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distributions of different values across ST_GMED_SU and ST_GMED_FLRL are equally likely.	Related-Samples McNemar Test	.001[1]	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

[1]Exact significance is displayed for this test.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distributions of different values across ST_ABS_SU and ST_ABS_FLRL are equally likely.	Related-Samples McNemar Test	.	Unable to compute.

Asymptotic significances are displayed. The significance level is .05.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distributions of different values across ST_HAM_SU and ST_HAM_FLRL are equally likely.	Related-Samples McNemar Test	.375[1]	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

[1]Exact significance is displayed for this test.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distributions of different values across ST_GAS_SU and ST_GAS_FLRL are equally likely.	Related-Samples McNemar Test	.016[1]	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

[1]Exact significance is displayed for this test.

Appendix K: Output File Frequency

Within-Subjects Factors

Measure: MEASURE_1

Freq_RF	Dependent Variable
1	Frequency_BR_RF
2	Fre_RF_SB
3	FRE_RF_LU
4	FRE_RF_SU
5	FRE_RF_FLRL

Descriptive Statistics

	Mean	Std. Deviation	N
Frequency_BR_RF	.8599	1.65978	20
Fre_RF_SB	.4835	2.06518	20
FRE_RF_LU	-.2041	2.33831	20
FRE_RF_SU	.2430	2.18543	20
FRE_RF_FLRL	-2.1385	1.71625	20

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Freq_RF	.628	8.095	9	.527	.813	1.000	.250

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept
Within Subjects Design: Freq_RF

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Pairwise Comparisons

Measure: MEASURE_1

(I) Freq_RF	(J) Freq_RF	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	.376	.614	1.000	-1.571	2.324
	3	1.064	.527	.577	-.608	2.736
	4	.617	.608	1.000	-1.314	2.548
	5	2.998*	.622	.001	1.024	4.972
2	1	-.376	.614	1.000	-2.324	1.571
	3	.688	.636	1.000	-1.332	2.707
	4	.240	.411	1.000	-1.063	1.544
	5	2.622*	.523	.001	.961	4.283
3	1	-1.064	.527	.577	-2.736	.608
	2	-.688	.636	1.000	-2.707	1.332
	4	-.447	.641	1.000	-2.482	1.588
	5	1.934	.699	.123	-.285	4.153
4	1	-.617	.608	1.000	-2.548	1.314
	2	-.240	.411	1.000	-1.544	1.063
	3	.447	.641	1.000	-1.588	2.482
	5	2.382*	.571	.005	.569	4.194
5	1	-2.998*	.622	.001	-4.972	-1.024
	2	-2.622*	.523	.001	-4.283	-.961
	3	-1.934	.699	.123	-4.153	.285
	4	-2.382*	.571	.005	-4.194	-.569

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

Within-Subjects Factors

Measure: MEASURE_1

Freq_GMAX	Dependent Variable
1	Frequency_GMax_BR
2	Fre_GMAX_SB
3	FRE_GMAX_LU
4	FRE_GMAX_SU
5	FRE_GMAX_FLRL

Descriptive Statistics

	Mean	Std. Deviation	N
Frequency_GMax_BR	-.1922	1.06817	19
Fre_GMAX_SB	-.2574	2.63866	19
FRE_GMAX_LU	1.2605	2.59089	19
FRE_GMAX_SU	.4005	2.97007	19
FRE_GMAX_FLRL	2.9037	2.21562	19

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Freq_GMAX	.500	11.393	9	.252	.791	.979	.250

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept
Within Subjects Design: Freq_GMAX

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Pairwise Comparisons

Measure: MEASURE_1

(I) Freq_GMAX	(J) Freq_GMAX	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	.065	.664	1.000	-2.057	2.188
	3	-1.453	.644	.367	-3.511	.605
	4	-.593	.727	1.000	-2.916	1.731
	5	-3.096*	.501	.000	-4.698	-1.494
2	1	-.065	.664	1.000	-2.188	2.057
	3	-1.518	.787	.698	-4.035	.999
	4	-.658	.595	1.000	-2.560	1.245
	5	-3.161*	.706	.003	-5.417	-.906
3	1	1.453	.644	.367	-.605	3.511
	2	1.518	.787	.698	-.999	4.035
	4	.860	.819	1.000	-1.757	3.477
	5	-1.643	.658	.225	-3.747	.461
4	1	.593	.727	1.000	-1.731	2.916
	2	.658	.595	1.000	-1.245	2.560
	3	-.860	.819	1.000	-3.477	1.757
	5	-2.503*	.546	.002	-4.249	-.758
5	1	3.096*	.501	.000	1.494	4.698
	2	3.161*	.706	.003	.906	5.417
	3	1.643	.658	.225	-.461	3.747
	4	2.503*	.546	.002	.758	4.249

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

Within-Subjects Factors

Measure: MEASURE_1

Freq_GMED	Dependent Variable
1	Fre_GMED_BR
2	FRE_GMED_SB
3	FRE_GMED_LU
4	FRE_GMED_SU
5	FRE_GMED_FLRL

Descriptive Statistics

	Mean	Std. Deviation	N
Fre_GMED_BR	-.0440	1.59047	20
FRE_GMED_SB	.1580	1.58249	20
FRE_GMED_LU	.7430	2.51307	20
FRE_GMED_SU	-.6183	2.72391	20
FRE_GMED_FLRL	2.3629	1.44612	20

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Freq_GMED	.463	13.394	9	.147	.751	.908	.250

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept
Within Subjects Design: Freq_GMED

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Pairwise Comparisons

Measure: MEASURE_1

(I) Freq_GMED	(J) Freq_GMED	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
1	2	-.202	.472	1.000	-1.701	1.297
	3	-.787	.662	1.000	-2.888	1.314
	4	.574	.610	1.000	-1.360	2.509
	5	-2.407*	.444	.000	-3.817	-.996
2	1	.202	.472	1.000	-1.297	1.701
	3	-.585	.544	1.000	-2.311	1.141
	4	.776	.681	1.000	-1.385	2.938
	5	-2.205*	.512	.004	-3.829	-.581
3	1	.787	.662	1.000	-1.314	2.888
	2	.585	.544	1.000	-1.141	2.311
	4	1.361	.691	.634	-.830	3.553
	5	-1.620	.720	.364	-3.903	.664
4	1	-.574	.610	1.000	-2.509	1.360
	2	-.776	.681	1.000	-2.938	1.385
	3	-1.361	.691	.634	-3.553	.830
	5	-2.981*	.785	.012	-5.474	-.488
5	1	2.407*	.444	.000	.996	3.817
	2	2.205*	.512	.004	.581	3.829
	3	1.620	.720	.364	-.664	3.903
	4	2.981*	.785	.012	.488	5.474

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

Within-Subjects Factors

Measure: MEASURE_1

Freq_ABS	Dependent Variable
1	Frequency_ABS_BR
2	freq_ABS_SB
3	FRE_ABS_LU
4	FRE_ABS_SU
5	FRE_ABS_FLRL

Descriptive Statistics

	Mean	Std. Deviation	N
Frequency_ABS_BR	.2200	1.69377	20
freq_ABS_SB	.9960	1.98839	20
FRE_ABS_LU	.6128	1.84851	20
FRE_ABS_SU	1.0525	2.24475	20
FRE_ABS_FLRL	2.4015	1.63810	20

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Freq_ABS	.602	8.834	9	.455	.799	.979	.250

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept
Within Subjects Design: Freq_ABS

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Pairwise Comparisons

Measure: MEASURE_1

(I) Freq_ABS	(J) Freq_ABS	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	-.776	.425	.835	-2.124	.572
	3	-.393	.661	1.000	-2.491	1.706
	4	-.833	.532	1.000	-2.521	.856
	5	-2.181*	.489	.003	-3.734	-.629
2	1	.776	.425	.835	-.572	2.124
	3	.383	.731	1.000	-1.935	2.702
	4	-.056	.584	1.000	-1.911	1.798
	5	-1.406	.499	.110	-2.988	.177
3	1	.393	.661	1.000	-1.706	2.491
	2	-.383	.731	1.000	-2.702	1.935
	4	-.440	.767	1.000	-2.874	1.994
	5	-1.789	.675	.157	-3.929	.352
4	1	.833	.532	1.000	-.856	2.521
	2	.056	.584	1.000	-1.798	1.911
	3	.440	.767	1.000	-1.994	2.874
	5	-1.349	.611	.398	-3.289	.591
5	1	2.181*	.489	.003	.629	3.734
	2	1.406	.499	.110	-.177	2.988
	3	1.789	.675	.157	-.352	3.929
	4	1.349	.611	.398	-.591	3.289

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

Within-Subjects Factors

Measure: MEASURE_1

Freq_ham	Dependent Variable
1	Fre_HAM_BR
2	FRE_HAM_SB
3	FRE_HAM_LU
4	FRE_HAM_SU
5	FRE_HAM_FLRL

Descriptive Statistics

	Mean	Std. Deviation	N
Fre_HAM_BR	.5393	1.14593	20
FRE_HAM_SB	.4570	1.79687	20
FRE_HAM_LU	.9785	2.18735	20
FRE_HAM_SU	.4745	2.35771	20
FRE_HAM_FLRL	2.5475	1.47381	20

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Freq_ham	.266	23.067	9	.006	.597	.689	.250

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept
Within Subjects Design: Freq_ham

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Pairwise Comparisons

Measure: MEASURE_1

(I) Freq_ham	(J) Freq_ham	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	.082	.469	1.000	-1.405	1.570
	3	-.439	.482	1.000	-1.969	1.091
	4	.065	.618	1.000	-1.895	2.025
	5	-2.008*	.389	.001	-3.243	-.773
2	1	-.082	.469	1.000	-1.570	1.405
	3	-.522	.600	1.000	-2.424	1.381
	4	-.018	.777	1.000	-2.485	2.450
	5	-2.091*	.423	.001	-3.433	-.748
3	1	.439	.482	1.000	-1.091	1.969
	2	.522	.600	1.000	-1.381	2.424
	4	.504	.860	1.000	-2.226	3.234
	5	-1.569*	.448	.024	-2.990	-.148
4	1	-.065	.618	1.000	-2.025	1.895
	2	.018	.777	1.000	-2.450	2.485
	3	-.504	.860	1.000	-3.234	2.226
	5	-2.073	.781	.157	-4.553	.407
5	1	2.008*	.389	.001	.773	3.243
	2	2.091*	.423	.001	.748	3.433
	3	1.569*	.448	.024	.148	2.990
	4	2.073	.781	.157	-.407	4.553

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

Within-Subjects Factors

Measure: MEASURE_1

Freq_ga	Dependent Variable
1	Fre_GA_BR
2	FRE_GA_SB
3	FRE_GA_LU
4	FRE_GA_SU
5	FRE_GA_FLRL

Descriptive Statistics

	Mean	Std. Deviation	N
Fre_GA_BR	.7591	1.25517	20
FRE_GA_SB	.2635	1.47767	20
FRE_GA_LU	.6040	1.57748	20
FRE_GA_SU	.8395	2.28433	20
FRE_GA_FLRL	1.8030	1.24441	20

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Freq_ga	.338	18.888	9	.027	.717	.857	.250

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept
Within Subjects Design: Freq_ga

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Pairwise Comparisons

Measure: MEASURE_1

(I) Freq_ga	(J) Freq_ga	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	.496	.315	1.000	-.505	1.496
	3	.155	.500	1.000	-1.431	1.741
	4	-.080	.573	1.000	-1.899	1.738
	5	-1.044*	.272	.011	-1.909	-.179
2	1	-.496	.315	1.000	-1.496	.505
	3	-.341	.439	1.000	-1.733	1.052
	4	-.576	.531	1.000	-2.262	1.110
	5	-1.540*	.377	.006	-2.735	-.344
3	1	-.155	.500	1.000	-1.741	1.431
	2	.341	.439	1.000	-1.052	1.733
	4	-.236	.602	1.000	-2.145	1.674
	5	-1.199	.546	.406	-2.931	.533
4	1	.080	.573	1.000	-1.738	1.899
	2	.576	.531	1.000	-1.110	2.262
	3	.236	.602	1.000	-1.674	2.145
	5	-.964	.519	.790	-2.611	.684
5	1	1.044*	.272	.011	.179	1.909
	2	1.540*	.377	.006	.344	2.735
	3	1.199	.546	.406	-.533	2.931
	4	.964	.519	.790	-.684	2.611

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.