EFFECTS OF A GLUTEAL ACTIVATION PROGRAM ON MUSCLE FATIGUE AND PERFORMANCE DURING A 5K RUN

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Master of Science in Applied Exercise Science

Oklahoma State University

Stillwater, OK

2019

Bachelor of Science in Athletic Training

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
Master of Science
July, 2019

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ACKNOWLEDGEMENTS

To all that helped me complete this labor of my educational degree; thank you. Most especially, thank you to Ale Barreria Curriel, whose help, patience, and kindness has been indispensable during my research. To my professors and committee members, thank you for your time and patience as I went through this process. To my friends and family, thank you for helping me persevere, for reminding me of the light at the end of the tunnel. And finally, to my cross country athletes, athletic training staff members, and friends I've made through my time at Oklahoma State, thank you for helping me, believing in me, and encouraging me through this process.

Name: CECILIA A. LANE

Date of Degree: JULY, 2019

Title of Study: EFFECTS OF A GLUTEAL ACTIVATION PROGRAM ON MUSCLE FATIGUE AND PERFORMANCE DURING A 5K RUN

Major Field: APPLIED EXERCISE SCIENCE

Abstract: Studies show that fatigue causes delayed and decreased muscle activation and motor control in hip musculature during prolonged activity, increasing the risk of injury due to poor joint kinematics and muscle weakness. Previous research has analyzed the intervention of gluteal activation exercises during dynamic and anaerobic activities, but have not investigated the effects of a low-load gluteal activation program during endurance activities. The current study compared hip muscle activity and performance during a controlled 5k run and a run preceded by gluteal activation (GA) exercises. Hip abduction and extension strength were measured before and immediately following a 5k run, while electromyography (EMG) data was recorded in five minute intervals during the run via surface electrodes. Performing GA exercises prior to an endurance run was expected to improve performance and delay muscular fatigue, indicated by a faster performance time and greater and more consistent muscle activation over time compared to a run absent of activation exercises. Results indicated there was no significant difference in muscle activation between condition and time during analysis of five consecutive steps as well as strength at the beginning and end of the run. However, performance was found to significantly improve during the GA condition. Findings may indicate that performing a GA routine prior to activity may promote improved gluteal function, improve performance, and indirectly prevent injury due to improved kinematics and muscular function.

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CHAPTER I

INTRODUCTION

Hip musculature and core stability are key components in the maintenance of proper biomechanical function during walking, running, sprinting, jumping, and other activities (Willson, Dougherty, Ireland, & Davis, 2005). Lumbar vertebrae, pelvic bones, 29 pairs of muscles, and surrounding ligaments help maintain stability and support within the lumbopelvic-hip complex, more commonly known as the "core" (Fredericson & Moore, 2005; Willson et al., 2005). Gluteal muscle strength and core musculature are integral aspects involved in gait and postural stability. Without it, hip and trunk kinematics suffer, which may lead to increased risk of injury due to poor kinematics or muscle imbalances (Ford, Taylor-Haas, Genthe, & Hugentobler, 2013; Willson, Kernozek, Arndt, Reznichek, & Straker, 2012).

Primary components of gluteal musculature are the gluteus maximus, gluteus medius, and to a lesser degree, the gluteus minimus. The gluteus medius is a hip abductor muscle that also provides primary lateral support of the hip and pelvis during walking and running (Selkowitz, Beneck, & Powers, 2013; Willson et al., 2005). The gluteus maximus is a hip extensor and external rotator, but the superior portion of the muscle also acts to abduct the hip during gait (Selkowitz et al., 2013). Both muscles are important in hip kinematics; weaknesses or impairments in these muscles are strongly associated with injury (Barton, Lack, Malliaras, Morrissey, 2013; Dierks, Manal, Hamill, & Davis, 2008; DiStefano, Blackburn, Marshall & Padua, 2009; Ford et al., 2013).

Previous research has shown that abnormal hip kinematics or impaired muscle function is associated with a multitude of musculoskeletal injuries, including patellofemoral pain syndrome, iliotibial band syndrome, ligamentous injuries, low back pain, tibial stress fractures, ankle sprains, and more (Barton et al., 2013; Dierks et al., 2008; DiStefano et al., 2009; Ekstrom, Donatelli, & Carp, 2007; Ford et al., 2013; Selkowitz et al., 2013; Semciw, Neate, & Pizzari, 2016; Taylor-Haas, Hugentobler, DiCesare, Hickey Lucas, Bates, Myer, & Ford, 2014; Willson et al., 2005; Willson et al., 2012). When compared to healthy populations, injured populations such as individuals with patellofemoral pain syndrome (PFPS) typically present with weaker hip muscles and altered hip kinematics (Barton et al., 2013; Willson et al., 2012). However, when using a hip strengthening program as an intervention for this population, quality of life increases while pain levels decrease, ultimately leading to a reduced risk of injury (Khayambashi et al., 2014).

Neuromuscular fatigue is defined as a decline in force or power observed during a period of repeated muscle activation (Harrison & McCabe, 2017). It may be noticed as a decrease in force production, contraction duration, or altered neuromuscular control during activity (Lessi & Serrao, 2017; Martin, Kerheve, Messonnier, Banfif, Geyssant, Bonnefoy, & Feasson, 2010). It plays a role in the risk for injury due to subsequent alterations in pelvis and trunk position and stability after fatigued conditions (Lessi, dos Santos, Batista, de Oliveira, & Serrao, 2017). Dierks et al. (2008) reported that during a fatiguing run, hip abduction strength was associated with larger hip adduction angles when endurance athletes perform to exertion. Similarly, Lessi et al. (2017) indicated that during single-leg drop vertical jumps, trunk and knee kinematics were altered after a fatiguing protocol. These alterations in biomechanical control and kinematics may lead to an increased predisposition for injury due to improper loading of stresses within the body (Fredericson & Moore, 2005).

Muscle activity can be measured through electromyography (EMG) analysis (Selkowitz et al., 2013). Surface electrodes are placed on the skin and are able to detect electrical activity within the muscle (Selkowitz et al., 2013). Through this technology, it is possible to detect how stimulated muscles are during activities or detect fatigue levels by comparing end results to initial results. Commonly, studies detect EMG activation throughout activities or during fatiguing exercises. Additionally, past research has studied EMG activity of the trunk, hip, core, and gluteal muscle during common therapeutic exercises to determine which exercises are the most effective or result in greatest activity within specific muscles in order to utilize these exercises in strengthening, rehabilitation, or activation programs (DiStefano et al., 2009; Ekstrom et al., 2007; Selkowitz et al., 2013).

Though fatigue is also associated with decreases in muscle strength and the ability to maintain stabilization during exercise, fatigue is also more positively associated with the idea of post-activation potentiation (Harrison & McCabe, 2017). Post-activation potentiation (PAP) is a phenomenon that occurs when force output in a muscle is increased after performing a brief heavy resistance exercise or a maximum voluntary contraction (Hamada, Sale, & MacDougall, 2000; Harrison & McCabe, 2017). In other words, after lifting a heavy weight or performing a maximal voluntary contraction, the force evoked in subsequent contractions is greater than normal (Hamada et al., 2000, Harrison & McCabe, 2017; Lorenz, 2005). For example: a baseball player may warm up to bat by swinging two bats or adding weights to the end of their bat, then drop the extra weight immediately before stepping in the batting box in order to make subsequent swings feel lighter or easier, theoretically allowing the ball to be hit farther. Post-activation potentiation occurs as a balance between fatigue and potentiation; it is also greatest in anaerobic activities in which the most active muscle fibers are Type II with short-twitch contraction times and during maximal voluntary contractions for ~10 seconds (Hamada et al., 2000; Harrison & McCabe, 2017). Though PAP is greatest for Type II fibers, it has also been shown to have potential effects on endurance athletes with Type I fibers (Hamada et al., 2000; Harrison & McCabe, 2017). This is because endurance athletes are trained against fatigue and are more able to prevail against the co-existing effects of fatigue during PAP (Hamada et al., 2000; Harrison & McCabe, 2017).

Gluteal post-activation potentiation has been studied in explosive exercise activities, but conflicting results have been reported (Comyns, Kenny, & Scales, 2015; Crow, Buttifant, Kearny, Hrysomallis, 2012; Parr, Price, & Cleather, 2017). Crow et al. (2012) and Comyns et al. (2015) have both shown potential improvements in anaerobic activities such as squat jumping or countermovement jumping, whereas Harrison & McCabe (2017) and Parr et al. (2017) did not show increased sprinting or drop jump performances after performing gluteal activation potentiation exercises. Most of the research performed thus far has centered around more anaerobic and dynamic activities; however, very few, if any, studies have been performed on the potential effects of gluteal activation potentiation on endurance trained runners. More research must be done to investigate the idea that post-activation potentiation in gluteal musculature can lead to improved performance, improved muscular function, and delayed fatigue effects in gluteal musculature, which would result in decreased injury rates and improvements in biomechanical function and movement efficiency.

The purpose of this study is to analyze the effects of a gluteal activation potentiation routine on fatigue in endurance trained athletes during a prolonged run. Electromyographic (EMG) data will be recorded on surrounding hip musculature to measure muscle activity before, during, and after a 5k distance run. Maximal voluntary isometric contractions will be performed to normalize the collected EMG data in order to assess gluteal activation levels throughout the fatiguing exercise. EMG data will measure gluteal muscle activity at five minute intervals throughout a fatigue inducing 5k run. It is hypothesized that performing a gluteal activation potentiation protocol will: (1) demonstrate delayed fatigue effects, indicated by improved hip muscle strength and longer, more regular activation over time than when compared to run excluding the gluteal activation protocol and (2) improve performance, indicated by improving the time to task completion than when compared to a controlled run.

CHAPTER II

REVIEW OF LITERATURE

(2.1) Introduction

This study, as proposed in the first chapter, aims to explore the effects of gluteal activation exercises on fatigue during a prolonged run. This chapter will focus on the key concepts involved in the anatomy of the core and hip musculature, running kinematics and implication for injury, neuromuscular fatigue, post-activation potentiation, and EMG analysis of common gluteal activation exercises. By the end of this chapter, pertinent information regarding the research question will be explained and the research question will be addressed.

(2.2) Anatomy

Before understanding how gluteal muscle activation can affect fatigue effects, it is important to know the anatomy and actions of key core and hip musculature. The "core" is a term used to define the muscles around the abdomen, including the abdominals, paraspinals and gluteals, diaphragm, and pelvic floor/hip girdle musculature (Fredericson & Moore, 2005). This lumbopelvic-hip region, or "core," is comprised of around 29 pairs of muscles that stabilize the spine, pelvis, and kinetic chain, and also acts on bones and ligaments such as the lumbar vertebrae, pelvis, hip joints, and surrounding ligaments

(Fredericson & Moore, 2005; Willson et al., 2005). Core stability is vital for distributing forces, optimizing control and efficiency of movement, absorbing ground-impact forces, and protecting the body from excessive stressful forces on the joints within the kinetic chain (Fredericson & Moore, 2005).

Key muscles of the core include the rectus abdominis, transverse abdominis, multifidus, erector spinae, tensor fascia latae (TFL), adductor muscles, gluteus maximus, gluteus medius, and gluteus minimus (Willson et al., 2005). These muscles all work together to stabilize the pelvis, flex and extend the trunk and hip, externally and internally rotate the hip, and abduct and adduct the hip (Willson et al., 2005).

Gluteal muscles. Gluteal muscles are very important muscles of the hip. The gluteus maximus (GMAX) helps transfer forces from the lower extremities to the trunk while the gluteus minimus (GMIN) and gluteus medius (GMED) are primary stabilizers of the lateral hip and function to maintain a stable pelvis (Selkowitz et al., 2013; Willson et al., 2005). The gluteus maximus is an extensor and external rotator of the hip, while the superior aspect of the muscle also acts as a hip abductor during gait (Selkowitz et al., 2013). The gluteus maximus works with the hamstrings to extend the hip while the leg is in the end of the swing phase, preparing for initial contact (Novacheck, 1998). The gluteus medius is a hip abductor, contracting eccentrically to abduct the

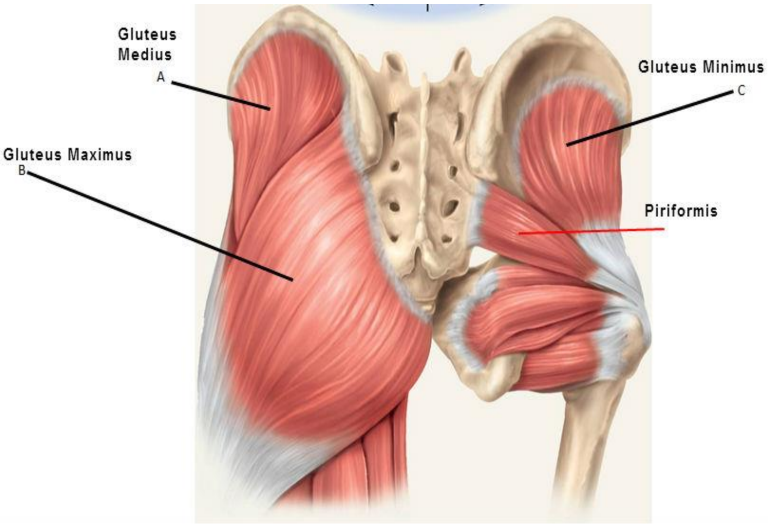

Figure 1: Gluteal musculature, including the gluteus maximus, gluteus medius, gluteus minimus, and piriformis. (Fitzgordon, 2014).

hip during the stance phase in order to prevent the hip from falling into adduction due to gravitational and acceleration loads (Novacheck, 1998; Selkowitz et al., 2013). Additionally, it concentrically abducts the hip to generate power when walking (Harrison & McCabe, 2017; Selkowitz et al., 2013). In a systematic review of research regarding gluteus medius function, it was found that the GMED produces the largest mean peak muscle force of all muscles in the hip during running (Lenhart, Thelen, & Heiderscheit, 2014; Semciw et al., 2016).

(2.3) Running Kinematics

The process of walking or running is considered “functional gait,” which can be further broken down into gait cycles (Novacheck, 1998). A gait cycle consists of two main phases, which begins when one foot makes contact with the ground and ends when the same foot comes in contact with the ground again (Novacheck, 1998). The stance phase of gait begins with initial contact, in which the foot comes in contact with the ground, and ends in toe-off, when the same foot is no longer in contact with the ground. (Novacheck, 1998). The swing phase begins when the stance phase ends and ends immediately prior to the start of the next stance phase; as the toe comes off the ground during toe-off, the foot swings forward and prepares for initial contact again. (Novachek, 1998). Electromyographic (EMG) data is most active in preparation for and immediately following initial contact; the hamstrings, hip extensors, rectus femoris, quadriceps, triceps surae, and anterior tibial muscles may all be active during this period (Novacheck, 1998). For efficient movement of the body during walking or running, optimal joint kinematics are required. These muscles must work in concert with each other to absorb shock, balance the upper body and control posture, generate energy for movement, and change direction (Fredericson & Moore, 2005; Novacheck, 1998; Winter & Bishop, 1992).

Impaired Gluteal Kinematics. When gluteal muscle function becomes impaired through weakness, fatigue, or improper firing patterns, injury can occur. It is well documented that muscle weakness at the hip is associated with patellofemoral pain syndrome (PFPS), iliotibial band syndrome, tibial stress fractures, ankle sprains or hypermobility, and other overuse injuries (Barton et al., 2013; Dierks et al., 2008; DiStefano et al., 2009; Ekstrom et al., 2007; Selkowitz et al., 2013; Semciw et al., 2016; Taylor-Haas et al., 2014; Willson et al., 2005; Willson et al., 2012). These injuries often result from improper loading of muscles and joints, leading to tissue damage and pain. Taylor-Haas et al. (2014) suggested that an inability to stabilize the hip while running can increase the quadriceps angle (Q angle), measured as the angle from the anterior superior iliac spine (ASIS) located on the pelvis to the midpatella. An increase in Q angle from weak musculature can result in abnormal contact pressure of the patella on surrounding structures, leading to patellofemoral pain syndrome (Taylor-Haas et al., 2014). Similarly, Dierks et al. (2008; 2011) suggested that weakness in the hip abductors may allow excessive femoral adduction to occur during running. Increased femoral adduction can lead to an increased valgus position of the knee and cause pain as a result of lateral forces acting on the patella (Dierks et al., 2008; Dierks, Manal, Hamill, & Davis, 2011). It has also been noted that when compared to healthy cohorts, runners with PFPS have weaker hip muscle strength than do healthy runners (Willson et al., 2012). Conversely, after an 8-week hip abductor and external rotator strengthening program, it has been found that individuals with PFPS have reduced pain and improved health status than when compared to a control group, enforcing the relationship between gluteal strength and the risk for injury (Khayambashi et al., 2014).

(2.4) Hip and Gluteal Exercises and EMG Data

Electromyography (EMG) is a tool that is can be used to assess muscle activity during exercise or at rest (Selkowitz et al., 2013). Surface EMG, fine wire EMG, or needle EMG may all be used to detect muscle activity. Though fine wire and needle EMG may result in more accurate results as they are inserted within the muscle, these EMG sources are invasive procedures and may potentially limit muscle contraction due to discomfort of needles within the muscle and during activity.

Several studies (DiStefano et al., 2009; Ekstrom et al., 2007; Selkowitz et al., 2013) have measured EMG data after common gluteal and core therapeutic exercises. Core, trunk, and hip EMG data were analyzed and compared throughout a variety of exercises, including weight bearing, non-weight bearing, dynamic, and isometric exercises. Ekstrom, Donatelli, and Carp (2007) measured nine rehabilitation exercises to determine which exercises activate trunk, core, and gluteal muscles the most. Gluteus medius (GMED), gluteus maximus (GMAX), vastus medialis obliquus, hamstring, longissimus thoracis, lumbar multifidus, external oblique abdominis, and rectus abdominis muscles were all measured with surface EMG electrodes (Ekstrom et al., 2007). Each of nine exercises were performed while EMG data for each exercise was collected. Active hip abduction, side bridges, unilateral bridges, and quadruped arm/leg lifts caused the greatest EMG activity in the gluteus medius while unilateral bridges, quadruped arm/leg lifts, lunges, and lateral step-up exercises caused greatest GMAX activity (Ekstrom et al., 2007).

DiStefano, Blackburn, Marshall, and Padua (2009) performed a similar, but more focused study; they measured EMG data during nine weight bearing and three non-weight bearing exercises. Unlike Ekstrom and colleagues, DiStefano et al. (2009) only focused on GMED and GMAX activation during the exercises. The authors found that side-lying hip abduction exercise produced significantly greater GMED activation than when compared to clamshell exercises, lunges, forward hops, or transverse hops (2009). Additionally, both single-limb squats and single limb deadlifts strongly activated both gluteal muscles, while side-lying hip abduction, lateral band walks, and sideways hop exercises significantly activated the GMED.

Additionally, tensor fascia latae (TFL) activity has been shown to influence gluteal muscle activity (Selkowitz et al., 2013). The TFL acts to antagonize external rotation of the gluteal muscles by abducting and internally rotating the hip, exerting a lateral force on the patella due to its connections to the iliotibial band (Selkowitz et al., 2013). Hyperactivity of the TFL may be associated with gluteus maximus atrophy in individuals with degenerative hip joint pathology (Selkowitz et al., 2013). Therefore, it is important to minimize TFL activity while maximizing GMAX and GMED activity in gluteal activation exercises. Selkowitz et al. (2013) attempted to measure EMG data for gluteal muscles while also minimizing tensor fascia latae (TFL) activity by comparing EMG activity during a series of exercises for the TFL, GMED, and GMAX. The authors determined that clamshell, unilateral bridge, sidesteps, and quadruped arm and leg extension had the greatest GMAX and GMED activation while minimizing TFL activity the most (Selkowitz et al., 2013).

Other studies have supported this data; Bolgla and Uhl (2005; 2007) performed studies comparing activation levels of hip abductor muscles during exercises as well as reliability methods of hip abduction EMG testing. Results from Bolgla and Uhl's (2005) study showed that weight bearing exercises influenced greater EMG activity than non-weight bearing exercises, excluding side-lying hip abduction. After considering all this information, the current study chose to perform exercises combining both non-weight bearing and weight bearing exercises with exercises primarily targeting the gluteus maximus and gluteus medius while minimizing tensor fascia latae activity for optimal performance and post-activation potentiation effects.

(2.5) Gluteal Muscle Maximal Voluntary Contractions

Maximum voluntary contractions (MVCs) are typically performed to compare maximal muscular activation to muscle activity levels during activity. By measuring MVCs, it is possible to determine the percentage of muscular contraction or activity that is present during physical activity. Maximal voluntary contractions are commonly measured using an isokinetic or isometric dynamometer with specific muscle testing positions. For example, gluteus medius and gluteus maximus MVC testing is commonly performed according to common manual muscle testing methods (Bolgla & Uhl, 2005; Bolgla & Uhl, 2007; Dierks et al., 2008; DiStefano et al., 2009; Ekstrom et al., 2007; Ireland, Willson, Ballantyne, & Davis, 2003; Selkowitz et al., 2013; Souza & Powers, 2009; Willson et al., 2012). The gluteus medius is measured in a sidelying position while the participant performs a resisted isometric contraction (Bolgla & Uhl, 2005; Bolgla & Uhl, 2007; DiStefano et al., 2009). The hip is positioned in 20-25 degrees of hip abduction, 5 degrees of extension, and slight external rotation while a strap is placed across the lateral epicondyle of the femur to resist hip abduction (Bolgla & Uhl, 2005; DiStefano et al., 2009; Souza & Powers, 2009). During gluteus maximus testing, the subject is in a prone position with the knee flexed to 90 degrees; a strap may be placed just proximal to the knee joint while the subject performs resisted hip extension (DiStefano et al., 2009; Ekstrom et al., 2007; Souza & Powers, 2009; Willson et al., 2012). Bolgla and Uhl (2007) reported high measurement reliability during hip abduction isometric MVC testing with these testing positions. However, isometric MVC testing may limit full maximum contractions; they only reflect strength at one point in the range of motion due to length-tension relationships of muscles (Brent, Myers, Ford, Paterno, & Hewett, 2013; Ekstrom et al., 2007; Taylor-Haas et al., 2014). Thus, isokinetic testing methods via an isokinetic dynamometer have recently been established to test concentric hip strength.

Brent et al. (2013) and Taylor-Haas et al. (2014) developed and adapted a concentric isokinetic hip abduction and hip extension testing protocol to evaluate strength in a more dynamic, weight-bearing position. Subjects stood facing an isokinetic dynamometer (Biodex System) and were secured by a strap around the waist above the iliac crest while the dynamometer head was aligned with the body according to the movement being tested. Intertester and intratester reliability for these tests were measured in a pilot study by these authors and found to have excellent intraclass correlation coefficient (ICC) reliability (Taylor-Haas et al., 2014). Though the method used by Taylor-Hass et al. (2014) and Brent et al. (2013) has great potential to be used in future studies, it was not chosen to be used in this study because of its newer, more novel nature and incompatibility with the technology available in our laboratory regarding the

EMG data acquisition and analysis. Instead, common manual muscle testing positions were performed during this study with the EMG software available in our laboratory.

(2.6) Neuromuscular Fatigue

Neuromuscular fatigue is defined as a decrease in force observed after a period of muscular activation or series of activations (Harrison & McCabe, 2017). This may be noticed as a decrease in force production, strength, contraction duration, or altered neuromuscular control (Lessi et al., 2017; Martin et al., 2010).

After fatiguing exercise, altered neuromuscular control can affect lower limb activation, function, and control, resulting in changes in pelvis and trunk position; ultimately, altered positioning can affect joint motion, or joint kinematics, and cause excessive stress on joints and other structures, increasing the risk for injury (Dierks et al., 2011; Lessi et al., 2017). Dierks et al. (2008) demonstrated that hip abduction strength was associated with a larger hip adduction angle in endurance athletes running to exertion; the relationship between these two variables increased at the end of the run when hip abductor muscles were fatigued, as noted by decreased hip abduction strength and a greater hip adduction angle post-run. The authors concluded that compensatory alterations in joint kinematics resulted from weakness and fatigue in hip abduction musculature (Dierks et al., 2008). Another study by Lessi et al. (2017) measured trunk flexion, knee angles, and pelvic drop during a single-leg drop vertical jump after a fatiguing squatting and jumping protocol. Results indicated that after completing a fatiguing protocol, there was notable contralateral pelvic drop during contact and landing after a single-leg drop vertical jump, greater knee abduction in women, and increased peak trunk flexion in men compared to women (Lessi et al., 2017). Any of these compensations in kinematics may increase the risk of injury in tissues that are unequally receiving and distributing load and stresses during activity.

(2.7) Post-Activation Potentiation

Though fatigue is associated with decreases in muscle strength and the ability to maintain stabilization during exercise, fatigue is also more positively associated with a phenomenon called post-activation potentiation (Harrison & McCabe, 2017). Post-activation potentiation (PAP) can be defined as the phenomenon in which the force of a muscular contraction is increased after a previous high-intensity or maximal voluntary contraction (Hamada et al., 2000; Lorenz, 2011; Robbins, 2005). PAP may play a role in performance due to its improvements in force production; when a muscle is activated through heavy load exercise for a short duration, the excited nervous system can produce an increase in contractile function during subsequent muscle contractions (Lorenz, 2011). Though PAP is typically induced by maximal voluntary contractions (MVCs), it can also occur after submaximal isometric contractions or low-load exercises (Lorenz, 2005). Because MVCs are involved, neuromuscular fatigue also plays a role in PAP (Harrison & McCabe, 2017). Enhancement of muscular performance is thus dependent on the balance between fatigue and potentiation (Harrison & McCabe, 2017).

Mechanisms of PAP. Two mechanisms to explain the PAP phenomenon have been proposed. First, phosphorylation of myosin light chains during MVCs can cause actin-myosin to be more sensitive to calcium released from the sarcoplasmic reticulum in cells during subsequent muscle contractions (Hamada et al., 2000; Lorenz, 2005). When this occurs, each twitch that occurs after the first MVC displays an increased force of contraction (Lorenz, 2005). Another theory of PAP is that synaptic excitation in the spinal cord occurs when strength training is performed prior to plyometric exercises; this in turn causes increased post-synaptic action potentials and an increase in the force generating capacity of innervated muscles (Lorenz, 2005). The myosin light chain theory seems to be more prevalent in current literature and may be more valid, though more research should be performed to address this consideration (Hamada et al., 2000; Lorenz, 2005).

Fiber types affected by PAP. The magnitude of PAP is most strongly affected by muscle fiber type; fast-twitch (Type II) fibers show greatest PAP due to their increased capacity to respond to myosin light chain phosphorylation (Hamada et al., 2000). Because Type II fibers have greater PAP potential, anaerobic athletes with greater percentages of Type II fibers (i.e., sprinters, weightlifters, throwers, or jumpers) may benefit more from PAP exercise than individuals with more Type I fibers (i.e. cyclists, distance runners, triathletes) (Hamada et al., 2000; Lorenz, 2005).

Endurance athletes are typically composed of greater percentages of slow-twitch, oxidative Type I muscle fibers (Hamada et al., 2000). Though Type II fibers may respond more greatly to PAP, endurance athletes with Type I fibers can still benefit from the phenomenon. Endurance training can increase the maximum shortening velocity of Type I fibers, which has been associated with an increase in “fast” myosin light chains (MLC) (Hamada et al., 2000). Having more “fast” MLC is also related to MLC phosphorylation, which would result in greater PAP, even if the individual does not have high percentages of Type II fibers (Hamada et al., 2000).

Another possible mechanism that allows endurance athletes to benefit from PAP is fatigue resistance resulting from endurance training effects. Potentiating effects occur after maximal voluntary contractions, which may cause fatigue; because endurance athletes are trained to resist fatigue, they may be able to prevail against fatigue resulting from MVCs, displaying greater potentiation effects, as indicated by greater twitch responses after performing MVCs (Hamada et al., 2000). Hamada et al. (2000) studied the effects of potentiation in endurance runners and triathletes. Results from the study showed that these endurance-trained individuals displayed effects from PAP in the muscles primarily predominantly active in their sport; triathletes had potentiation effects in both arms and legs, while distance runners only showed potentiation effects in their legs (Hamada et al., 2000). Additionally, Millet, Martin, Lattier, and Ballay (2003) studied the effects of fatigue on ultra-marathoners during a prolonged run, finding that fatigue and potentiation effects were simultaneously present in these athletes, and potentiating effects were evident for up to 20 minutes after the end of the fatiguing exercise. Further, they noted that post-activation potentiation effects are greater in endurance athletes than in sedentary subjects (Millet et al., 2003).

Benefits of PAP. As previously stated, PAP is thought to enhance force production following heavy resistance exercise (Harrison & McCabe, 2017). This is beneficial in sports or activities in which an increased force production is desired, such as weightlifting, sprinting, jumping, or running. Results from Hamada et al. (2000) suggested that potentiation effects are more pronounced during dynamic exercise rather than isometric exercise. Additionally, maximal (vs submaximal) activity for ~10 seconds causes the greatest PAP in individuals (Hamada et al., 2000). Relating to endurance exercise, PAP can potentially compensate for low-frequency force output (low-frequency fatigue) that may occur during exercise and potentially decrease motor unit firing rates if initiated in early stages of activity (Hamada et al., 2000). Reducing the required motor unit firing rates would help offset low-frequency fatigue in endurance exercise, which would help maintain membrane excitability and excitation-contraction coupling to improve endurance exercise performance (Hamada et al., 2000). Additionally, potentiation effects are still found to be evident even after 20 minutes following the end of a fatiguing exercise, which indicates that potentiation effects may continue throughout exercise instead of only the beginning of an exercise bout (Millet, Lepers, Maffiuletti, Babault, Martin & Lattier, 2002).

Performance and PAP. In regards to performance, gluteal muscle PAP has shown mixed results. Crow et al. (2012) tested a low load, gluteal warm up protocol on Australian football athletes during countermovement and squat jumps and found that low load exercises targeting gluteal muscles can cause an acute increase in peak power output. Comyns et al. (2015) used the research from Crow et al. (2012) to measure the effects a gluteal warm up protocol on a variety of track and field athletes performing a countermovement and explosive jump squat, observing changes in jump height and peak ground reaction forces. Performing gluteal warm up exercises caused decreased jump height, but improved force production levels during a jump squat (Comyns et al., 2015).

Conversely, Harrison and McCabe (2017) studied the effects of a gluteal activation protocol on sprint and drop jump performance, finding that these exercises do not produce consistent improvements in acute performance for either activity (Harrison & McCabe, 2017). Similarly, Parr, Price, and Cleather (2017) studied the effects of gluteal activation warm-ups on explosive exercise performance and found that mean peak EMG activity of the gluteus maximus was lower after the warm up and there was no effect on performance outcomes (increases in ground reaction forces). However, Parr et al. (2017) found there were possible potentiation effects in the gluteus maximus and hamstring muscles; after the gluteal activation exercises, the kinematics of movement may have improved their length-tension curve and allowed for greater force production in the muscle. The variation in these findings may be due to a difference in methodology or due to the researchers potentially fatiguing the athletes after completing a fairly high number of reps in an explosive activity sport before they were tested in another dynamic activity.

These studies analyzed the gluteal activation effect on a variety of different athletes; however, a limitation of these studies could be the absence of specificity for these muscle groups to the sport. Though track and field athletes, Australian football players, and sprinting athletes use gluteal muscles for pelvic stability during exercise, a low-load exercise for a high intensity sport or exercise may not be an ideal representation of the potential effects of a gluteal activation protocol. Harrison & McCabe. supported this suggestion after measuring the effect of a low-load gluteal activation program on explosive activity performance, finding that there was no clear fatigue-potentiation response to suggest an enhancement of performance due to low-load activation during explosive activity (Harrison & McCabe, 2017).

Lack of research in endurance athletes and PAP. Though several studies have analyzed gluteal activation exercises on explosive activity, few studies have examined the effects of PAP or gluteal activation potentiation on endurance athletes. In one study, Hamada et al. (2000) measured PAP on the triceps brachii and triceps surae in endurance runners and triathletes. The authors found that PAP of twitch force was greater in endurance-trained athletes than sedentary or generally active individuals. Additionally, PAP was specific to the muscles trained; distance runners only had enhanced PAP in the triceps surae while triathletes had greater PAP in both the triceps brachii and triceps surae due to training effects specific to muscles trained within the scope of their sport (Hamada et al., 2000). Few, if any, other research articles have been published regarding the potential effects of PAP and gluteal activation potentiation for endurance runners. Therefore, more research must be performed to investigate the effects of gluteal musculature PAP for endurance athletes.

(2.8) Research Question

Taking all the information presented into consideration, the research topic in question seeks to study the effects of a gluteal activation protocol on fatigue in endurance runners during a distance run. Specifically, the questions are:

1. Does performing a gluteal activation protocol affect EMG signals of the gluteus medius and gluteus maximus, specifically in maintaining a more level activation over time than when compared to a controlled run?
2. Does performing a gluteal activation protocol cause post-activation potentiation and improved performance, indicated by an improvement in performance time during a 5-k run?

The hypothesis for the research questions at hand is that a gluteal activation protocol will: (1) increase muscle activation and cause a more consistent activation over time, measured via EMG activity, and; (2) improve performance time, measured by time to complete a 5-k run. The questions will be investigated through EMG analysis and performance time during two 5-k runs, where each subject completes one run preceded by a gluteal activation protocol and one run without activation exercises. The results will be analyzed individually and as a whole cohort to examine potential differences resulting from a gluteal activation potentiation intervention.

(2.9) Summary

This chapter presented a broad overview of the background information regarding gluteal activation potentiation and its potential effects on fatigue in endurance athletes. Current research suggests that there is a lack of knowledge surrounding post-activation potentiation and endurance athletes, specifically that of gluteal activation potentiation and endurance runners. The present study will seek to address these topics, specifically by measuring EMG data, biomechanical analysis, and time to task completion. The next chapter will address the methodology of the current study and delineate the study's testing parameters.

CHAPTER III

METHODOLOGY

(3.1) Study Design

The current study was designed in a cross-over manner, where the subjects completed both a run preceded by a gluteal activation protocol, and a controlled run that excludes the gluteal activation protocol. Subjects completed an initial visit where they filled out subject demographics and were introduced to the testing procedures and gluteal activation exercises. Afterwards, the subject was randomly assigned into two groups via an online subject randomizer (randomizer.org), in which subjects either completed the gluteal activation protocol prior to the 5-k run, or completed the run with a 4-minute waiting period between maximal contraction testing and the treadmill run. Within one week of the initial visit, the subject completed the first testing session. Subjects completed their second session with the opposite testing conditions no sooner than 48 hours after the first session.

Participants. 15 female collegiate cross country and track athletes competing at a large Midwest university were used as the population for the study. Previous research has reported that gender differences exist in hip kinematics for healthy individuals and other individuals presenting with symptoms of patellofemoral pain (Willson et al., 2011; Willson et al., 2012). Thus, to minimize the potential influence of gender differences on gluteal muscle activation and hip kinematics, only females were chosen to be recruited for the current study. Recruitment for the study was performed via flyers, word of mouth, and snowball effect between athletes.

Females were included in the study if they were 18-35 years old, able to run for at least 30 minutes continuously, physically active at least four days/week (30+ minutes per day of moderate physical activity), and did not have any current neuromuscular or cardiovascular conditions. Subjects were an average height of 64.47cm ± 7cm, average weight of 56.70kg ± 12kg and were an average age of 22.00 years old. Weekly mileage of the athletes ranged from 56km/week to 88km/week (35-55 miles per week) and had an average of 10.20 years of experience in running. A summary of the means of subject demographic information is available on Table 1.

	Mean (Standard deviation)
Height (cm)	64.47 (2.67)
Weight (kg)	56.70 (6.67)
Age (years)	22.00 (3.68)
Weekly mileage (miles)	46.00 (8.06)
Experience in running (years)	10.20 (4.13)

Table 1: Demographic information from subjects

(3.2) Procedure and Instruments

Prior to participation in the study, subjects completed an initial visit, where they completed an informed consent document, physical activity readiness questionnaire (PAR-Q), health history, and answered demographic information, including height, weight, age, and weekly mileage and experience in running. Table 1 shows a list of the demographic information that was recorded from the subjects as well as the means and standard deviations of the collected data. Copies of the forms used are included in

Appendix A-C. For each session, the subjects were asked to wear a t-shirt and compression shorts; the compression shorts helped to hold the EMG surface electrodes in place during the run. Additionally, the subjects were asked to refrain from heavy exercise 24-48 hours prior to testing sessions to prevent delayed onset muscle soreness from affecting performance.

The testing sessions were conducted in the following manner. Upon arrival to the lab, EMG electrodes were placed on the subject's hip musculature. A five-minute warm-up on a stationary bike then commenced. Following the warm-up, maximal voluntary contractions (MVC's) were completed for pre-test values. After the strength test, one of two conditions were completed. In the gluteal activation condition, subjects immediately performed a pre-determined set of exercises after the strength test, as defined in the next section. In the controlled run setting, subjects waited for four minutes prior to beginning the treadmill run. Four minutes was selected as the waiting period as it was the average length of time that was required to complete the gluteal activation protocol. Following this step, the subjects completed a 5k run on a treadmill, running for 3.12 miles. Afterwards, an MVC post-test was completed in the same manner as completed at the beginning of the test. Figure 2 represents this series of events in a flow-chart.

EMG data was collected using Biopac hardware (Model #BN-EMG2-T & #BN-EMG2, Biopac, Goleta, CA.), Biopac data acquisition software (Model: MP150WSW, Biopac Systems, Inc.; Santa Barbara, CA, USA), and Acqknowledge 4.0 software (Biopac Systems, Inc,; Santa Barbara, CA, USA). All data was stored on a personal computer (Dell Optiplex 780, Dell, Round Rock, TX) and confidentiality was maintained by converting subject names and information into a coded list; all documentation was

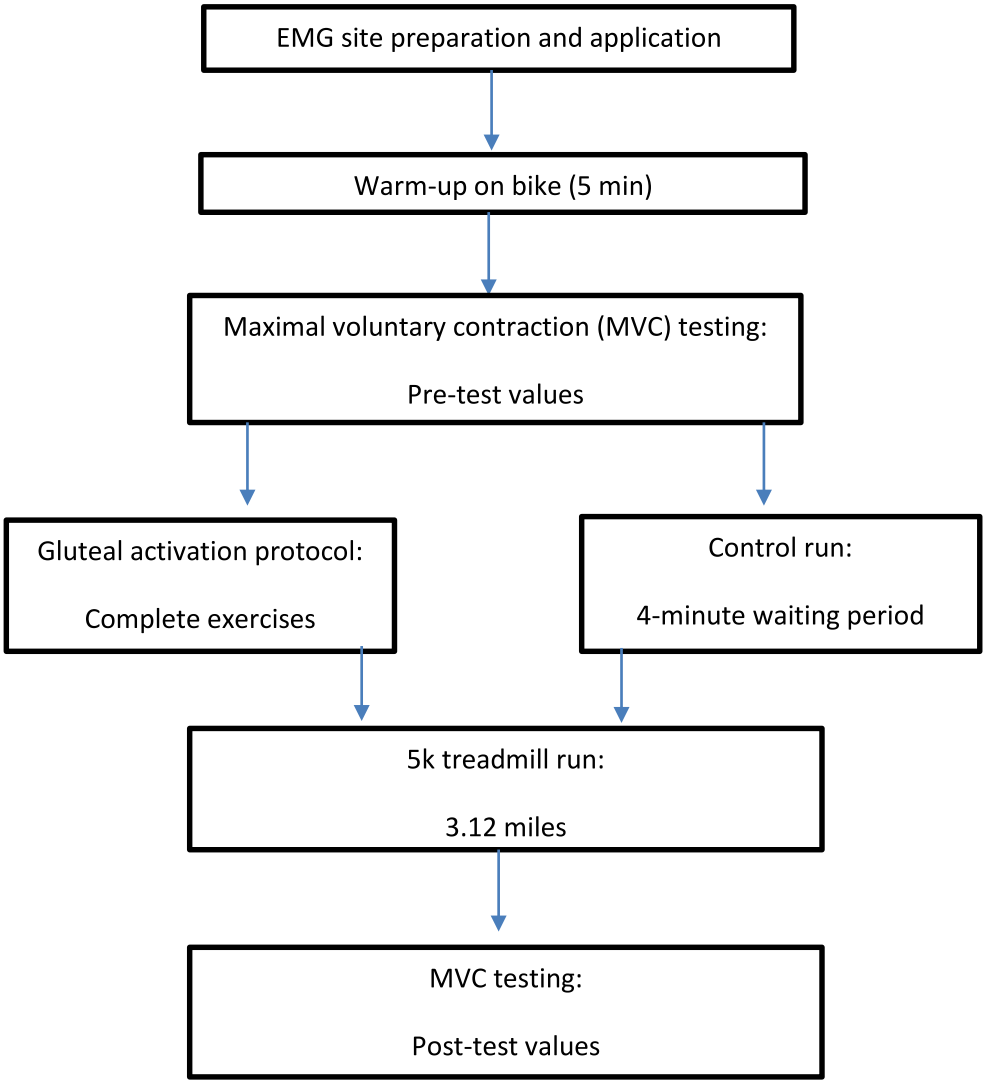

Figure 2: Flowchart of testing procedure for running sessions

kept by the primary researcher in a locked drawer. The warm-up at the beginning of the testing procedure was completed on a cycle ergometer (Model Ergomedic 828E, Monark, Sweden). Isometric maximal voluntary contraction testing was performed via manual muscle testing and data was collected through the EMG software as previously mentioned. Gluteal activation exercises were completed with a resistance band (Model: First Place Mini Band, 9" L x 2" W, heavy band (blue), PerformBetter, West Warwick, RI) above the knees and around the midfoot, depending on the exercise. The 5k run was completed on a Trackmaster treadmill located in the laboratory (Model: TMX425c, Trackmaster, Newton, KS), while EMG data was collected throughout the run in five minute intervals. During the run, heart rate was measured with a wristwatch with heart rate detecting capabilities (Model: Forerunner 235, Garmin, Olathe, KS) while other performance values were recorded throughout the run. Following completion of the run, maximal voluntary contractions were re-tested to assess for fatigue in regards to changes in muscle strength and muscle activation.

(3.3) Familiarization Session

During the first initial visit, the subject completed all paperwork for the study, including the informed consent, PAR-Q, health history, and demographic information. The subject was then introduced to the maximal contraction testing procedure and explained the process and flow of the testing session to be followed. Isometric maximal voluntary contraction (MVC) testing protocols were completed based on common manual muscle testing positions for the gluteus maximus and gluteus medius. Figures 3 and 4 represent the testing position for gluteus maximus and gluteus medius during resisted hip extension and abduction. Subjects practiced three submaximal repetitions of hip extension and hip abduction during this initial session. The subjects then performed five practice repetitions of the exercises to be performed during the gluteal activation protocol. Figures 5-9 represent the position of the exercises completed. After practicing these testing procedures that were be followed on subsequent days, any questions by the subjects were answered by the primary researcher and subjects left the lab.

Isometric muscle testing. During isometric hip extension testing, subjects were in a prone position on a table. A weightlifting belt was used as an additional resistance strap during testing. The belt was placed just superior to the lateral condyles of the femurs, covering most of the mid-thigh, while the subject was stabilized at the low back and resisted at the hamstring. During the test, subjects held a maximum contraction for three seconds before relaxing for one minute between tests. A total of two MVCs were performed on the right limb for hip extension during the testing procedure. During the initial visit, three submaximal repetitions were performed for practice. Figure 3 represents the testing position of hip extension.

Hip abduction was tested with the subject in a side-lying position, testing the right limb. The belt was placed just superior to the lateral condyles of the femur, covering most of the mid-thigh, while the subject was stabilized at the pelvis along the iliac crest and resisted near the lateral condyles of the femur. The subject performed a side-lying leg raise with resisted motion, holding the contraction for three seconds before relaxing for one minute between tests. A total of two MVCs on the right limb was performed for hip abduction during the testing procedure and three submaximal contractions were performed during the practice session. Figure 4 represents the testing position of hip abduction.

Figure 3: Resisted hip extension positioning. Clinician is standing to the side of the subject, stabilizing at the low back and resisting at the hamstring. Subject is prone, contracting through the glute with the cue, "raising the heel"

Figure 4: Resisted hip abduction. The clinician stands behind the subject, stabilizing at the pelvis and resisting at the mid-thigh. The subject is side-lying, abducting the hip.

Gluteal activation protocol. After familiarization of isometric MVC testing procedures, subjects were shown the gluteal activation protocol (GAP) exercises. Using prior research from DiStephano et al. (2009), Ekstrom et al. (2007), and Selkowitz et al. (2013), the exercises chosen to activate gluteal muscles for the greatest post-activation potentiation effects were clamshells, prone hip extension and abduction, sidelying hip abduction, double leg bridges, and lateral band walks. These exercises recruited both the gluteus maximus and gluteus medius the most while minimizing antagonist effects of the tensor fascia latae, and included both weight bearing and non-weight bearing positions. All the gluteal activation exercises were performed in one set of twelve repetitions and completed bilaterally. A resistance band (PerformBetter, First Place Mini Band, 9” L x 2” W, heavy band (blue)) was used during all exercises to provide resistance and increase muscle activity during the exercises. Using prior studies from Ekstrom et al (2007) and DiStephano et al. (2009), the following instructions was given to the subjects:

1. Clamshells: this exercise will be performed in the side-lying position on the floor with the subject’s knees flexed to 90° and hips flexed to 30°. A resistance band will be placed just superior to the knee joint. A foam roller will be placed underneath the ankles to isolate the gluteus medius. The top knee will abduct and externally rotate from the bottom knee while the subject’s feet remain together and the anterior superior iliac spines remain facing forward and in line with each other, then return back to the starting position. See Figure 5, A-B.
2. Prone hip extensions and abductions: this exercise will be performed in the prone position with a resistance band just superior to the knee joint. With

both feet extending off the table in a neutral to dorsiflexed position, the subject will alternatively extend the hip, abduct the hip to 30-45°, adduct the hip back to the starting position, and return back to the original starting position. See Figure 6, C-E.

3. Side-lying hip abduction: This exercise begins in a side-lying position with both legs in full knee extension, neutral hip position, and ankle dorsiflexion, while a resistance band is placed just superior to the knee joint. The bottom leg will slightly flex at the knee and hip to provide stability during the exercise. The subject will slowly raise the straightened top leg to 30° of hip abduction and slowly lower back down the starting position. See Figure 7, F-G.
4. Double-leg bridge: this exercise is performed in a supine position with a resistance band placed just superior to the knee joint. While lying on their back and maintaining a space of about 6 inches between the knees, the subject lift the hips and pelvis up by squeezing the glutes and hamstring muscles while keeping the spine in a neutral position, achieved by cueing the subject to "pull the belly button to the spine." The subject will then slowly lower back to the ground and repeat. See Figure 8, H-I.
5. Lateral side-steps: in a standing position with a resistance band placed around the midfoot of both feet, the subject will maintain 30° of flexion in both their knees and hips. The subject will sidestep approximately 130% of their shoulder width with the leading limb abducting from the body; the trail leg will adduct toward the lead leg to return back to the starting position. Both

feet should remain facing forward and the knees should remain in line over the toes. See Figure 9, J-K.

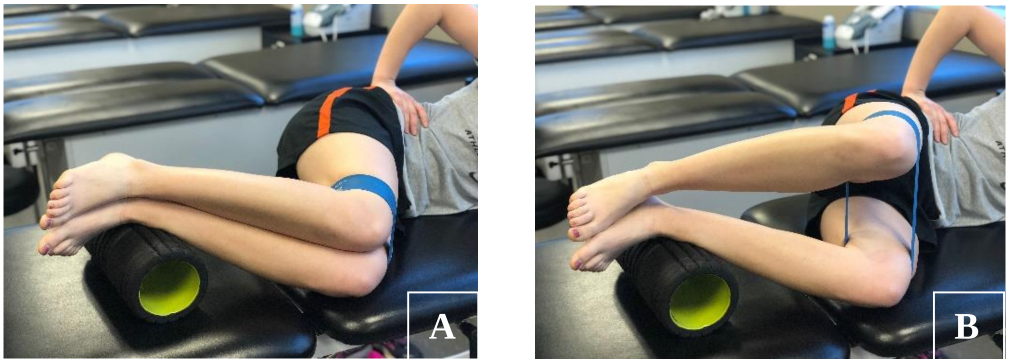

Figure 5: Clamshell exercise. A: Starting position. The knees are flexed to 90 degrees and hips are flexed to 30 degrees. A resistance band is above the knee joint. Ankles should be elevated on a foam roller. B: Ending position. The top knee abducts and externally rotates from the bottom knee while keeping the ankles together. The hips remained "stacked" on top of each other. Complete bilaterally.

Figure 6: Prone hip extension and abduction. C: Starting position. The subject is laying prone with a resistance band above the knees. The feet are in a neutral to dorsiflexed position. D: The subject extends the hip. E: Ending position. The subject abducts the hip to 30-45 degrees, then returns back to the starting position by adducting and relaxing the leg back to the table (C). Complete bilaterally.

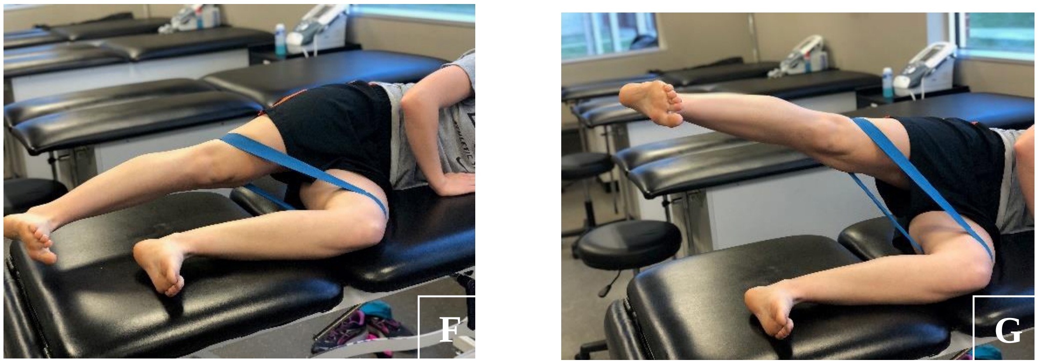

Figure 7: Side-lying hip abduction. F. Starting position. Subject lies on the side with the top leg in full knee extension, neutral hip position, ankle dorsiflexion, and a resistance band above the knee. G: Ending position. The subject abducts the top leg to 30 degrees, then slowly lowers back to the starting position (F). Complete bilaterally.

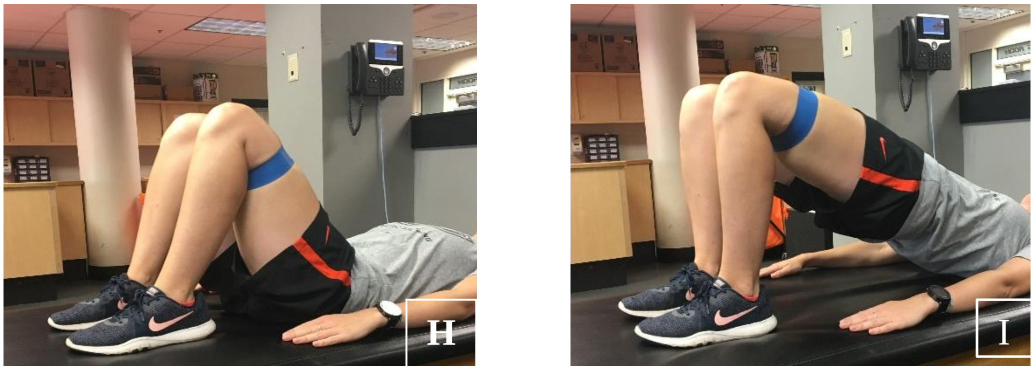

Figure 8: Double leg bridge. H: Starting position. Laying in supine, both legs will be bent at the knee, slightly pulling apart so knees are in line with shoulders. I: Ending position. The subject will squeeze the glutes and hamstrings and lift the hips up make a straight line between the thighs and torso, in a "bridge" type position, then return to the starting position (H).

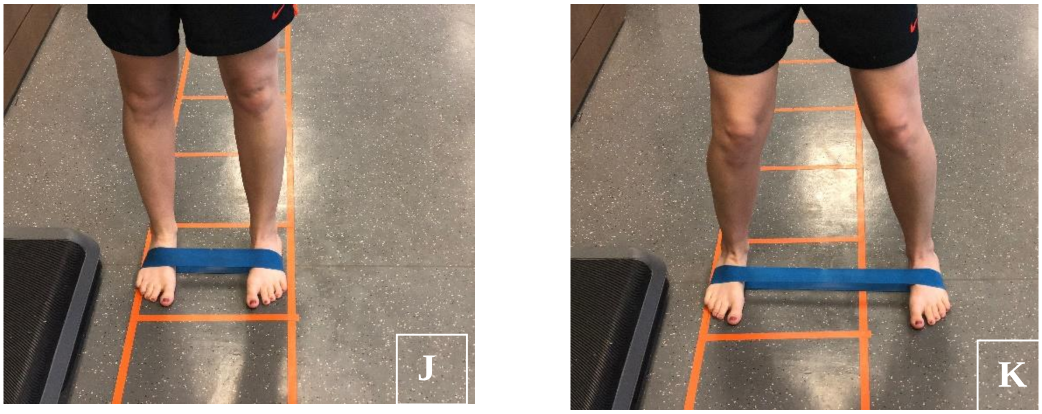

Figure 9: Lateral side steps. A: Starting position. In a standing position, both feet should be shoulder width apart with a resistance band placed around the midfoot. The knees and hips should be flexed to 30 degrees. B: Ending position. The subject will sidestep approximately 130% of their shoulder width while keeping the knees and hips bent to 30 degrees. Complete steps bilaterally.

After the subject was shown the exercises and explained the process of the 5k run trials, any potential questions were answered, contact information was given to the subject, and subsequent testing days were scheduled.

(3.4) 5k Running Sessions

Overview. During the second and third sessions, subjects began by placing a Garmin watch with heart rate detecting capabilities on their wrist. Electromyographic (EMG) electrode site preparation and placement was then performed. Following, the subject performed a warmup on a cycle ergometer, or stationary bike, for five minutes, completed a total of four pre-run MVCs; after, the subject either completed the gluteal activation protocol or waited four minutes, then proceeded to the 5k run on the treadmill. After completing the run, subjects were retested for their post-run MVCs, and were finished with the session's testing. On the subsequent session, the subject completed the condition not previously performed according to the same testing protocol. Figure 2 within section 3.2 represents a flowchart demonstrating the order that the testing procedure follows.

EMG acquisition and analysis. Data was collected on the right leg of each subject; all subjects reported their dominant leg, as defined as the leg used to kick a ball for maximal distance, to be their right leg, and was thus used as the testing limb. Surface electrodes were placed on the muscle bellies of the GMED and GMAX, consistent with previous research (Bolgla & Uhl, 2005; DiStephano et al., 2009). The GMED electrode was placed one-half of the distance between the lateral aspect of the iliac crest and the ipsilateral greater trochanter, in line with the greater trochanter (Bolgla & Uhl, 2005; DiStephano et al., 2009; Willson et al., 2012). The GMAX electrode was placed one-half of the distance between the greater trochanter and the inferior lateral edge of the sacrum, which is located near the second sacral vertebrae (Willson et al., 2012). A reference electrode for the GMED electrode was placed on the bony prominence of the anterior superior iliac spine (ASIS) while the reference electrode for the GMAX was placed over the head of the greater trochanter. Electrode sites were prepared by lightly abrading the skin's surface with fine sandpaper to remove dead skin cells, cleansing the skin with 70% isopropyl alcohol pads, and applying electrodes; two electrodes were placed side-by-side on the GMAX area as defined above, two were placed on the GMED area, and one electrode was placed on the ASIS and greater trochanter, respectively. Following EMG application protocol, a five minute warm up commenced on a stationary bike to physiologically prepare for activity.

Warm-up and MVIC. The warm-up was performed on a stationary bike with the speed at a low-intensity with the heart rate approximately at 120 beats per minute or below. The subject then tested pre-run hip abduction and extension strength, measured using isometric testing procedures as explained in the prior section. Two maximal contractions were performed for each position during hip extension and hip abduction, with a one-minute resting period between contractions. Following isometric strength measurements, subjects were given the chance to stretch before the treadmill run. Subsequently, they randomly perform either the gluteal activation protocol or continue directly to the prolonged run. Eight subjects performed the non-gluteal activation program run first, while seven subjects began with the gluteal activation run. The testing order was randomly selected for each participant to prevent bias in testing methods or results. During the gluteal activation protocol, the exercises were performed in one set with 12 repetitions with a resistance band, all as described in the prior section. The 5k run protocol began immediately following the gluteal activation exercises or lack thereof.

5k run. The 5k run protocol consisted of an initial period of determining a self-selected speed by the subject. The subject was instructed to select a pace that most similarly represented their 5k race pace. A Garmin watch was receiving heart rate data throughout the run and compiled information into a graphic chart, allowing heart rate to be identified at any given point during the run. EMG data was assessed at minutes 0, 5, 10, 15, and at the end of the test; EMG data was collected for 15 seconds on the right limb at each time point. Collected data was analyzed to determine the highest amplitude of EMG contraction of three steps within the interval, as well as the highest amplitude values of the GMAX and GMED during five consecutive steps, represented by five consecutive, individual bursts of EMG data.

Performance analytics were recorded in two ways. At each five-minute interval, the speed of the treadmill was recorded, and each mile split was recorded during the run. At the end of 3.12 miles on the treadmill, a final time was recorded. Immediately following the running protocol, the subject was re-tested for isometric muscle strength. A longer cool-down on a bike or treadmill was permitted after collection of post-test isometric strength values if the subject was sore or chose to cool-down for longer period of time.

(3.5) Statistical Analysis

All statistics were analyzed using SPSS software (SPSS, version 24). Separate 2-way [Time (0, 5, 10, 15, end) x Visit (GA vs. control)] repeated measures ANOVAs were performed for each dependent variable (GMED and GMAX activation) to analyze the activation levels over time for each condition. Another set of separate 2-way [Time (pre-, post-) x Visit (GA vs control)] repeated measures ANOVAs were analyzed, comparing maximal activation levels pre- and post-run between conditions. A paired samples t-test was also performed to compare performance times between both sessions. 1-way ANOVAs and t-tests were performed as post-hoc analyses if needed. Bonferroni Pairwise comparisons were utilized post-hoc to determine specific differences between conditions and time-points during the study. An alpha level of $p < 0.05$ was utilized for all analyses.

CHAPTER IV

FINDINGS

(4.1) Statistics

Gluteal activation via EMG analysis was compared between runs with a gluteal activation program (condition “GA”) and a controlled run. During analysis, all raw data was quantified and converted to Root Mean Square (RMS) data through the Biopac System and ACQ Knowledge software. After quantification, data was analyzed through SPSS software for statistical significance. Gluteus maximus and gluteus medius data were respectively analyzed according to activation levels during five consecutive steps over the course of five time intervals through a 2-way repeated measures ANOVA. Gluteus maximus and gluteus medius activation levels were also analyzed based on pre- and post-run maximal voluntary contraction activation levels with a 2-way repeated measures ANOVA. Finally, mile splits were compared between trials using a paired-samples t-test. During analysis of the data, the following statistics were derived.

Gluteus maximus activation levels during a five consecutive step analysis over time indicated that there was no significant 2-way interaction between gluteal activation conditions and time (p=0.595). Gluteus medius activation levels during the five step analysis also indicated that there was no significant difference in a 2-way interaction between gluteus medius activation levels during condition and time (p=0.626); however, there was a significant interaction between gluteus medius activation values and time (p=0.025), but on post-hoc analysis with 1-way ANOVA, there was not a significant difference (p>0.05). Means and standard deviations for these tests are included in Table 2. Figures 10 and 11 are line graphs, demonstrating the difference between activation over time for the gluteus maximus and gluteus medius, respectively.

Additionally, there was no 2-way interaction between activation levels of the gluteus maximus (p=0.452) or gluteus medius (p=0.138) over time during pre- and post-run MVC testing. Means and standard deviations for these results are included in Table 3. Figures 12 and 13 are bar graphs, showing the difference in pre- and post-activation maximal contraction values for both conditions.

A paired-samples t-test was conducted to compare average mile split times in subjects during a run with a GA program compared to a controlled run. There was a significant difference in the scores for average mile split times during the GA condition (M=8:04:32, SD= 0:38:69) and controlled condition (M=8:21:67, SD=0:11:47); t(14)=-3.180, p=0.007. Table 4 shows the average mile split times with their means and standard deviations. Figure 14 is a line graph, showing the differences between mile times for each participant.

(4.2) Figures and graphs

Gluteal activation levels during 5-consecutive-step analysis: Mean and Standard Deviation values								
	Gluteus Maximus				Gluteus Medius			
	GA condition		Control condition		GA condition		Control condition	
	M	SD	M	SD	M	SD	M	SD
0 min	43.12	12.88	50.96	16.93	55.83	25.71	51.69	26.43
5 min	42.81	16.32	52.81	20.89	57.01	28.77	74.43	115.71
10 min	49.40	20.39	57.21	44.23	53.11	26.36	58.11	65.19
15 min	47.72	18.40	67.52	44.47	52.06	29.06	54.34	43.12
END	47.69	17.70	82.10	65.63	52.201	27.62	46.67	32.07

Table 2: Mean and standard deviation of activation levels in the Gluteus Maximus and Gluteus Medius over time during a 5-step analysis. Values are representative of the average percentage of activation relative to total maximal contraction (% of max).

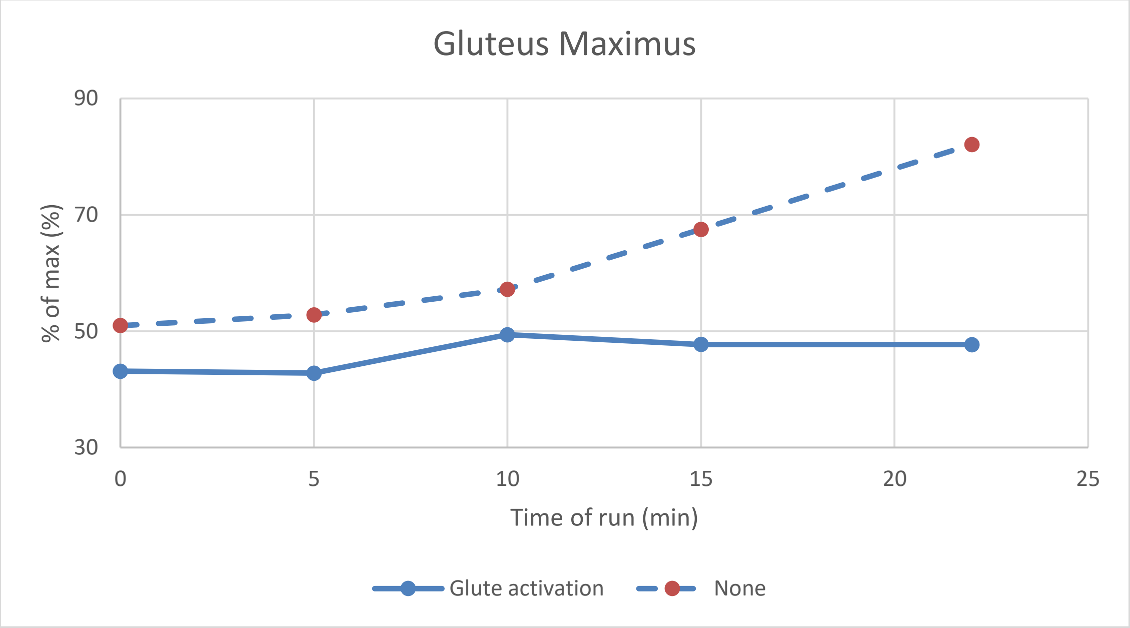

Figure 10: Gluteus maximus activation levels during 5 consecutive steps over time during 2 conditions. Values indicate muscle activation levels as a percentage of the total maximal voluntary contraction during the pre-test MVC. Solid line indicates gluteal activation condition, dashed line indicates control condition.

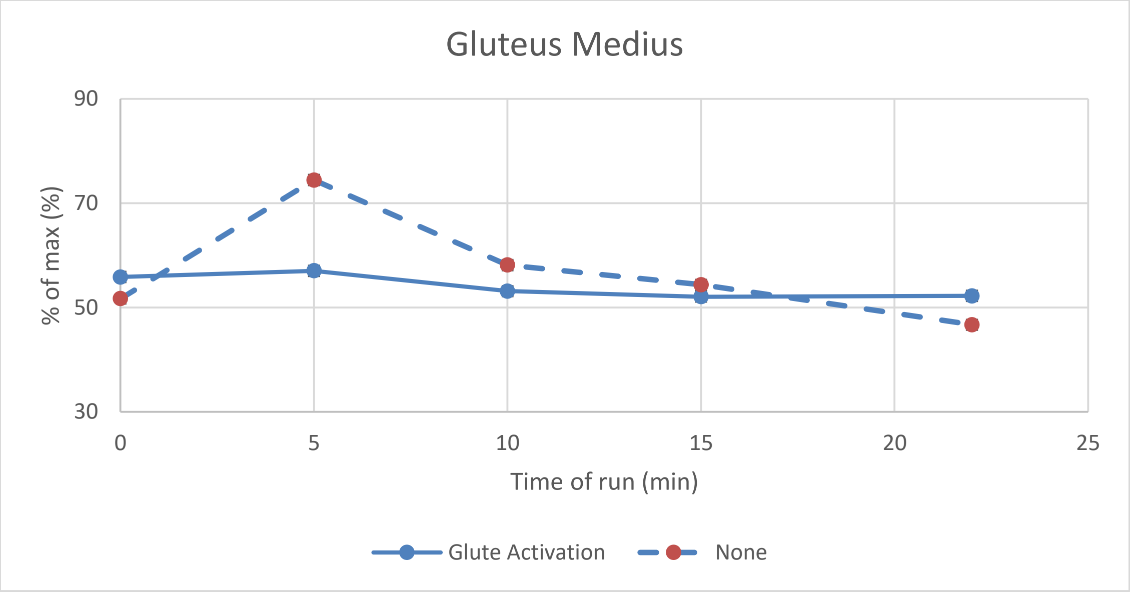

Figure 11: Gluteus medius activation levels during 5 consecutive steps over time during 2 conditions. Values indicate muscle activation levels as a percentage of the total maximal voluntary contraction during the pre-test MVC. Solid line indicates gluteal activation condition, dashed line indicates control condition.

Maximal activation levels of gluteal muscles pre- and post-run: Mean and Standard Deviation values								
	Gluteus Maximus				Gluteus Medius			
	GA condition		Control condition		GA condition		Control condition	
	M	SD	M	SD	M	SD	M	SD
Pre-run	0.55	0.42	0.66	0.49	0.0119	0.0123	0.0121	0.0077
Post-run	0.63	0.65	0.62	0.72	0.0121	0.0117	0.0103	0.0075

Table 3: Mean and standard deviation of maximal activation levels in the Gluteus Maximus and Gluteus Medius before and after the run. Values are in volts (V).

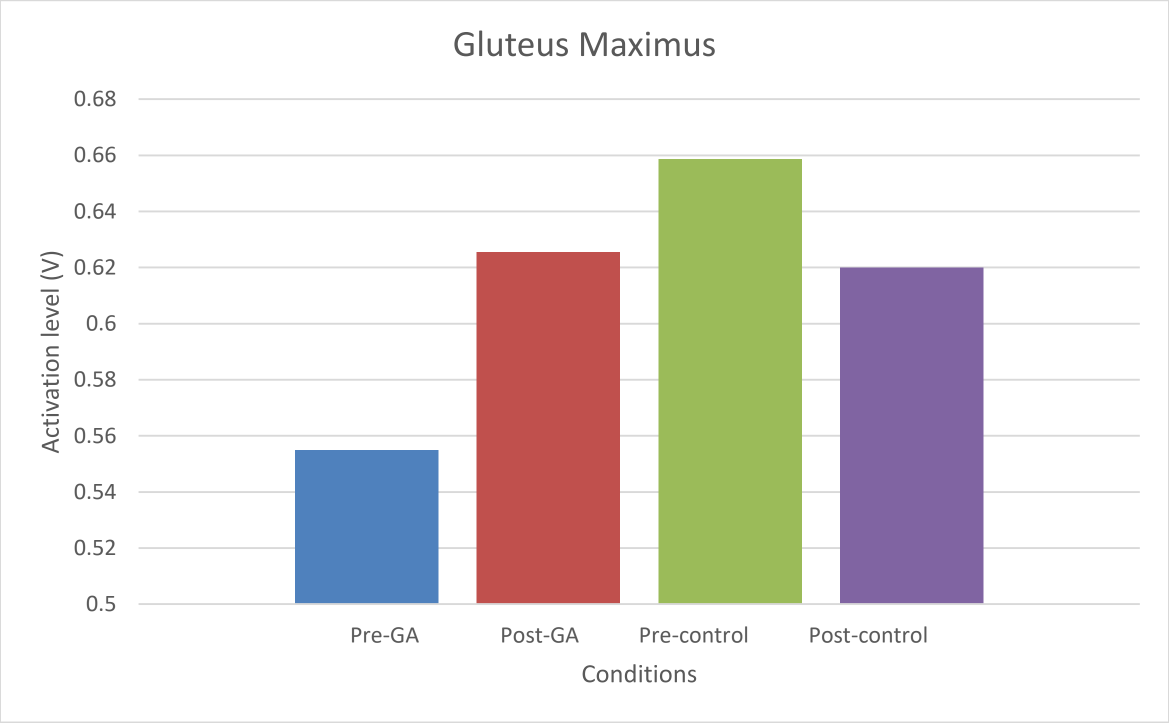

Figure 12: Maximal activation levels of the Gluteus Maximus pre- and post-run for both testing conditions. Activation levels measured in volts (V).

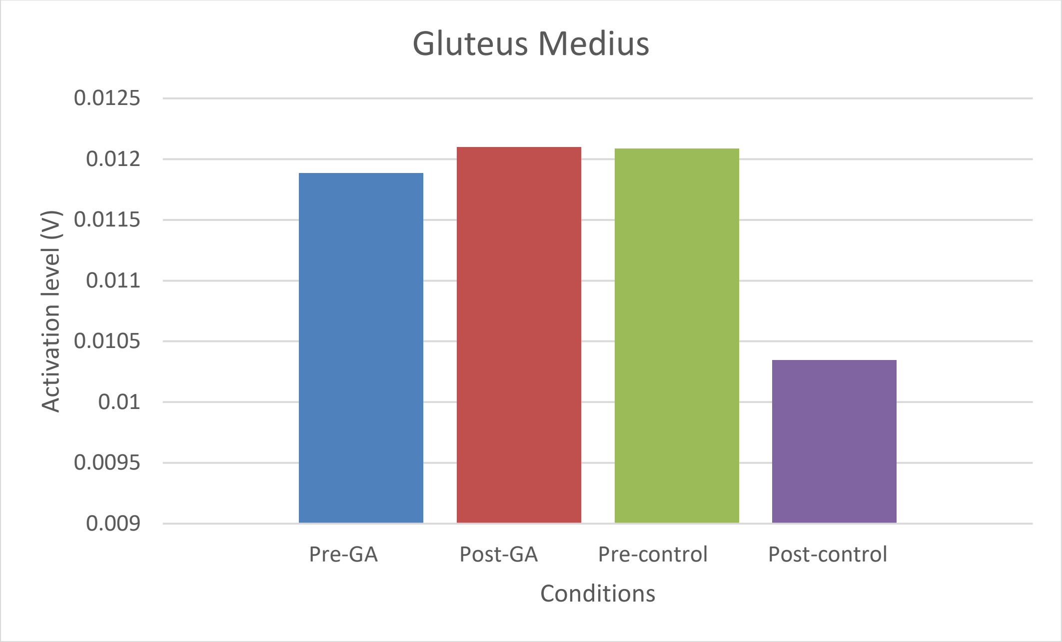

Figure 13: Maximal activation levels of the Gluteus Medius pre- and post-run for both testing conditions. Activation levels measured in volts (V).

Mile-Splits over time: Mean and Standard Deviation values				
	GA condition		Control condition	
	M	SD	M	SD
Mile 1	8:32:52	0:33:55	8:51:56	0:49:09
Mile 2	7:53:12	0:41:18	8:12:04	0:44:49
Mile 3	7:47:16	0:46:47	8:01:24	0:46:27
Average split:*	8:04:27	0:38:39	8:21:48	0:44:24

Table 4: Mean and Standard deviation for mile splits during miles 1, 2, 3, and the average mile time per participant. All values in min:sec:ms.
**Average mile splits were found to be significantly different during paired-sample t-test analysis.*

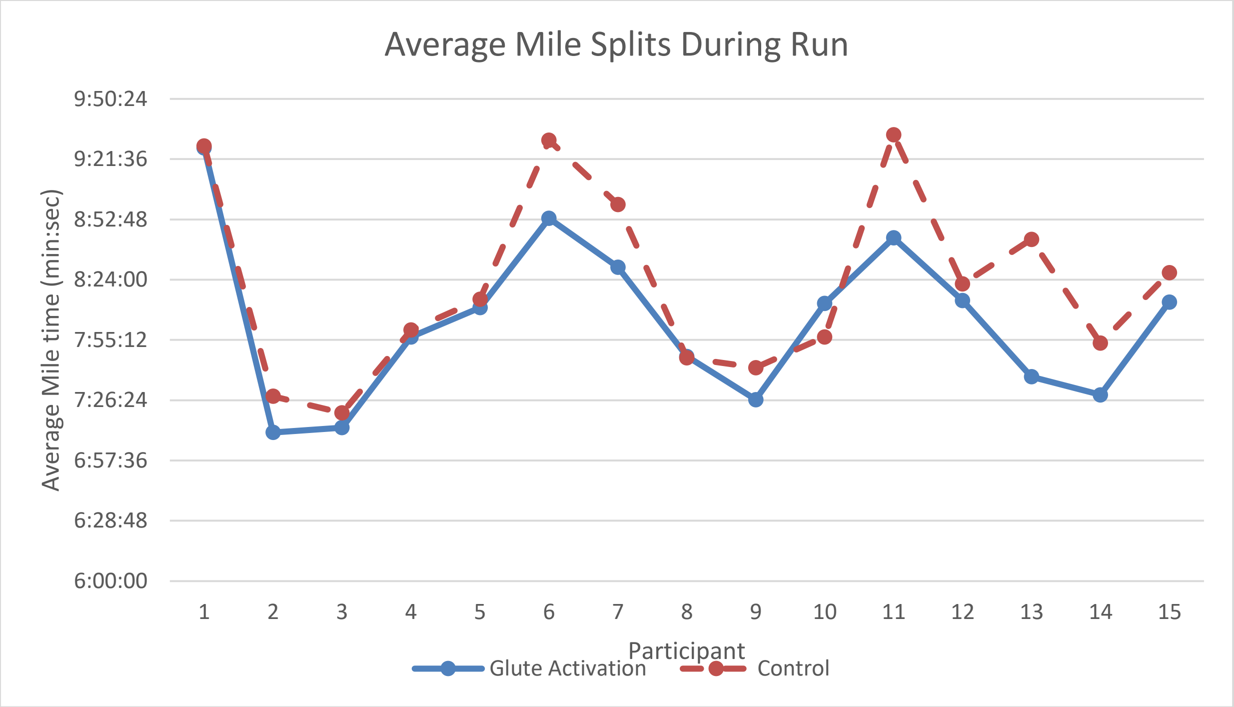

*Figure 14: Line graph comparing average mile times for each participant during both conditions. Solid line indicates gluteal activation condition, dashed line indicates control condition. *Average mile splits were found to be significantly different during paired-sample t-test analysis.*

CHAPTER V

CONCLUSION

(5.1) Introduction

The purpose of this study was to analyze the effects of a gluteal activation protocol intervention on neuromuscular fatigue and performance during a 5-k run. Specifically, performance statistics and muscle activation levels of the gluteus maximus (GMAX) and gluteus medius (GMED) were to be analyzed during two conditions: a gluteal activation (GA) intervention condition, and a controlled run condition. The hypothesis for this study was that performing a GA protocol prior to a run would: (1) increase muscle activation and cause a more consistent activation over time, measured via EMG activity, and; (2) improve performance time, measured by time to complete a 5-k run. The data collected during analysis indicated that: (1) there is not a significant difference in activation levels during five consecutive steps over time, nor a significant difference between pre- and post-run maximal activation levels of gluteal musculature, but (2) there is a significant difference in performance times, specifically during average mile splits when compared between both conditions.

(5.2) EMG activation over time

During the current study, EMG activation was not found to be significantly different between the GA and controlled run conditions during analysis of peak EMG amplitude of the GMAX and GMED during five consecutive steps. Despite this fact, activation levels appeared to be different between conditions for the GMAX and GMED, respectively. In the study, activation levels for the GMAX and GMED remained fairly level over time during the GA condition than when compared to the controlled condition. This result of varied activation levels over time may be due to a combination of neuromuscular fatigue, potentiation effects, and increased activation levels of the gluteal musculature when speed is increased.

Gluteus medius activation. In previous studies, gluteal EMG activity has been performed during running while researchers evaluated variances in kinematics, gender, and activation levels during the gait cycle, among other factors. Semciw et al performed a systematic review on EMG analysis for the GMED during running, specifically noting that EMG activation for the GMED is at its peak force during the early stance phase when running, and increases with increased speed through the GMED’s contribution to increased stride frequency at the hip during the late swing phase, increased stride length, and increased cadence during running (Semciw et al., 2016; Dorn, Schache, & Pandy, 2012; Lenhart, Thelen, & Heiderscheit, 2014). During the current study, GMED activation remained level throughout the run within the GA condition compared to the controlled condition, in which it increased within the first five minutes, then gradually decreased over time. Additionally, both runs gradually increased speed throughout the run. If what Semciw and fellow researchers said is true, increased speed during running should result in increased GMED EMG activation over time (Dorn, et al., 2012; Lenhart et al., 2014; and Semciw et al., 2016), and theoretically, both runs should have demonstrated gradually increased activation levels in the GMED over time. However, because GMED activation during the controlled condition decreased over time while activation in the GA condition remained level, other factors must be involved.

Post-activation potentiation may play a role in maintaining muscle activation over time through its ability to co-exist with fatigue and potential to delay it (Hamada et al., 2000; Harrison & McCabe, 2017). Performance is directly related to the balance between fatigue and potentiation; potentiation effects have been shown to be evident throughout the entirety of an exercise, even up to 20 minutes after the end of a fatiguing exercise (Millet et al., 2002). In the present study, when completing a GA routine prior to a run, performance improved and activation levels in the GMED were able to remain level comparative to a controlled run. Considering this, performing a low-load gluteal activation routine before a run may cause potentiation effects, delaying the effects of fatigue throughout the course of the run; this would allow for increased GMED EMG activation during increased speeds to take place and counter fatigue effects, which in turn would allow the participant to maintain a more level activation in gluteal musculature over time compared to a controlled run, as demonstrated in the current study. Should this theory ring true, a gluteal activation potentiation routine may influence several factors affecting muscle activation throughout a fatiguing activity and lead to an improved performance during an endurance run.

Gluteus maximus activation. In this study, gluteus maximus activation increased throughout the run in the controlled condition, while it maintained fairly consistent activation levels during the GA condition, though these values were not significant during SPSS statistical analysis. To explain this result, several factors must be addressed, specifically regarding anatomical structure, biomechanical movement, and potentially gender bias.

Anatomically, the gluteus maximus connects the pelvis to the lumbar and thoracic spine, influencing postural control during walking and running (Ford et al., 2013). It can thereby be stated that the gluteus maximus is related to an erect posture, hip flexion, and hip extension through the muscle's strength or weakness. An increase in hip/pelvic complex strength is also related to decreased thoracic and pelvic motion during running (Ford et al., 2013). Biomechanically, it has been shown that as speed increases from walking to running, the trunk is pitched forward more and more while the GMAX increases its activation in order provide hip extension and propel the body forward faster (Lieberman, Raichlen, Pontzer, Bramble, & Cutright-Smith, 2006). In other words, the GMAX increases its activation level with a forward-pitched torso and increased hip flexion angle in order to increase speed. Lessi and colleagues have also noted that decreases in lower limb muscle activation occur due to fatigue and in turn may result in alterations in trunk and pelvic position (Lessi et al., 2017). Considering these studies, the increase in GMAX activation levels during the current study would make sense. During the beginning of the controlled run condition, the GMAX was unfatigued; as the run progressed and the body became more tired, GMAX activation may have potentially decreased due to this fatigue, leading to an alteration in trunk posture to compensate for decreased activation. As the subject continued to increase their speed with a potentially altered trunk position, GMAX activation may have increased to compensate for this forward-leaning trunk position. Conversely in the GA condition, the GMAX maintained consistent activation over time, indicated by regular levels throughout the run. Because the GMAX was activated before the run through post-activation potentiation during the GA protocol, the onset of fatigue in this muscle may have been delayed, enabling the body to maintain proper trunk posture for a longer period of time and allow the body to maintain a more consistent activation level throughout the run.

In another study, Willson and colleagues performed a study in which gluteal activation and kinematics were compared between males and females during a run (Willson et al., 2012). Researchers found that females had greater average and peak GMAX activation during the run than when compared to males, additionally suggesting that this increase in GMAX activation levels during running can lead to earlier onset of fatigue, reducing the force-generating capacity of females after exertion (Willson et al., 2012). This theory provides conflicting results when used to explain the current study's findings. EMG activation for the GMAX slowly increased over time in the controlled setting than when compared the more consistent activation levels during the GA condition, opposing the theory from Willson et al. that early onset fatigue due to increased activation would cause decreased force after exertion. However, following the run, maximal force-generating capacity of the GMAX was decreased compared to the pre-run MVC test, supporting Willson and colleagues' theory. Another factor that may have influenced the recorded GMAX activation levels over time was the concept of cross-talk with surrounding musculature, which is known to occur during analysis of gluteal musculature with surface electrodes (Ekstrom et al., 2007; DiStefano et al., 2009; Semciw et al., 2016). Crosstalk and other limiting factors are discussed in more detail within section 5.7.

GMAX activation during the GA condition was similar to that of GMED activation in the same condition, in that activation for both muscles remained consistent over time rather than fatiguing or increasing over time. This may also be potentially related to the effects of post-activation potentiation on delaying fatigue within musculature while an increase in speed allows for a continual increase in GMAX muscle activation, resulting in a more consistent activation level over time while balancing with fatigue (Hamada et al., 2000; Harrison & McCabe, 2017; Millet et al., 2012). More research may benefit this possible theory and provide more insight, specifically by performing studies in which speed is a controlled factor while a GA protocol acts as an intervention between running conditions.

(5.3) EMG maximal activation

Maximal levels of GMED and GMAX activation were not found to be statistically significantly different between pre- and post-run maximal voluntary contraction (MVC) testing during the GA or controlled run conditions. In the GA condition, both the GMAX and GMED tended to increase in maximal activation levels during post-run MVC testing than when compared to pre-run MVC levels; however, the opposite was found in the controlled run condition, in which both muscles decreased in maximal activation in post-run testing during the controlled run condition.

Gluteus medius. In the study, maximal contractions were performed before and after the run. When statistically analyzing the data, there was no statistically significant maximal activation levels in the GMED between pre- and post-testing sessions. However, GMED pre- and post-run maximal activation levels remained fairly consistent, while conversely, post-run maximal activation levels dropped to 85% of the pre-run activation level during the controlled run condition. This may have been related to the GA protocol's ability to cause post-activation potentiation, delaying fatigue in the musculature and allowing for an increased maximal contraction following the run. This is also supported by the fact that post-activation potentiation effects may last up to 20 minutes after the end of a fatiguing exercise, indicating that potentiation effects may continue throughout the entirety of the run (Millet et al., 2012). In the controlled run setting, fatigue may have decreased the ability for the GMED to maintain its pre-run activation levels, resulting in an overall decrease in activation in the post-run MVC trial.

Gluteus maximus. When comparing pre-run to post-run maximal activation levels of the GMAX, maximal contractions of the GMAX were found to increase in the post-run MVC compared to pre-run MVC during the GA condition, though not significantly different upon statistical analysis. Conversely, in the controlled run condition, maximal contractions of the GMAX decreased during post-run MVC testing than when compared to the pre-run MVC, though again, not statistically significant. This decrease in post-run MVC levels may be supported by the claim from Willson et al., that greater GMAX activation levels during activity in females may lead to a reduction in force-generating capacity after exertion (Willson et al., 2012). Similarly stated, after a bout of exercise and exertion, a higher GMAX activation in females during the activity will result in a decreased ability to generate force in the musculature following the activity. The results of the current study may also support this claim. Additionally, previous suggestions of the effects of post-activation potentiation on GMED maximal contraction levels may also hold true. In other words, if the body is able to withstand neuromuscular fatigue through post-activation potentiation prior to a fatiguing exercise, activation levels of the muscle may be higher in post-testing than in pre-testing, as potentiation effects can last up to 20 minutes after a fatiguing exercise (Millet et al., 2012).

(5.4) Performance.

In the study, paired-sample t-tests were performed on performance times between conditions; average mile split times were found to be significantly different between the GA and controlled run conditions. As it has been continually stated throughout this paper, post-activation potentiation is directly related to performance due to its ability to co-exist with and delay fatigue. If fatigue is able to be held-off through this phenomenon, performance is inevitably improved due to the body's increased ability to withstand the stresses that are imposed upon it during a fatiguing exercise. In another physiological sense, post-activation potentiation can potentially compensate for low-frequency force output, or low-frequency fatigue, that may occur during endurance activity (Hamada et al., 2000). It may also potentially decrease motor unit firing rates if initiated in early exercise, as was performed in the current study by performing a GA protocol prior to the run (Hamada et al., 2000). Reducing motor unit firing rates can offset the low-frequency fatigue that may be experienced during endurance activity, which in turn can help physiological factors, such as maintaining membrane excitability, which leads to increased excitation-contraction coupling during muscle contraction and overall leads to an improvement in endurance performance (Hamada et al., 2000). Therefore, results of this study may indicate that performing low-load activation exercises prior to an endurance run may produce improved performance, contrasting data from previous researchers that low-load gluteal activation protocols did not improve performance during explosive activities (Comyns et al., 2015; Harrison & McCabe, 2017; Parr et al., 2017).

In another capacity, muscular strength and proper kinematic movement during running may affect performance. Ford and colleagues found that there is a direct relationship between hip strength and pelvic motion, indicating that as hip strength increases, pelvic motion decreases, allowing the body to maintain better posture and perform more efficiently (Ford et al., 2013). When the body is able to work efficiently, forces are distributed appropriately, movement becomes more efficient and controlled, ground-impact forces are absorbed, and there are less damaging factors that can result in overuse injuries (Fredericson & Moore, 2005). In another study, it has been found that reduction in hip strength may be related to increases in hip motion and knee motion during long-distance running (Dierks et al., 2008; Taylor-Haas et al., 2014). For example: as changes in hip abduction strength occur, hip adduction angle is directly affected, leading to compromised length-tension relationships and an inability to efficiently fire the muscle, potentially leading to other muscles compensating for this decrease (Taylor-Haas et al., 2014). In the current study, as a gluteal activation program helped the subject to maintain activation levels over time, proper kinematics may have been sustained and efficiency in motion upheld, leading to an improvement in performance (Fredericson & Moore, 2005).

(5.5) Subjective data

Though subjective data cannot be relied on solely for analysis, it is worth noting the subjective effects that a gluteal activation program had on subjects during their run. Several subjects self-reported that they felt better when performing GA exercises prior to the run, which may have affected the subject psychologically, if not just physiologically, adding a possible placebo effect that could be related to an increase in performance. Subjects reported that when performing a GA program prior to their runs, they felt better during the actual run. Subject 008 specifically said that she “automatically felt a difference” after starting her run after doing a GA protocol; she reported that she had never performed a GA program prior to a run before the session completed in the lab, and that she normally hates running on the treadmill. However, after completing the exercises, she continuously said that she felt a “million times better” and that her “lower half” felt much better than she ever does when she runs on a treadmill. Conversely, during her first visit for the study, she completed the controlled run condition, reporting that she felt “warmed up” around the 8-minute mark of the run. During the second visit for the study when completing the GA protocol, she reported that she felt like she warmed up much faster and the run felt easier after performing the gluteal activation exercises. Subject 004 reported that she has completed the GA exercises prior to her runs every day for the past year; when she performed a run without the exercises, she automatically felt a difference, noting that she felt like it took her longer to warm up during the controlled run than during her normal runs with a GA program. Subject 001, 003, 007, 011 and 015 all reported similar feelings during the run with GA exercises, that it felt “easy,” felt their body was “working better,” and overall felt “much better” than when completing the controlled run condition. The frequent positive verbal support of the gluteal activation exercises is an important finding in the study, even if only just to support the idea that if individuals feel better when beginning an endurance exercise bout, they may perform better as well.

(5.6) Clinical Implications

Clinically, implications of the current study suggest that performing a GA program prior to a distance run may affect the runner psychologically and physiologically, allowing the runner to perform better and more efficiently. When psychological influences suggest to the runner that they feel better and perform better when completing a specific intervention, runners may be more likely to continue completing the intervention, even outside of the laboratory setting. Additionally, if a gluteal activation program helps maintain consistent muscle activation over time and delay fatigue effects, postural control may be maintained, which can allow for more efficient movements during running and enforce a better “feeling” during running with more proper mechanics (Ford et al., 2013; Leiberman et al., 2006). More efficient kinematic movements in turn lead to decreased injuries due to proper distribution of stresses during movement (Fredericson & Moore, 2005). It has been well documented that in injured populations, altered kinematics are present during running that either compensate for the pain resulting from the injury or was the primary factor that led to the injury in the first place; conversely, it has also been found that when performing a hip strengthening program in uninjured runners, kinematics of running was improved (Barton et al., 2013; Dierks et al., 2008; Taylor-Haas et al., 2014). Another study indicated that an 8-week hip strengthening program helped decrease pain and improve function in individuals with patellofemoral pain syndrome (Khayambashi et al., 2014). These findings continue to support the idea that improvements in hip muscle strength and activation of gluteal musculature can improve performance while minimizing the risk for injury, all of which are very important in endurance performance.

(5.7) Limitations

As in any research, limitations exist within aspects of the study. Within the present study, limiting factors were attempted to be minimized through the use of the same research tester throughout each session and by using the same testing procedure in every session, among other factors. However, some factors beyond the control of the researcher took place.

In previous research, EMG activation data of gluteal musculature has been shown to be affected through a variety of factors. Ekstrom et al. and DiStefano et al. reported that surface electrode placement for the GMED and GMAX may allow for crosstalk to occur between musculature in the area due to the close proximity of the muscles, leading to a limited reliability on true activation levels gathered during the study (Ekstrom et al., 2007; DiStefano et al., 2009). Crosstalk, or the picking-up of EMG signal from surrounding musculature, can affect the accuracy of collected EMG data, such as the GMED picking up activation levels of the tensor fascia latae or gluteus maximus, as mentioned by DiStefano and colleagues in their study of EMG activation of gluteal musculature during therapeutic exercises (DiStefano et al., 2009). Another study also noted that despite proper electrode site preparation and placing surface electrodes consistently on the same area over muscle bellies, factors such as movement artifact, electrical interference, and nearby muscle activity can influence muscle activation recordings during EMG analysis (Willson et al., 2012). Semciw et al. also supported this limitation of surface electrode analysis, specifically noting that the GMED has three distinct sections, two of which are covered by the tensor fascia latae and GMAX, respectively (Semciw et al., 2016). Despite proper placement of surface electrodes, this feature of overlying muscle can lead to crosstalk and influenced muscle activity readings. DiStefano and colleagues also noted that EMG signal during dynamic activity can cause a highly variable EMG activation level during collection (DiStefano et al., 2009). Running is a very dynamic activity, and a combination of sweat and dynamic movement during running can cause a highly variable EMG signal and movement artifact, as noted within the study. A few subjects had very noisy, potentially inaccurate EMG signals during the run, providing inconclusive data for certain time-points. Subjects with data that was an outlier far beyond the standard deviation for the data point was eliminated from the analysis in order to provide a more accurate analysis of the whole. Because of this, the sample size for gluteus maximus activation during five consecutive steps was decreased to 10 subjects, which was below the already low sample size of 15 and may have affected the overall results. This overall low sample size may also be considered a limitation for the current study. In another case, an increase in adipose tissue over the gluteus maximus may have also limited EMG data collected in a few of the participants within this study, preventing true muscle activation levels from being collected and analyzed.

To make this study stronger, it would have been beneficial to add a placebo effect group into the testing conditions, allowing subjects to think they were doing a treatment that would also increase performance during the run. The placebo effect may have been doing a deep breathing treatment, doing an upper extremity activation, or something similar. The current study did not have enough time to make the placebo option feasible within the time frame of the study. Additionally, recording the rate of perceived exhaustion (RPE) as a subjective variable may have increased the confidence of the study, ensuring that subjects were putting the same amount of effort into both running sessions instead of slacking off during one run. Subjects were asked to treat the run as a time trial, but using stronger and clearer verbiage might have ensured that they treated both running conditions equally and improve the confidence that the gluteal activation intervention was the reason for the improved performance within the study.

Despite these limitations, extraneous factors were attempted to be minimized as much as possible, as subjects were all asked to wear similar outfits, most subject wore the same shoe type, all were asked to avoid coffee as a potential ergogenic aid, none were told which condition they would be performing prior to arrival at the lab, and the same testing procedure was performed during each session by the same researcher during the entirety of the study.

(5.8) Direction for future studies

As one study cannot control for many variables that play a role in endurance running, future studies may be performed to analyze factors that may contribute to the post-activation potentiation phenomenon. In the current study, kinematic activity was initially recorded, but not analyzed due to time constraints of the study. After reading the research and identifying potential causes for the effects seen within the study, future research would benefit from recording kinematic activity throughout the run in order to analyze joint angles and alterations in running posture. This may help explain the increased activation levels in the GMAX over time in the controlled run as well as the maintenance of activation levels during the GA condition. Additionally, now that an increase in performance has been indicated by the results of this study, controlling for speed in future studies may help determine kinematic affectations during a run with a GA protocol intervention, preventing the increase in speed from affecting postural control unrelated to fatigue.

Another idea for future research regards EMG acquisition. There may be a benefit in utilizing fine-wire EMG in the acquisition of EMG data in gluteal musculature. If discomfort due to the invasive nature of using fine-wire EMG was able to be minimized, this instrument could allow for an improved collection of gluteal activation levels. This could help limit noise and artifact when initially collecting gluteal activation levels during the course of the run. Additionally, analyzing muscle activation duration and timing of activation may provide a clearer picture of the effects that occur with a gluteal activation routine. The current study was unable to utilize the proper equipment during the course of the study to analyze this data, but future studies would benefit from this possible source of knowledge.

Another factor to take into consideration is performing a similar study outside of the academic school year and athletic season, which may also help to limit extraneous factors such as stress and the competition season of athletes. Though running sessions were scheduled by the subject according to their personal schedules and performances, stress may have played a factor in the case of a few of the subjects, as a majority of the sample size were student-athletes in the middle of their spring season of training or finishing final exams in the academic semester. Controlling this factor by completing the same study in the summer, as school is out of session and training becomes an individual rather than team event, extraneous factors may be better controlled for.

Additionally, a laboratory setting may not be completely comparative to real-world application. Several subjects noted that it was difficult to “naturally” increase and decrease speed over time, which may play a role in their performance data. Future studies may seek to apply the current study into an over-ground running study rather than a treadmill running study, seeking to identify changes in gluteal activation over time during an endurance run in a real-world application setting.

(5.9) Conclusion

Overall, the purpose of this study was to analyze the effects of a gluteal activation program on fatigue and performance during a 5k run. Statistical analysis suggested that there was not a significant difference in gluteal activation of the gluteus medius or gluteus maximus during a 5k run when performing a gluteal activation program prior to the run, nor within a controlled run. Further, there was not a significant difference in pre- and post-maximal activation values of the gluteal muscles between running conditions. However, there was a significant difference in 5k run performance, specifically in mile split times throughout the course of the run; performing a gluteal activation program prior to the run resulted in a significantly improved performance in mile splits compared to that of a controlled run that lacks the activation routine. Results of this study may suggest that performing a low-load gluteal activation program prior to an endurance run may improve overall endurance running performance through the effects of post-activation potentiation and its relation to delaying neuromuscular fatigue and maintaining level gluteal activation levels over time during an endurance activity. Future studies would benefit from performing a similar study, analyzing kinematic activity during the course of the run or utilizing fine-wire EMG, seeking to identify changes in postural control and gluteal muscle activation throughout the course of an endurance activity.

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APPENDICES

A. Consent form.

Department of Education, Health, and Aviation:

School of Kinesiology, Applied Health, and Recreation

CONSENT FORM

The Effects of a Gluteal Activation Program on Hip Muscle Fatigue During a Prolonged Run

Background Information

You are invited to be in a research study of hip muscle activation during prolonged runs. You were selected as a possible participant because of your physical activity levels and ability to participate in endurance activities. We ask that you read this form and ask any questions you may have before agreeing to be in the study. Your participation is entirely voluntary.

This study is being conducted by: Cecilia Lane, graduate student in applied exercise science, under the direction of Dr. Jason DeFreitas, assistant professor in Health and Human Performance, Dept. of Education, Health, and Aviation.

All testing will be conducted in the Applied Neuromuscular Physiology Laboratory (ANPL) located in 199 Colvin Recreation Center building at Oklahoma State University – Stillwater campus. All measures and tests are conducted for research purposes only. The results will not be used to diagnose any illness or disease, and will not provide any meaningful information your physician.

Procedures

If you agree to be in this study, we would ask you to do the following things:

During the familiarization session, you will fill out this consent form, a physical activity readiness questionnaire (PAR-Q), participant demographics, including your name, contact information, health history, and exercise history. The researchers will measure your height and weight. Your hip strength will be measured on an isokinetic dynamometer and practice gluteal activation exercises. Any questions will be answered after this point. Pre-exercise questions asked during the familiarization session are to: ensure that you are healthy, physiologically prepared, and able to participate in exercise; provide baseline information to compare your results to yourself and to other participants anonymously, and; to provide the investigators with contact information to schedule your subsequent testing sessions for this study.

During each of the two sessions after the familiarization session, you will be weighed and warm up on a treadmill for 5 minutes. Your hip strength will be measured and afterward, you will complete one 5-k run per session; one 5-k run will be preceded by gluteal activation exercises. EMG data will be measured through surface EMG electrodes that will be placed on your skin prior to the run. Hip strength will be measured again after the run. Additionally, we ask that you avoid strenuous exercise 24 hours before the session to prevent soreness that may affect the results of the testing.

Participation in the study involves the following time commitment:. Three 45-60 minute sessions; one session is a familiarization session (~45 min), and two testing sessions include a 5k run, data collection, and measurements (total of ~60 min per session).

Risks and Benefits of being in the Study

Risks: There are no known risks associated with this project, which are greater than those ordinarily encountered in daily life or physical activity. You may experience some delayed onset muscle soreness (DOMS) following the exercise 24-48 hours following the run; however, this is temporary and will subside within a few days.

However, if you sustain injury during the study or as a result of the study, steps are in place for treatment. The IRB will be informed if a serious event occurs. An AED and emergency medical equipment will be available during all sessions will be on hand for any emergency situation. The researcher is CPR/AED certified and will help manage situations as presented. If you feel any discomfort or injury, you will be instructed to contact Cecilia Lane, the principal investigator. 911 will be called in the case of an emergency. If professional intervention is needed, OSU counselling services or the OSU student health center will be available for treatment. Counselling services can be contacted at 405-744-5458 and the student health center can be contacted at (405) 744-7665.

The benefits to participation are: You will be allowed to see your results from the two exercises and gain knowledge of different exercises to include in your everyday exercise sessions. You will also be able to see your performance results of a 5k run from both testing conditions. More broadly, the results from your participation in this study may help the researchers learn more about the effects of gluteal activation exercises on the delay of muscular fatigue and may help prevent future injuries by promoting preventative exercise techniques to improve gait mechanics.

Compensation

You will not receive payment for participating in this study.

Confidentiality

The information that you give in the study will be handled confidentially. Your information will be assigned a code number/pseudonym. Information connecting your name to this code will be kept on a jump drive in a locked file. When your participation in the study is completed and the data have been analyzed, the identifiable information connected to your results will be destroyed. Your name will not be used in any report.

We will collect your information through subject demographics, EMG data, running performance time, and dynamometer measurements. Your health history, PAR-Q, and demographic information will be uploaded to an Excel document and the paper copies will be subsequently shredded to maintain confidentiality. This data will be stored in an encrypted flash drive kept in a locked cabinet in the laboratory. The data will be analyzed as a group and not by individual results, thus maintaining your confidentiality. When the study is completed and the data have been analyzed, the code list linking names to study numbers will be destroyed. This is expected to occur no later than 6 months following the completion of data collection. This informed consent form will be kept for 6 months, ending at the end of May 2019. Your data collected as part of this research project will not be used or distributed for future research studies.

It is unlikely, but possible, that others responsible for research oversight may require us to share the information you give us from the study to ensure that the research was conducted safely and appropriately. We will only share your information if law or policy requires us to do so. Finally, confidentiality could be broken if materials from this study were subpoenaed by a court of law.

Voluntary Nature of the Study

Your participation in this research is voluntary. There is no penalty for refusal to participate, and you are free to withdraw your consent and participation in this project at any time. There are no penalties for your withdrawal. Your results may also be withdrawn from the study if you fail to adhere to the study's procedure or protocols or the researcher's instructions. The alternative to the study's procedures is to not participate. Your decision whether or not to participate in this study will not be held against your or affect your medical care.

Contacts and Questions

The Institutional Review Board (IRB) for the protection of human research participants at Oklahoma State University has reviewed and approved this study. If you have questions about the research study itself, please contact the Principal Investigator at 316-648-8941, celane@okstate.edu or Dr. Jason DeFreitas at jason.defreitas@okstate.edu. If you have questions about your rights as a research volunteer or would simply like to speak with someone other than the research team about concerns regarding this study, please contact the IRB at (405) 744-3377, 223 Scott Hall, Stillwater, OK 74078, or irb@okstate.edu. All reports or correspondence will be kept confidential.

You will be given a copy of this information to keep for your records.

Statement of Consent

By signing this document, you are certifying that you have read the above information, you have had the opportunity to ask questions and have all your questions answered, and you consent to participate in the study.

Indicate Yes or No:

I give consent to participate in the study:
___Yes ___No
I understand that my participation is voluntary and I may end participation at my choosing:
___Yes ___No

Signature:____ Date: _________

Signature of Investigator:___________________________________ Date: _________

B. Health History Questionnaire

PRE-EXERCISE
TESTING HEALTH &
EXERCISE STATUS

OKLAHOMA STATE UNIVERSITY

DEPARTMENT OF HEALTH AND HUMAN PERFORMANCE

Name ____ Date______________

Work Phone ________________ Home Phone (Cell)________________________

E-mail address_________________ Preferred method of contact: Call, email, or text

Person to contact in case of emergency________________________________

Emergency Contact Phone ______________________

Gender______ Age ______(yrs) Height _____(ft)_____(in) Weight______(lbs)

A. JOINT-MUSCLE STATUS (✓Check areas where you currently have problems)

<u>Joint Areas</u>
(   ) Wrists
(   ) Elbows
(   ) Shoulders
(   ) Upper Spine & Neck
(   ) Lower Spine
(   ) Hips
(   ) Knees
(   ) Ankles
(   ) Feet
(   ) Other______________________

<u>Muscle Areas</u>
(   ) Arms
(   ) Shoulders
(   ) Chest
(   ) Upper Back & Neck
(   ) Abdominal Regions
(   ) Lower Back
(   ) Buttocks
(   ) Thighs
(   ) Lower Leg
(   ) Feet
(   )

Other____________________

B. HEALTH STATUS (✓Check if you currently have any of the following conditions are known to you)

(   ) High Blood Pressure
(   ) Heart Disease or Dysfunction
Abnormality
(   ) Peripheral Circulatory Disorder
(   ) Lung Disease or Dysfunction
(   ) Arthritis or Gout
(   ) Edema
(   ) Epilepsy

(   ) Acute Infection
(   ) Diabetes or Blood Sugar Level
(   ) Anemia
(   ) Hernias
(   ) Thyroid Dysfunction
(   ) Pancreas Dysfunction
(   ) Liver Dysfunction

(   ) Multiply Sclerosis
(   ) High Blood Cholesterol or Triglyceride Levels
(   ) Allergic reactions to rubbing alcohol
(   ) Kidney Dysfunction
(   ) Phenylketonuria (PKU)
(   ) Loss of Consciousness

C. PHYSICAL EXAMINATION HISTORY

Approximate date of your last physical examination________________________

Physical problems noted at that time, if any______________________________

Has a physician ever made any recommendations relative to limiting your level of physical exertion? _________YES __________NO

If YES, what limitations were recommended? ____________________________
____

D. PHYSICAL PERCEPTIONS (Indicate any unusual sensations or perceptions. ✓Check if you have recently experienced any of the following during or soon after *physical activity* (PA); or during *sedentary periods* (SED))

PA	SED	
( )	( )	Chest Pain
( )	( )	Heart Palpitations
( )	( )	Unusually Rapid Breathing
( )	( )	Overheating
( )	( )	Muscle Cramping
( )	( )	Muscle Pain
( )	( )	Joint Pain
( )	( )	Other________________________

PA	SED	
( )	( )	Nausea
( )	( )	Light Headedness
( )	( )	Loss of Consciousness
( )	( )	Loss of Balance
( )	( )	Loss of Coordination
( )	( )	Extreme Weakness
( )	( )	Numbness
( )	( )	Mental Confusion

E. EXERCISE STATUS

Do you regularly engage in aerobic forms of exercise (i.e., jogging, cycling, walking, etc.)? YES NO

How long have you engaged in this form of exercise? ______ years ______ months

How many hours per week do you spend for this type of exercise? _______ hours

Do you regularly lift weights? YES NO

How long have you engaged in this form of exercise? ______ years ______ months

How many hours per week do you spend for this type of exercise? _______ hours

How many days per week do you dedicate a weight lifting session to lower body muscle groups?

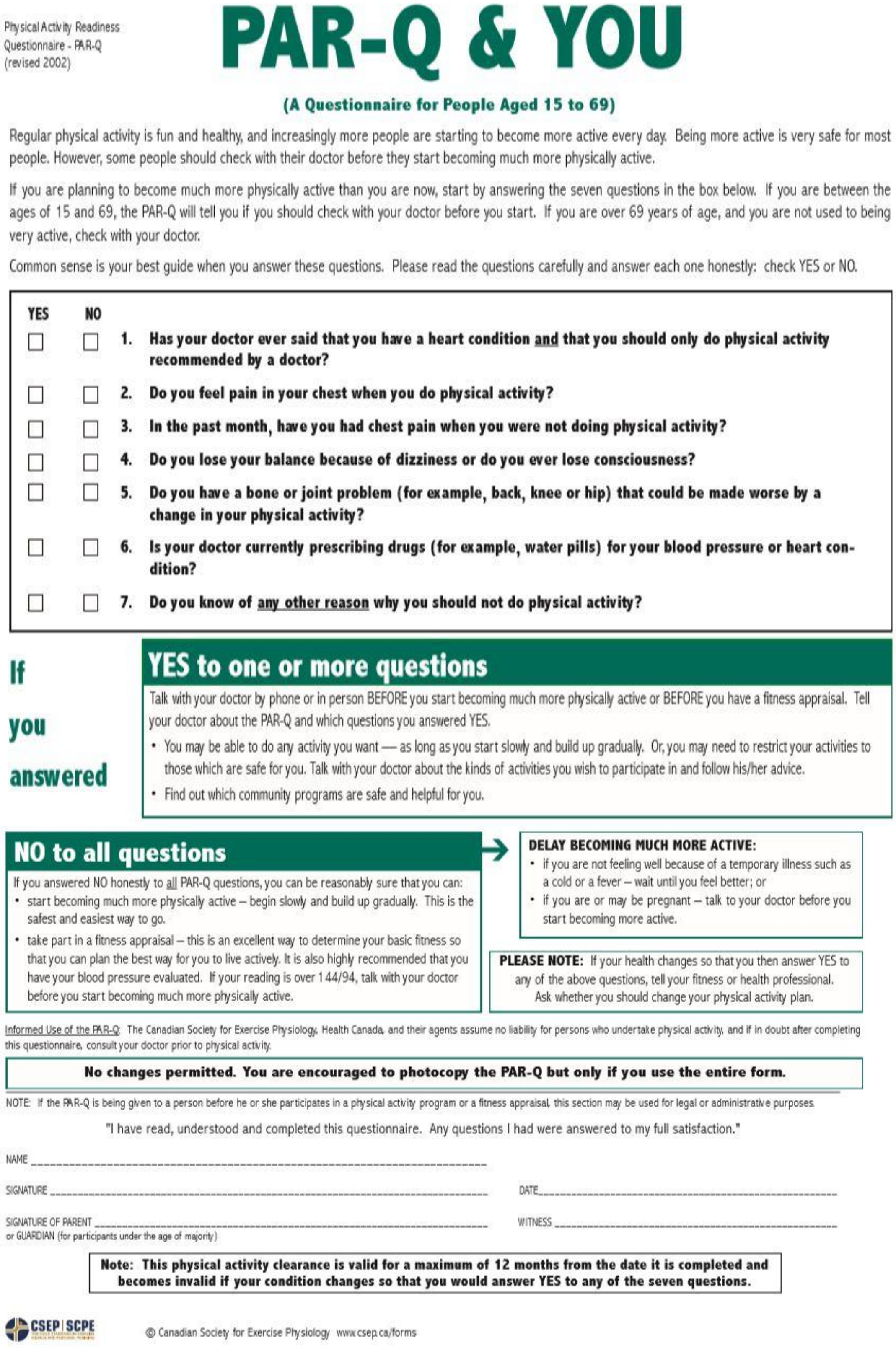
____

Do you regularly play recreational sports (i.e., basketball, racquetball, volleyball, etc.)? YES NO

How long have you engaged in this form of exercise? ______ years ______ months

How many hours per week do you spend for this type of exercise? _______ hours

C. Physical activity readiness questionnaire (PAR-Q)



Physical Activity Readiness
Questionnaire - PAR-Q
(revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO		
☐	☐	1.	**Has your doctor ever said that you have a heart condition <u>and</u> that you should only do physical activity recommended by a doctor?**
☐	☐	2.	**Do you feel pain in your chest when you do physical activity?**
☐	☐	3.	**In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	4.	**Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	5.	**Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	6.	**Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	7.	**Do you know of <u>any other reason</u> why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to <u>all</u> PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

→

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

<u>Informed Use of the PAR-Q</u>: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME ____

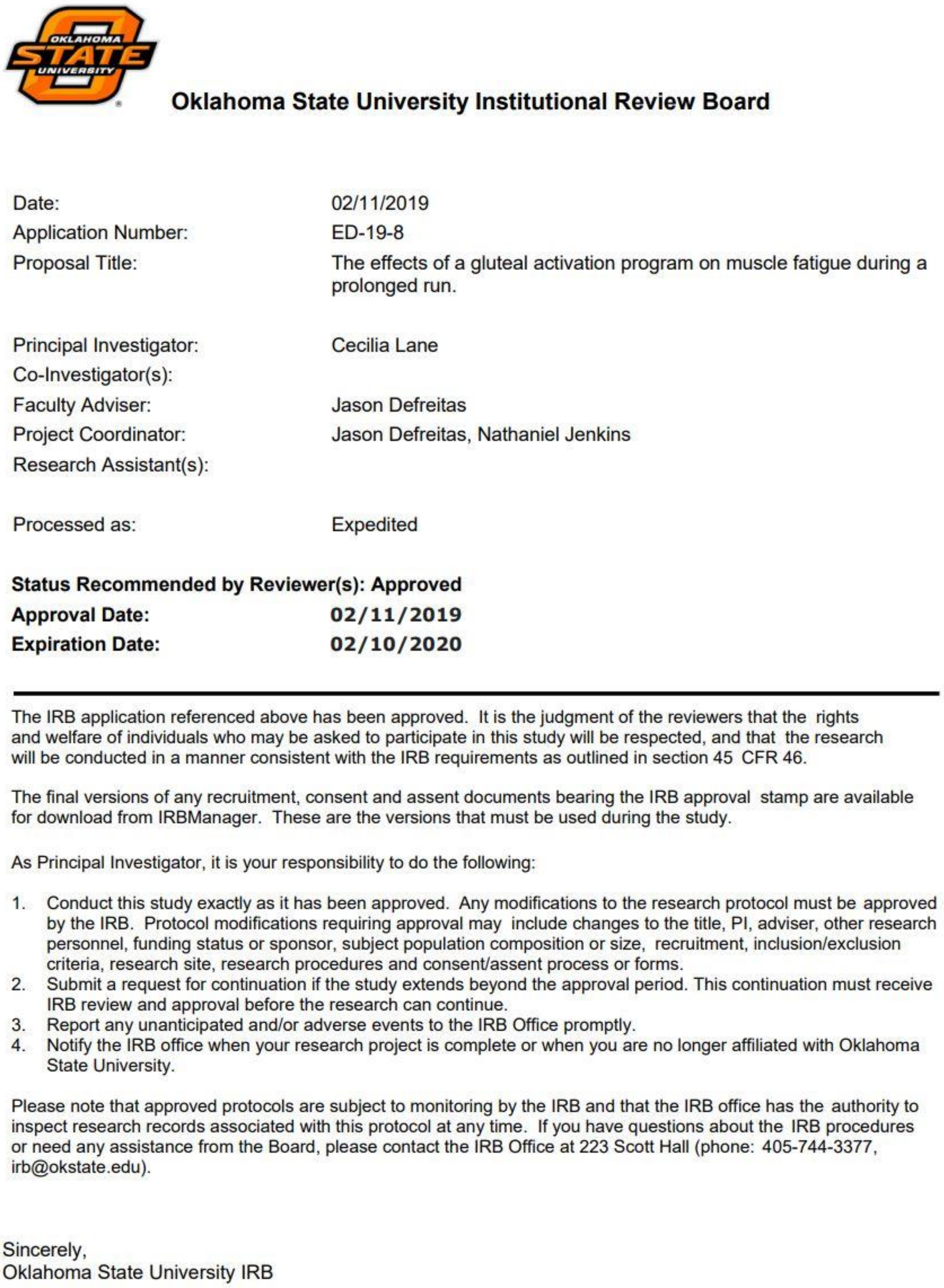
SIGNATURE ____ DATE________________________________

SIGNATURE OF PARENT ____ WITNESS ______________________________
or GUARDIAN (for participants under the age of majority)

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

CSEP | SCPE

D. Institutional Review Board (IRB) acceptance letter



Oklahoma State University Institutional Review Board

Date:	02/11/2019
Application Number:	ED-19-8
Proposal Title:	The effects of a gluteal activation program on muscle fatigue during a prolonged run.
Principal Investigator:	Cecilia Lane
Co-Investigator(s):	
Faculty Adviser:	Jason Defreitas
Project Coordinator:	Jason Defreitas, Nathaniel Jenkins
Research Assistant(s):	
Processed as:	Expedited

Status Recommended by Reviewer(s): Approved

Approval Date:	**02/11/2019**
Expiration Date:	**02/10/2020**

The IRB application referenced above has been approved. It is the judgment of the reviewers that the rights and welfare of individuals who may be asked to participate in this study will be respected, and that the research will be conducted in a manner consistent with the IRB requirements as outlined in section 45 CFR 46.

The final versions of any recruitment, consent and assent documents bearing the IRB approval stamp are available for download from IRBManager. These are the versions that must be used during the study.

As Principal Investigator, it is your responsibility to do the following:

1. Conduct this study exactly as it has been approved. Any modifications to the research protocol must be approved by the IRB. Protocol modifications requiring approval may include changes to the title, PI, adviser, other research personnel, funding status or sponsor, subject population composition or size, recruitment, inclusion/exclusion criteria, research site, research procedures and consent/assent process or forms.
2. Submit a request for continuation if the study extends beyond the approval period. This continuation must receive IRB review and approval before the research can continue.
3. Report any unanticipated and/or adverse events to the IRB Office promptly.
4. Notify the IRB office when your research project is complete or when you are no longer affiliated with Oklahoma State University.

Please note that approved protocols are subject to monitoring by the IRB and that the IRB office has the authority to inspect research records associated with this protocol at any time. If you have questions about the IRB procedures or need any assistance from the Board, please contact the IRB Office at 223 Scott Hall (phone: 405-744-3377, irb@okstate.edu).

Sincerely,
Oklahoma State University IRB

VITA

Cecilia Ann Lane

Candidate for the Degree of

Master of Science

Thesis: EFFECTS OF A GLUTEAL ACTIVATION PROGRAM ON MUSCLE FATIGUE AND PERFORMANCE DURING A 5K RUN

Major Field: Applied Exercise Science

Biographical:

Education:

Completed the requirements for the Master of Sciences in Applied Exercise Science at Oklahoma State University, Stillwater, Oklahoma in July, 2019.

Completed the requirements for the Bachelor of Science in Athletic Training at Kansas State University, Manhattan, Kansas in 2016.

Experience: Athletic training student, 2014-2016; Graduate assistant athletic trainer, 2017-2019

Professional Memberships: NATA, 2012-current; BOC, 2017-current; ASOP, 2017-2018