The Effect of Postactivation Potentiation on Gluteus Medius Muscle Activation During Rehabilitation Exercise in Division l Athletes

By

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Dedicated to my grandfather, Dario Barreto, for never doubting my capabilities, supporting my educational career in every way possible and reminding me during every Sunday 12pm phone call that everything is going to be okay.

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ABSTRACT

The purpose of this study was to investigate the effects of postactivation potentiation (PAP) on the activation of a lower-extremity stabilizer muscle (gluteus medius) in female division 1 collegiate athletes when performing an integrative rehabilitation exercise. Ten female collegiate athletes actively participating in sport were recruited from the women's soccer, track and cross country teams. Participants were asked to perform one set of three repetitions of a single leg glute bridge (SLB) rehabilitation exercise with and without a PAP protocol. Mean, peak and time to peak muscle activation data were obtained via surface electrode electromyography (EMG). Results of this study revealed a statistically insignificant increase in peak, mean and decrease in time to peak muscle activation when comparing baselines EMG values of SLB to SLB performed after a PAP protocol within a 10-second time interval. These results suggest a PAP protocol may be implemented in the rehabilitation of a lower-extremity stabilizer muscle without harm to the patient however, potentiation may or may not occur within the 10-second time interval between PAP protocol and rehabilitation exercise performance task. Future studies should investigate different methodologies such as PAP prescription parameters, population injury status and EMG data analysis.

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LIST OF ABBREVIATIONS & TERMS

PAP	Postactivation Potentiation
PAPE	Postactivation Performance Enhancement
SLB	Single leg glute bridge
IWW	Isometric Wall Warrior
NASM	National Academy of Sports Medicine
NCAA	National Collegiate Athletics Association
AE	Athlete Exposures
VMO	Vastus Medialis Oblique
CEC	Corrective Exercise Continuum
MRLC	Myosin Regulatory Light Chain
MRLCK	Myosin Regulatory Light Chain Kinase

CHAPTER I

INTRODUCTION

Injuries that occur within athletic populations can be the result of a multitude of factors including improper biomechanics. The ways in which the body receives and reacts to the forces placed upon it by the surrounding environment can lead to harmful adaptations such as compensatory movements, malalignments of joints and functional imbalances. Athletic participation offers an abundance of opportunities for biomechanical perturbation by often placing the body in unfavorable positions and requiring athletes to utilize agility, strength and power to adapt and overcome several different forces.

Despite the effectiveness of collegiate strength and conditioning training programs in improving sport-specific fitness, some athletes require further intervention from sports medicine clinicians such as athletic trainers, team physicians and physical therapists in order to provide individualized interventions for the correction of inherent biomechanical deficiencies predisposing them to injury. These interventions can be categorized as injury prevention programs or corrective-maintenance rehabilitation and can be implemented as soon as deficiencies are identified whether this occurs before or after the onset of pain, dysfunction or injury.

Corrective exercise protocols have been strategized and organized by the National Academy of Sports Medicine (NASM) to create the Corrective Exercise Continuum. This process involves four phases including inhibition, lengthening, activation and integration. The primary goals of this protocol are to inhibit overactive muscles or soft tissue structures and increase activation of underactive muscles to reclaim balance of the patient’s biomechanical function.

Many techniques exist to inhibit overactive tissues such as myofascial release, neuromuscular stretching, and various manual therapy techniques however, other than general strengthening, not many techniques exist for increasing activation and integration of underactive muscles. Postactivation potentiation (PAP) and postactivation performance enhancement (PAPE) are potentiation protocols that have been applied in the strength and conditioning setting to increase activation and therefore performance of specific muscle groups. These performance enhancing activation protocols have not yet been translated to sports medicine rehabilitation likely due to the lack of consensus on prescription parameters.

In summary, it is widely accepted that biomechanical insufficiencies in athletic populations can increase injury risk. Although clinicians have identified the need for increasing targeted muscle activation, there is a lack of muscle activation techniques to elicit this effect other than general strengthening of involved musculature. More research on postactivation potentiation and postactivation performance enhancement protocols is warranted in order to determine their applicability in a sports medicine rehabilitation setting.

Purpose of Study

The purpose of this study was to investigate the effects of postactivation potentiation on the activation of a lower-extremity stabilizer muscle (gluteus medius) in female division 1 collegiate athletes when performing an integrative rehabilitation exercise.

Hypothesis

1. The dominant gluteus medius mean and peak muscle activation will increase and time to peak muscle activation will decrease during the single leg glute bridge performance task following the potentiation protocol compared to baseline measures of the same performance task.

Delimitations

1. The present study controlled for gender, athletic NCAA division, conference, and university.
2. Participants had no history of lower extremity injury within the last six months requiring surgery, physical therapy, treatment and being withheld from sport for greater than four weeks.
3. Participants had no history of neuromuscular disorders affecting the lower extremity.
4. Participants had no scarring or deformity affecting the lower extremity region of the gluteus medius.

Limitations

1. It is not possible to ensure participants contracted their gluteus medius with maximum effort when asked to do so.
2. The presence of true postactivation potentiation was not confirmed from a physiological and molecular standpoint within the scope of the current study.

Basic Assumptions

1. Participants performed all exercises with full effort regarding form and accuracy in both baseline and experimental trials.
2. Participants were honest about recent medical history.

Significance of Study

The results of the current study could serve as evidence for or against the implementation of a potentiation protocol in the athletic rehabilitation setting. The purpose of applying a potentiation protocol prior to rehabilitation exercises would be to enhance the muscle activation of targeted muscles in efforts to improve muscular imbalances and increase strength to treat chronic and acute injuries as well as improper biomechanics for injury prevention purposes.

CHAPTER II

REVIEW OF THE LITERATURE

Lower-Extremity Injury Prevalence in Athletic Populations

Chronic and acute injuries to the lower extremity are common within athletic populations and can occur at multiple skill levels (Kakouris et al., 2021; Lambert et al., 2021). Injuries can result in time lost from training or competition, time spent in physical therapy, surgical intervention, and burdensome costs of treatment interventions. In addition to physical pain and dysfunction, injured athletes may also endure negative psychological effects due to injury and being withheld from their sport, (Appaneal et al., 2009; McGuine et al., 2012; Valovich et al., 2009) hindering progress toward recovery. The increased intensity and frequency of training in the collegiate or professional athletic settings provides more opportunities for athletic injury exposure.

Muscular injuries account for a large amount of lower-extremity dysfunction in collegiate athletics. The National Collegiate Athletics Association (NCAA) reported an overall quadricep injury incidence rate of 1.07 per 10,000 athlete exposures (AE) during the 2009-2010 through 2014-2015 seasons with the majority of injury incidents occurring in preseason (57.8%) compared to in-season athletics (Eckard et al., 2017a). Hip adductor and hip flexor injuries during this same time yielded injury incidence rates of 1.29 and 1.60 per 10,000 AE, respectively and were mostly attributed to non-contact mechanisms (Eckard et al., 2017b). The number of hamstring injuries was significantly greater during this time producing an incidence rate of 3.05 per 10,000 AE with 72.3% occurring due to non-contact mechanisms (Dalton et al., 2015).The highest proportion of musculoskeletal injury incidence in runners was found in the knee, ankle and lower leg (Kakouris et al.,

2021) likely due to the repetitive nature of the sport (Bertelson et al., 2017). Chronic overuse injuries to the lower extremity have included many pathologies such as iliotibial band syndrome, patellofemoral stress syndrome, plantar fasciitis, medial tibial stress syndrome, achilles tendinopathy and stress reactions/fractures (Kakouris et al., 2012). An epidemiological study conducted by Bratsman et al. (2021) found the prevalence of bone stress injuries in the NCAA between the 2009-2010 and 2013-2014 seasons was highest in women's track, cross country and gymnastics with an overall prevalence of 12.76 bone stress injuries per 10,000 athlete exposures (AE) for all collegiate sports.

Patellofemoral injuries can be both acute and chronic including patellar tendinitis, subluxation, dislocation, fracture, bursitis, osteoarthritis and patellofemoral stress syndrome (Trojan et al., 2019). Between the years of 2009-2014 the NCAA reported a patellofemoral injury incidence rate of 16.10 per 100,000 AE with the highest prevalence in women's volleyball (39.57 per 100,000 AE) (Trojan et al., 2019). Patellar subluxation and dislocation resulted in the greatest number of total days and mean days lost to injury, respectively (Trojan et al., 2019). All patellofemoral injuries reported in this study were found to be most common in sports requiring biomechanical efficiency to produce agile movements such as change of direction and jumping (Trojan et al., 2019). NCAA ankle and foot injuries in jumping sports were reported during the 2009-2010 through 2013-2014 seasons resulting in an injury incidence rate of 1.85 per 1,000 AE with lateral ankle sprains (63.7%) being the most common (Lytle et al., 2021). Contact during jumping in both game and competition proved to be the most common mechanism for the ankle and foot injuries reported, leading researchers to conclude the implementation of proper landing mechanics could improve anticipatory actions to prevent these injuries from occurring in the future (Lytle et al., 2021). Injury prevention programs and functional movement screenings in addition to incoming athlete physicals have attempted to aid in the process of early detection and active prevention of biomechanical insufficiency that could potentially lead to injury. Sports medicine clinicians, including athletic trainers and physical therapists, continue to search for methods to improve biomechanics in sport to reduce the prevalence and negative effects associated with athletic injury.

Biomechanical Contribution to Lower Extremity Injury

Implementing effective programs and interventions for improving biomechanics in athletic populations requires that clinicians gain a better understanding of the relationship between functional imbalances in the lower extremity and acute and chronic injuries. Muscular imbalance is a common topic discussed when determining biomechanical insufficiencies and is typically characterized by altered muscle activation due to tightness or weakness in agonist versus antagonist muscle groups (Matsunaga et al., 2021; Mills et al., 2015; Payne et al., 2020). In a study conducted by Mills et al. (2015) the authors investigated the effects of restricted hip flexors on the activation patterns of the biceps femoris and gluteus maximus muscles in female soccer players and the role of reciprocal inhibition and synergistic dominance. They found those with restricted hip flexors had significantly less gluteus maximus activation and a decreased gluteus maximus to biceps femoris co-activation ratio further supporting that tight or weakened muscles can alter movement patterns through changes in activation and possibly increase injury risk (Mills et al., 2015). Similar results have been demonstrated with gluteal muscle fatigue resulting in synergistic dominance via the increased contribution of the hamstring muscles rather than the gluteus maximus (Edouard et al., 2018; Matsunaga et al., 2021). Muscle tightness is a common biomechanical risk factor for lower extremity injury in athletes. However, there are many other risk factors such as pes planus (Rath et al., 2016), decreased lumbopelvic control (Dehcheshmeh et al., 2021; Letafatkar et al., 2018), and weakness of hip musculature (Dolak et al., 2011; Glaviano et al., 2019; Mirzae et al., 2019).

Malalignment of the ankle joint and arches of the foot can lead to unfavorable changes in force distribution to the ankle, knee and hip (Rath et al., 2016). For example, pes planus can cause internal rotation of the tibia and lead to rotational stress of the knee joint and may promote knee valgus or femoral internal rotation (Coplan et al., 1989; Rath et al., 2016; Shultz et al., 2006). Individuals with pes planus have been found to have increased ground reaction forces and decreased gluteus maximus and biceps femoris maximal voluntary contraction (MVC%) than those without pes planus, indicating poor control over force attenuation throughout the lower extremity (Rath et al., 2021). Poor lumbopelvic control in repetitive jumping athletes has shown to increase lateral trunk flexion, dynamic knee valgus (Fadaei Dehcheshmeh et al., 2021) and decreased gluteus medius muscle activation during landing (Fadaei Dehcheshmeh et al., 2021; Letafatkar et al., 2018). A study conducted by Meinerz et al. (2015) investigated the neuromechanics of the lower extremity during unanticipated cutting in collegiate female soccer athletes and found an increased reliance on hip musculature, specifically the gluteus maximus, when quick change of direction was required. This evidence further supports the injury prevalence research revealing non-contact mechanisms account for most lower extremity injuries in collegiate athletics (Eckard et al., 2017a, Eckard et al., 2017b).

As previously mentioned, biomechanical changes in the lower extremity can lead to internal rotation of the femur and consequential lateral displacement of the patella (MacIntyre et al., 2006; Souza et al., 2010). Changes in the patellofemoral joint can lead to or be a consequence of pathologies such as patellofemoral pain syndrome (PFPS) (Macintyre et al., 2006; Souza et al., 2010). PFPS has been associated with decreased vastus medialis oblique (VMO) in males (Mirzaie et al., 2019) and increased VMO activity in females (Glaviano et al. 2019) during knee rehabilitation exercises. Both males and females with PFPS demonstrated decreased gluteus medius activation in single leg exercises (Glaviano et al., 2019; Mirzaie et al., 2019) with one study revealing nearly a 40% decrease in gluteus medius activity in PFPS patients compared to healthy controls (Glaviano et al., 2019). Variable muscle activity during rehabilitation exercises allowed these studies to conclude the gluteus medius is responsible for stabilization in the transverse and frontal planes of the lower extremity (Glaviano et al., 2019; Mirzae et al., 2019). These results could also explain why rehabilitation programs with early hip strengthening appear to reduce pain sooner in patients with PFPS than programs focusing on the quadricep muscles alone (Dolak et al., 2011; Ferber et al., 2015; Khayambashi et al., 2014). One study conducted by Jellad et al. (2021) found favorable outcomes for PFPS patients following a hip abductor and external rotator strengthening protocol when combined with hip internal rotator stretching. The above evidence further demonstrates that dysfunction at a single joint could be related to dysfunction of distal or proximal joints and the implementation of hip strengthening could benefit the biomechanical efficiency of lower extremity athletes and possibly reduce injury risk (Dolak et al., 2011; Ferber et al., 2015; Glaviano et al., 2019; Mirzaie et al., 2019).

Corrective Exercise Continuum

Muscular imbalance, synergistic dominance, anatomical deficiencies and chronic adaptations to poor movement appear to contribute to biomechanical dysfunction in athletic populations. Once deficiencies are identified, sports medicine clinicians are tasked with implementing effective treatment protocols to correct deficiencies and improve kinematics. To obtain this goal, the National Academy of Sports Medicine (NASM) created a systematic process utilizing stretching or mobilization of restricted tissues and activation of weakened muscles to improve neuromusculoskeletal deficiencies termed the Corrective Exercise Continuum (CEC; Clark & Lucett, 2011).

The CEC is implemented in a three-step process beginning with an integrated assessment during which the patient completes a health risk appraisal and is evaluated for static postural habits, movement, range of motion (ROM) and strength (Clark & Lucett, 2011). The second phase is the designing of the corrective program followed by the third and final step of integrating the protocol strategies (Clark & Lucett, 2011).

Four primary phases comprise the CEC once the biomechanical insufficiencies have been identified (Clark & Lucett, 2011). The inhibitory phase utilizes inhibitory myofascial techniques such as foam rolling, ischemic compression via positional and active release therapy, joint mobilizations, graston and percussion to decrease the tension and activity in muscles considered to be overactive or tight (Clark & Lucett, 2011). NASM attributes the release of muscle tension to decreasing trigger points and decreasing sympathetic nervous system activity (Clark & Lucett, 2011). The goal of the second phase of the CEC process is to increase range of motion by lengthening the mechanically shortened muscles and corresponding connective tissue (Clark & Lucett, 2011). This is typically accomplished with static and neuromuscular stretching such as proprioceptive neuromuscular facilitation (PNF) (Clark, & Lucett, 2011). Once lengthening of the overactive tissues has occurred, the activation phase may begin. The activation phase is implemented via isolated strengthening exercises of the underactive muscles (Clark, & Lucett, 2011). The exercises prescribed should be intended to increase intramuscular coordination by increasing motor unit activation, firing rates and synchronization (Clark & Lucett, 2011). The fourth and final phase of the CEC process is the integration phase in which the clinician prescribes integrative exercises to increase intermuscular coordination to improve the function of muscle synergies throughout the targeted joints (Clark, & Lucett, 2011). The exercises should be functionally progressive and place the patient in an unstable environment to increase synergistic muscle strength and decrease injury risk (Clark, & Lucett, 2011).

Few studies have directly investigated the Corrective Exercise Continuum and there is insufficient evidence of its use in athletic populations. A study conducted by Jellad et al. (2021) investigated an intervention for PFPS with characteristics similar to a CEC protocol. The rehabilitation program for the PFPS patients strengthened the hip abductors and external rotators similarly to other successful protocols, however the authors supplemented this with stretching of the internal rotators which yielded favorable results including decreased pain and increased function (Jellad et al., 2021). Increasing the activation of muscles is another important component of the CEC and is traditionally accomplished in clinical settings via neuromuscular re-education with electrical stimulation following surgical procedures. Increasing muscle activation has also been investigated from a performance enhancement perspective via postactivation potentiation or postactivation performance enhancement (do Carmo et al., 2021; Kilduff et al., 2007; McCann & Flanagan 2010). General strengthening of underactive muscles as the CEC suggests, would seemingly increase strength however, there is currently no evidence of attempts to acutely increase activation of a stabilizing muscle during a functional movement for the purpose of correcting biomechanical insufficiencies.

Postactivation Potentiation

Postactivation Potentiation (PAP) vs. Postactivation Performance Enhancement (PAPE)

Postactivation potentiation is a phenomenon in which it is believed performance characteristics and enhancements are a direct result of the recent contractile history of the given muscle fiber or fibers (Hodgson et al., 2005; Robbins, 2005). The controversy surrounding postactivation potentiation (PAP) and postactivation performance enhancement (PAPE) is mostly in relation to the defining characteristics and prescription parameters required to invoke true PAP or PAPE. Researchers struggle to agree upon time interval, training status, pre-conditioning stimulus, and physiological mechanisms among many other factors contributing to these perceived performance enhancements. A frequent topic of debate has been the differentiation between postactivation potentiation (PAP) and the more recently proposed concept of postactivation performance enhancement (PAPE) which can be categorized by their differing outcome measures, time intervals and possible physiological mechanisms.

Post-activation potentiation (PAP) has been defined as the increase in muscular force and rate of force development due to previous excitation of that muscle induced by a potentiating initial heavy load pre-stimulus contraction (Judge, 2009; Mitchell & Sale, 2011; Rixon et al., 2007). Following an initial muscular contraction, a muscle enters a concurrently fatigued yet potentiated state. Kilduff et al. (2007) described PAP as muscular performance enhancement at the moment that concurrent fatigue is lowest, and potentiation is highest. PAP is observed via electromyography (EMG) data demonstrating an increase in peak twitch force or rate of force development (Blazevich & Babault, 2019). Although a defined, consistent, and widely accepted time interval between initial pre-conditioning contraction and onset of PAP effects does not yet exist, preliminary research and numerous trial and error studies would allow one to conclude PAP effects are greatest immediately following the pre-conditioning stimulus contraction and begin to decline rapidly within the first approximately 28 seconds, and nearly disappear within approximately 5 minutes (Hamada et al., 2000; Macintosh & Willis, 2000; O'Leary et al., 1997; Vandervoort et al., 1983).

As the study of PAP continued, the large range in onset and duration of potentiation effects from 28 seconds to 20 minutes led researchers to believe there was more than one process or phenomenon contributing to the performance enhancements associated with PAP. Cuenca-Fernandez et al. (2017) proposed the term "postactivation performance enhancement" or "PAPE" when referring to performance enhancements with longer time intervals. PAPE has been defined as an observed improvement in voluntary muscular performance following a high intensity pre-conditioning stimulus without electromyography data confirmation (Cuenca-Fernandez et al., 2017, Blazevich & Babault, 2019). The performance enhancing effects of PAPE have been observed much later in the time course of potentiation than PAP, with an assumed onset of PAPE approximately 6-10 minutes following the pre-conditioning stimulus contraction with effects lasting up to 20 minutes (Bevan et al., 2010; Chiu et al., 2003; do Carmo et al., 2021; Jones & Lees, 2003; Kilduff et al., 2007; Nibali et al., 2015; Seitz et al., 2014a; Wilson et al., 2013).

Researchers struggle to define and differentiate PAP from PAPE across multiple disciplines. In a recent opinion article written by Prieske et al. (2017), strength and conditioning specialists claim a primary definitive quality of PAP and PAPE is their category of research. Prieske et al. (2017) believe the mechanistic effects of PAP can be categorized as basic research while the performance effects of PAPE can be considered applied research. This notion supports the evidence presented in a review article written by Blazevich & Babault (2019) suggesting the phosphorylation of the myosin regulatory light chain is the primary physiological mechanism behind PAP while the physiology of PAPE remains unknown although likely due to concurrent effects of general warm-up such as increased blood flow and muscle fiber water content (Edman & Andersson, 1968; Gordon & Godt, 1970; Thames et al., 1974; Mansson, 1989; Sugi et al., 2013) rather than extension of the "classic" PAP physiological effects.

Background & Physiology of Postactivation Potentiation (PAP)

Although the true origin of the term "postactivation potentiation" remains unclear, the study of potentiation appears to have begun in the early 1870's with staircase and treppe potentiation (Bowditch,1871), leading to the study of post-tetanic potentiation in the 1930's (Guttman et al., 1937) which later may have evolved into "postactivation potentiation" in the late 1970's as Burke et al. (1979) utilized this term when referring to potentiation occurring after a voluntary muscle contraction rather than involuntary, electrically evoked muscle contractions (Blazevich & Babault, 2019). The predominant physiological mechanism of PAP appears to be the phosphorylation of the myosin regulatory light chain (MRLC) located on the myosin neck (Manning & Stull, 1979, 1982; Klug et al., 1982; Moore & Stull, 1984; Vandenboom et al., 2013; Vandenboom, 2017) which increases calcium sensitivity of the actin-myosin complex (Rassier & Macintosh, 2000; Sweeney et al., 1993), therefore increasing the likelihood and rate of actin-myosin cross-bridge formation (Metzger et al., 1989; Sweeney and Stull, 1990).

The process of myosin regulatory light chain phosphorylation is dependent upon myosin regulatory light chain kinase (MRLCK), an enzyme that becomes activated by an accumulation of calcium ions (Sweeney et al., 1993; Persechini et al., 1984). Phosphorylation of the MRLC therefore increases myosin head mobility evidenced by the detachment of the myosin head from the myosin backbone (Levine et al., 1998), bringing the myosin head closer to its' binding site on the actin filament (Alamo et al., 2008; Alamo et al., 2015; Brito et al., 2011; Levine et al., 1996). It is believed that this process not only increases the likelihood of cross-bridge formation, but also increases the rate of transition from weak-binding to strong-binding cross-bridge formation and therefore increases force generation of the muscle (Rassier et al. 2000; Sweeney & Stull, 1990). Phosphorylation may also increase ATPase activity within the acto-myosin complex, allowing for more successive and efficient cross-bridge formation and detachment (Szczesna et al., 2002).

A study performed in 2009 by Greenburg et al., revealed the process of MRLC phosphorylation does not have a direct effect on the myosin filament alone, suggesting an encompassing effect on the mechanical properties of actin-myosin complex as a functional unit. Multiple studies have demonstrated greater PAP effects related to MRLC phosphorylation in muscles with shorter twitch contraction times (Vandenboom et al., 1995; Hamada et al., 2000; Gordon et al.,1990; Vandenboom et al., 1993) and with predominantly type ll fast twitch muscle fibers (Grange et al., 1993; Hamada et al., 2000; Young et al., 1995) due to their already naturally increased sensitivity to calcium (Gardetto et al., 1989; Metzger & Moss, 1990) and higher MRLCK enzyme content compared to type l fibers (Moore & Stull, 1984). PAP effects appear to be greater with concentric contractions than isometric contractions for a given level of MRLC phosphorylation (Abbate et al., 2000; Grange et al., 1998; Macintosh & Bryan, 2002; Xeni et al., 2011).

MRLC phosphorylation is initiated rapidly and reverses rapidly, explaining the short time course of true PAP effects rapidly declining in 28 seconds (Hamada et al., 2000; Macintosh & Willis, 2000; Manning & Stull, 1979; O'Leary et al., 1997; Vandervoort et al., 1983). Some researchers believe that successive contractions can maintain and potentiate the phosphorylation of the MRLC (Gossen & Sale, 2000; Sale, 2002), explaining the effects lasting up to 5 minutes. This evidence enhances the argument that MRLC phosphorylation is less likely to be the physiological mechanism behind PAPE effects observed 6-20 minutes after an initial pre-conditioning stimulus contraction.

Postactivation performance enhancement (PAPE) may be better explained via mechanisms of general warm-up including muscle temperature increase, muscle-tendon stiffness, spinal motor neuron excitability, and muscle fiber water content. Muscle temperature increase appears to be directly correlated to muscle metabolism (Gray et al., 2011) by creating an environment in which ATP can be utilized more quickly and with a higher rate of turnover (Gonzalez-Alonso & Calbet, 2003; Gray et al., 2008) therefore, increasing myosin cross-bridge formation rate (Karatzaferi et al., 2004). This increases rate of phosphocreatine utilization (Gray et al., 2008), muscle fiber conduction velocity (Gray et al., 2008), muscle glycogenolysis (Febbraio et al., 1996), glycolysis and total anaerobic ATP turnover (Gray et al., 2005) yielding perceived performance enhancements across multiple studies (Bailey et al., 2012; Gray et al., 2005; Mohr et al., 2004). The rise in temperature within a muscle fiber also increases the influx of sodium ions and outward movement of potassium in each muscle cell, allowing the depolarization to occur more quickly and consequent muscle contractions to occur at an increased rate (Jenerick, 1964). Increased rate of depolarization leads to a greater calcium release from sarcoplasmic reticulum and increased cross-bridge formation (Gray et al., 2005; Rutkove et al., 1997). With the speeding of these processes, there is a reduction in time to reach peak force development (Bobbert et al., 1996; Farina et al., 2005; Gray et al., 2005) and therefore an increase in power performance (Bobbert et al., 1996; Karvonen, 1992; Maffiuletti et al., 2001).

Another possible mechanism for PAPE is the increase in spinal-level excitability. Nuzzo et al. (2016) found increased motor neuron output lasting up to 20 minutes following bouts of high intensity muscle contractions, fitting the timeline of perceived PAPE effects. Some studies have demonstrated an increased reflex amplitude following high intensity or high load voluntary muscle contractions, suggesting attenuated neural activation (Aargaard et al., 2002; Enoka et al., 1980; Folland et al., 2008; Güllich and Schmidtbleicher, 1996; Trimble and Harp, 1998).

Muscle water content increases following exercise can create a state of hypotonicity which has been associated with increases in muscular force (Edman and Andersson, 1968; Gordon and Godt, 1970; Thames et al., 1974; Mansson, 1989; Sugi et al., 2013). Muscle-tendon stiffness could also contribute to increase in muscular force due to the energy stored in elastic structures during and following successive muscle contractions (Blazevich & Babault, 2019). Increased titin stiffness due to calcium influx could also play a role in increased stiffness and force transmission during a series of contractions (Blazevich & Babault, 2019). Future research is warranted in order to confirm the physiological mechanisms of PAPE to assist in the differentiation of PAPE from PAP.

PAP Prescription

Recent literature has attempted to better understand how to properly administer a PAP or PAPE protocol efficiently from an evidence-based perspective. Many variables appear to play a role in the proper prescription of potentiation protocols to elicit ideal PAP or PAPE responses, as demonstrated by the varying results from articles investigating different genders (Rixon et al., 2007), ages (Baudry et al., 2005; Fernandes et al., 2020; Arabatzi et al., 2004), level of athleticism (Kilduff et al., 2007; McCann & Flanagan, 2010, Sue et al., 2016), type of preload stimulus contraction (Ferreira et al., 2012; Kilduff et al., 2007; Rixon et al., 2017) and optimal rest interval (Buttifant & Hrysomallis, 2015; Ferreira et al., 2012; do Carmo et al., 2021; Kilduff et al., 2007; Morana & Perrey, 2009; Sue et al., 2016).

Rest Interval

The theory of the “window of opportunity” refers to the optimal timing following a pre-load stimulus in which the potentiating effect is maximal, and the fatiguing effect has diminished, allowing for enhanced performance (Docherty & Hodgson, 2007). This time interval has been difficult to define and may be highly individualized based upon many variables (Chen et al., 2017; Golas et al., 2016; Hamada et al., 2003; Naclerio et al., 2015). There is disagreement in the literature regarding early potentiation effects within the first minute post-stimulus contraction as some studies have shown performance enhancements in as little as 60 seconds to 4 minutes (Jensen & Ebben, 2003; Morana & Perrey, 2009; Seitz et al., 2014; Sue et al., 2016) while others show initial decreases in performance especially in the first 15 to 60 seconds (Kilduff et al., 2007). There are studies supporting the rest interval times of 4 minutes (Sue et al., 2016; Young et al., 1998), 6 to 7 minutes (do Carmo et al., 2021), 5 to 9.5 minutes (Nibali et al., 2015), 8 to 12 minutes (Bevan et al., 2010; Kilduff et al., 2007;) and 18 to 20 minutes (Chiu et al., 2003; Jones & Lees, 2003). In a study conducted by do Carmo et al. (2021), they found a significant increase in PAP effects when allowing the subjects to self-select their rest intervals. Time interval between pre-conditioning stimulus contraction and performance task is the most frequently debated concept surrounding PAP and PAPE prescription however, pre-stimulus contraction type, age, gender, and level of athleticism are also argued.

Pre-Conditioning Stimulus

Some research has suggested concentric contractions near 1- repetition maximum (1-RM) demonstrate greater PAP effects with traditional set configurations (Ferreira et al., 2012; Sale et al., 2002; Siriero et al., 2021) while others state 85% of 1-RM would be a sufficient pre-conditioning stimulus load (Matthews et al., 2009). Ferriera et al. (2012) concluded 3 sets of 3- second isometric contractions would elicit PAP effects in both trained and untrained males and females compared to a dynamic pre-conditioning stimulus contraction. Similarly, Rixon et al. (2007) found isometric squat contractions of 3-seconds produced greater PAP effects compared to a dynamic squat. Although minimal studies exist, most eccentric PAP protocols did not have an effect on performance (Beato et al., 2019; Ulrich & Pastforter, 2017) despite one study producing significant increases in lower extremity power and vertical jump height following eccentric overload PAP (Beato et al., 2021). A study performed by Piper et al. (2020) found concentric, isometric, and plyometric muscle stimulating contractions all produced PAP effects but at different points in time during the rest interval. While results from previous studies vary, the majority of them conclude that concentric or isometric contractions of maximal or near maximal load are successful in potentiation of muscle (Beato et al. 2019; Ferriera et al., 2012; Piper et al. 2020; Rixon et al., 2007; Ulrich & Pastforter, 2017; Zero et al., 2021).

Patient Characteristics

Postactivation potentiation effects appear to be greater in type ll muscle fibers therefore, the increased type ll muscle fiber composition in males versus females could explain the greater PAP effects seen in male subjects (Arabatzi et al., 2014; Rixon et al., 2007). Despite this physiological explanation, a study conducted by McCann and Flanagan (2010) resulted in no significant difference in potentiation effects between genders. Trained or athletic individuals have demonstrated PAP effects sooner (Seitz et al., 2014) and at greater magnitudes than untrained individuals (Rixon et al., 2007, Sañudo et al., 2020; Seitz et al., 2014). PAP efficacy decreases with aging demonstrated by the lack of voluntary muscular force produced for the same level of neural activation in older adults (Baudry et al., 2005). When potentiation protocols were applied to pediatric populations, children did not show effects of PAP during performance tasks (Arabatzi et al., 2014). More research is warranted on patient characteristics such as age and gender, however it is commonly accepted that potentiation is positively correlated with training status (Rixon et al., 2007, Sañudo et al., 2020; Seitz et al., 2014) and therefore potentiation protocols may be more useful in physically active populations.

PAP or PAPE Applicability within the Rehabilitation Setting

Any advancements in specifying applicability of PAP continues to be limited by a lack of consensus on proper PAP prescription parameters. The relevance between PAP effects, fast twitch muscle fibers and higher speed concentric contractions discussed earlier explains the tendency for current PAP and PAPE applied research to be primarily within the field of strength and conditioning._Whether a potentiation protocol could play a role in athletic rehabilitation, post-surgical intervention, or athletic pre-game or competition settings is unknown or inconclusive at this time (Fernandes et al., 2020; Hodgson et al., 2005; Lorenz, 2011; Lorenz & Reiman, 2011). One study that could potentially connect PAP to rehabilitation or physical therapy in older adults was conducted by Fernandes et al. (2020). The researchers investigated the effects of a PAP protocol on single leg balance in older adults with balance deficiencies and found that those who completed a PAP protocol for rise-to-toe task had significantly improved balance compared to controls.

A possible reason why PAP or PAPE are not thought to apply to injury rehabilitation could be the tendency for potentiation protocols to require high intensity pre-stimulus contractions prior to performance tasks. It is important to note that not all phases of rehabilitation contraindicate high intensity power movements or contractions and that they are often an integral part of the return to play phase of rehabilitation or injury prevention programs within athletic populations. In a real-world setting, sports medicine clinicians are tasked with prescribing corrective or preventative rehabilitation exercises for athletes with chronic or overuse conditions such as patellofemoral pain syndrome, lower-crossed syndrome or poor co-activation of hamstrings and gluteal muscles. Increasing activation of stabilizing muscles to assist in improving biomechanics is often a primary goal of these rehabilitation programs. If these clinicians could utilize a phenomenon such as PAP or PAPE to accomplish this isolated increase in activation of target muscles by simply performing a pre-condition stimulus contraction prior to or throughout the rehab session, this could ultimately increase effectiveness of their intervention.

Summary of Literature Review

A thorough review of the literature establishes the importance of biomechanical correction in athletic populations and the prospective role of potentiation protocols to enhance the activation and therefore performance of underactive muscles. Inconsistencies in the literature are found in regard to prescription of PAP or PAPE protocols, specifically the type of pre-load stimulus, rest interval between pre-stimulus contraction and performance task, and patient characteristics. The physiological mechanisms responsible for PAP and PAPE effects are also debated and inconclusive although, commonly proposed theories include phosphorylation of the myosin regulatory light chain and increased spinal-level neural excitability. Throughout the literature, many researchers investigate PAP and PAPE in the strength and conditioning setting and utilize high load pre-stimulus contractions and advanced performance tasks however, they have neglected to determine the applicability of such protocols to a sports medicine rehabilitation or physical therapy setting. In order to confidently prescribe a safe and effective PAP or PAPE protocol for corrective exercise purposes in sports medicine rehabilitation, additional research is warranted involving clinically applicable corrective or rehabilitation pre-conditioning stimuli and performance tasks.

CHAPTER III

METHODS

Participants

Ten female division I soccer (*n* = 6), track sprinter-jumper (*n* = 3), and cross country (*n* = 1) athletes from Middle Tennessee State University were asked to participate in the present study. All participants were currently in-season or in spring-ball season of their athletic year and were engaged in a low to moderate intensity training program with their respective team's strength and conditioning coaches with additional sport specific skill sessions or practices no more than 20 hours total per week. Participants were all female (age 20.2 ± 1.8 years, body mass 60.9 ± 5.6 kg, height 165.0 ± 6.0 cm) and varied in years of collegiate athletic experience (2.6 ± 1.6 years). Inclusion criteria consisted of (1) at least 1 prior year of regular exercise and athletic activity, and (2) the ability to complete single leg glute bridge (SLB) and isometric wall warrior (IWW) exercises with correct technique. Regular exercise and athletic activity were defined as independent and organized team sport-specific training, practices, competitions, resistance, or cardiovascular training on a weekly basis for the majority of months in the most recent year. The exclusion criteria consisted of: 1) recent (< 6 months) lower extremity musculoskeletal injury requiring surgery, treatment or rehabilitation and being withheld from sport participation for greater than 4 weeks, 2) neuromuscular conditions or nerve damage affecting the lower extremity or pending diagnosis of such conditions, and 3) deformity, scarring from previous procedures or abnormalities of the skin or muscle tissue within the electrode placement region including ports or incisions made in the muscles surrounding the hip during past surgical procedures. This study was approved by the Institutional Review Board (IRB; see Appendix A) and permission was granted from the university's head women's soccer coach and head women's track and field and cross country coach. All participants were informed of the purpose, procedures, risks and benefits of the study prior to signing an informed consent.

Instrumentation

Height and Weight. Each participant was measured using the same stadiometer (213-Portable, SECA, Mount Pleasant, SC) and recorded to the nearest millimeter and kilogram. All participants were weighed wearing only spandex or athletic shorts, a single t-shirt, sports bra, underwear, and socks. Participants were asked to wear the same pair of athletic shoes for each session and to maintain the same clothing requirements described above.

Muscle Activity. Mean, peak, and time to peak muscle activation of the dominant gluteus medius muscle was recorded using a wireless surface electromyography system (Delsys Trigno Research+, Natick, MA) with a single electrode with amplification factor of 1,000 (20-450) Hz. The identification of the dominant leg was determined by asking the participant which leg they would kick a soccer ball with and considering the indicated leg to be the dominant limb. The surface electrode sensor was placed in the center (50%) of the line from the iliac crest to the greater trochanter oriented along the muscle fibers on the long axis of the same reference line. The electrode was applied to the dominant limb while the patient was side lying on a treatment table following skin preparation which included the marking of the anatomical location, abrasion with an abrasive paste (Redux, Parker Laboratories, Fairfiled, NJ), and cleansing of the skin using an alcohol prep pad.

The surface electrode was secured with 4-inch Cover-Roll (BSN, Hamburg, Germany) adhesive bandage enabling viewing of the electrode’s light to confirm the device was on during testing.

Procedures

Assessment

The present study consisted of three total sessions with one session per day for three days. The three sessions were separated by a minimum of 24 hours with the sessions lasting approximately 30 minutes, 1 hour and 10 minutes, and 1 hour, respectively. Session 1 was consistent for all participants and began with an explanation of the study including the purpose, procedures, risks, and benefits prior to signing an informed consent. All participants were given the opportunity to ask questions prior to consenting to participate in the study. Next, participants were asked to complete a participant information questionnaire (see Appendix C) regarding their basic demographic and contact information, number of years participating in organized sport prior to and including collegiate athletics and the disclosure of recent (within 3 years) lower extremity musculoskeletal injury, known muscle restrictions or weaknesses and injury prevention or “prehab” programs. Height and weight measurements were then obtained for each participant and recorded in centimeters and kilograms, respectively. Participants were then instructed on how to perform the single leg glute bridge and isometric wall warrior and were allowed to practice the exercises until they felt confident in doing so and the researcher observed proper form and effort.

Session 2 and 3 were randomized for each participant (see Figure 1). Session 2 began with the application of electromyography (EMG) surface electrodes to the gluteus medius of the dominant limb following cleansing and abrading of the skin in the electrode region. Participants were then asked to complete a 5-minute bike warm-up (Ergomedic 828 E; Monark Exercise AB, Vansbro, Sweden) and were instructed to maintain intensity between 50-60 revolutions per minute (RPMs) with 1 kilogram resistance. After the bike warm-up was completed, the dominant gluteus medius maximal voluntary isometric contraction (MVIC%) of each participant was then recorded with the participant in a side-lying position on a treatment table with a researcher (certified and licensed athletic trainer) resisting the force from the participant's abducted, slightly extended and externally rotated dominant leg. At this time the participant was instructed to push maximally for 3 trials of 3 seconds against the researcher's hands which were placed over the distal lateral femur above the knee and distal 1/3 of the lower leg. The three trials were separated by 5-second rest periods and mean peak of the three trials was recorded as their gluteus medius MVIC%. Following this measurement, participants were instructed to wait for a 30-minute time period in order to eliminate any possible potentiation effects from maximal contractions during the MVIC% recording. During this time, the participants were asked to remain in a seated and relaxed position. Following the 30-minute rest period, EMG data of the dominant gluteus medius mean, peak and time to peak muscle activation were recorded for the baseline performance task of single leg glute bridge (SLB).

The SLB was performed while wearing the same pair of athletic shoes as all previous and future sessions, on the floor of the laboratory with a yoga mat and no external weights. Participants were instructed to lay in a supine hook-lying position with the dominant leg flexed at the knee and hip with the foot in a closed chain position flat on the ground. The uninvolved leg remained in an open chain position, flexed at 90 degrees at the knee and hip throughout the motion. The researcher then asked the participant to raise their hips off the ground and to maintain an even hip raise with both “hip bones” (anterior superior iliac crests) in line and parallel to the ground. The researcher made the analogy that if someone were to place a broomstick across their hips, the broom would not lean one way or the other but be parallel to the ground. The researcher asked that the participants perform the SLB with good form and to the best of their capabilities. The SLB was performed for 1 set of 3 repetitions to a metronome set to 60 beats per minute.

Sessions 2 and 3 consisted of identical procedures however during session 3, once the 30-minute rest period was complete, participants were then instructed to perform the PAP protocol prior to the performance task exercise (SLB). The PAP protocol pre-stimulus contraction exercise chosen for the present study was the isometric wall warrior (IWW). Participants were asked to stand parallel to a wall in the exercise science laboratory and asked to enter an “athletic stance” with knees and trunk slightly flexed, then isometrically contract by pushing their non-dominant leg into abduction against the wall for 3 sets of 10 seconds with 5-second rest intervals. The IWW is performed with the non-dominant leg slightly raised 1 inch minimum off of the ground, with only the non-dominant hip, thigh, knee, lower leg and foot in contact with the wall. All participants were instructed to create the main point of contact pressure between their knee and the wall and to not use their torso or upper body to contribute to the force against the wall. A piece of floor tape was placed on the wall indicating a 1-inch distance from the ground where the participant’s foot should be raised above. Immediately following the 3 sets of the IWW, a new timer began, and each participant then performed the SLB at a time interval of 10 seconds following the cessation of the last IWW.

Data Processing

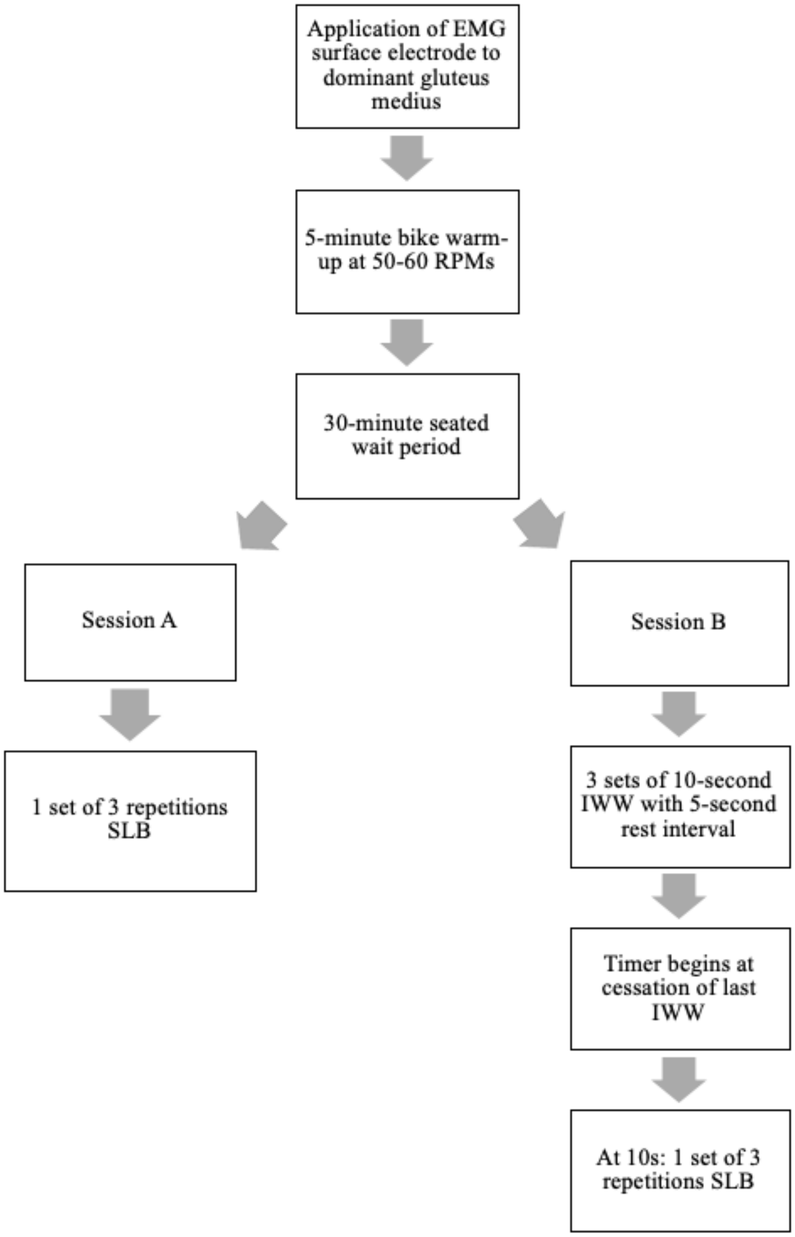
Surface EMG (sEMG) data was collected at 1926 Hz through EMGworks acquisition software (Delsys Inc., Natuck, MA). Onset and offset times of muscle activity were determined without normalization to time by visually identifying the time when sEMG had a phasic increase in activation above baseline. Signal processing was accomplished through EMGworks Analysis software (Delsys Inc., Natuck, MA). Initially, data was filtered with a 2nd order Butterworth band-pass filter at 20 Hz and 450 Hz. A root-mean-square algorithm with a 125ms window was then applied to the filtered data. Glute bridge data was then normalized to peak MVIC values.

Statistical Analyses

A power analysis was performed, and it was determined that a minimal of 8 participants were needed to conduct the study (G*Power 3.1.9.7, Kiel, Germany). All statistical analyses were performed via Statistical Package for the Social Sciences (SPSS Version 28.0, IBM). A one-way repeated measures ANOVA was used to compare normalized peak, normalized mean, and TTP scores of the SLB between the sessions. No post-hoc analyses were performed on the data due to lack of significance in the model.

Figure 1

Overview of Experimental Protocol for Electromyography Sessions A and B



Note. RPMs= revolutions per minute SLB= single leg glute bridge, IWW= isometric wall warrior

CHAPTER IV

RESULTS

The population sample consisted of 10 female collegiate soccer, track, and cross-country athletes actively participating in sport. Descriptive characteristics of participants can be found in Table 1. A one-way repeated measures ANOVA revealed that SLB peak muscle activity, mean muscle activity, and TTP values were not significantly different between the sessions, $F(3, 7) = 0.54$, $p = .67$. Mean and standard deviation of baseline and postactivation potentiation protocols are reported in Table 2.

Table 1.
Descriptive Characteristics of Participants (N=10)

Variable	*M* *SD*
Age (years)	20.2 ± 1.81
Height (cm)	165.01 ± 6.03
Body mass (kg)	60.87 ± 5.64
Collegiate sport participation	SOC (*n* = 6), XC (*n* = 1) TRK (*n* = 3)
NCAA experience (years)	2.6 ± 1.58
Total sport experience (years)	11.8 ± 2.74

Note. SOC= soccer, XC= cross country, TRK= track sprinter, triple jumper and longer jumper. Total sport experience includes club, high school and children's leagues.

Table 2.
Normalized Peak, Mean, and Time to Peak Muscle Activation (N=10)

	SLB	PAP+SLB
	M *SD*	*M* *SD*
Peak	.50 ± .35	.53 ± .22
Mean	.20 ± .14	.22 ± .10
TTP (seconds)	.73 ± .13	.69 ± .14

Note. TTP= time to peak, SLB= baseline single leg glute bridge, PAP+SLB= single leg glute bridge performed 10s after the PAP protocol.

Table 3.

Participant Case Studies of Normalized Peak, Mean, and Time to Peak Muscle Activation (N=10)

	Peak		Mean		TTP	
Participant	SLB	PAP+SLB	SLB	PAP+SLB	SLB	PAP+SLB
1	.56	.53	.25	.22	.64	.50
2	.34	.41	.13	.17	.66	.66
3	.11	.37	.06	.18	.91	1.02
4	.66	.58	.29	.22	.66	.69
5	.40	.77	.20	.34	.46	.71
6	1.00	.90	.35	.36	.79	.54
7	.23	.25	.08	.10	.77	.79
8	.42	.32	.14	.14	.71	.62
9	.14	.36	.05	.13	.87	.64
10	1.14	.79	.47	.34	.79	.73

Note. TTP= time to peak, SLB= baseline single leg glute bridge, PAP+SLB= single leg glute bridge performed 10s after the PAP protocol.

CHAPTER V

DISCUSSION

The purpose of this study was to investigate the effects of postactivation potentiation (PAP) on the activation of a lower-extremity stabilizer muscle (gluteus medius) in female division 1 collegiate athletes when performing an integrative rehabilitation exercise. Throughout the literature, PAP and postactivation performance enhancement (PAPE) studies are most often conducted within the strength and conditioning setting and are applied to larger muscle groups and power movements such as squats and vertical jumps. To our knowledge, this was the first study to examine the effects of a PAP protocol in the collegiate athlete rehabilitation setting and specifically targeting a lower-extremity hip stabilizer muscle. Although the current study did not reveal statistically significant findings, a consistent increase in mean (.20 ± .14 and .22 ± .10) and peak (.50 ± .35 and .53 ± .22) muscle activation, and a decrease in time to peak (.73 s ± .13 and .69 s ± .14s) was observed in the PAP protocol when compared to the baseline SLB protocol, respectively. Case summaries revealed that changes in single leg glute bridge (SLB) muscle activation from baseline to post-PAP SLB protocol among individual participants ranged from a 35% decrease to a 37% increase in peak, 13% decrease to 14% increase in mean, and .25 seconds increase or decrease in time to peak (TTP) muscle activation. This demonstrates the high level of variability in response to the potentiation protocol and further promotes the need for individualized prescription parameters.

The inconsistency and lack of standardized prescription parameters for PAP and PAPE protocols is greatly emphasized within recent literature, specifically regarding rest interval between pre-conditioning stimulus and performance task. Despite this discrepancy, commonly referenced physiological time courses of PAP (0-28 s) was mimicked while attempting to translate the concept of potentiation from larger power muscles (rectus femoris, gluteus maximus) to a stabilizer muscle such as the gluteus medius in the present study. Although rest interval is the most highly debated prescription parameter, evidence exists suggesting age, training status, gender, type II muscle fiber composition, and pre-conditioning stimulus may influence the presence of potentiation for some individuals.

Pre-conditioning stimulus contraction is controversial however, a concentric contraction appears to produce the best results in larger muscle groups. In the present study, the isometric wall warrior (IWW) was chosen for the ease of use and the ability to successfully activate the gluteus medius quickly and efficiently. The goal when prescribing a pre-conditioning stimulus is to optimize the “window of opportunity” in which fatigue is lowest and potentiation is highest. It is possible that the three sets of 10-second repetitions of the IWW may have been too fatiguing and therefore may have produced detrimental effects on some of the participants. The high degree of variability associated with mechanisms of fatigue (Twist & Highton, 2012) and the large individual variability response to the PAP session make it plausible that fatigue may be a factor.

Additionally, when choosing a performance task, one must recognize that there is a fixed amount by which a muscle can increase activation compared to baseline measures. In other words, if the performance task chosen already induced high levels of muscular activation when performed on baseline without a potentiation protocol, there is only so much potential for improvement once a potentiation protocol is applied. Noting this concept, it is possible that the SLB was already greatly activating the gluteus medius therefore, the increase in activation following the IWW PAP protocol did not elicit as great of an effect as it would have in a performance task with lower baseline muscle activation values.

The most successful potentiation protocols appear to be those that are highly individualized and may even consist of self-selected rest intervals. In the present study, all participants were prescribed the same protocol parameters with a standardized warm-up, pre-conditioning stimulus (IWW), performance task (SLB) and rest interval (10s). This standardization serves as a great control for experimental purposes however, it does not allow for individualization of the PAP protocol as the participants displayed variation in sport (distance runner n=1, sprinter/triple jumper n=3, soccer player n=6), body frame, injury history and potentially in basal level of strength as this was not tested prior to the study other than obtaining MVIC% of gluteus medius. Age, gender, and NCAA Division l athlete status were all controlled for in efforts to eliminate the variation in PAP effects that these patient characteristics have displayed in past studies.

Muscle imbalances (underactivity or overactivity) were not assessed prior to the study, nor did this serve as exclusion criteria. A potential purpose of prescribing a PAP protocol would be for the rehabilitation of muscular imbalances or synergistic dominance. Without identifying muscle imbalances in the present population, basal muscle activation and the effects of PAP may vary in those individuals in which muscular imbalance was undetected or not diagnostically confirmed. It may be of importance to note that within the original data set (see Figure 1) there is a larger standard deviation (SD) for baseline peak and mean muscle activation as well as the decreasing of the SD for the same variables following the PAP protocol. This could be a representation of different basal levels of strengths due to muscular imbalances or history of injury.

Interestingly, when two participants are separated from the population and placed in a “chronic injury” group (*n* = 2) due to identifying diagnosed chronic conditions of the knee (patellar tendonitis in participant 6; patellofemoral pain syndrome and chondromalacia in participant 4) versus the remaining population uninjured (*n* = 8), there are notable differences in baseline and PAP outcome measures. Baseline SLB peak muscle activation in the chronic injury group is nearly twice that of the uninjured group (.83 ± .25 and .42 ± .33, respectively). The chronic injury group demonstrates a favorable decrease in time to peak muscle activation (.73 s ± .09 to .61 s ± .10) compared to the uninjured group (.73 s ± .14 to .71 s ± .15) however, the chronic injury group decreases in mean and peak muscle activation following the PAP protocol (.83 ± .25 to .74 ± .22). Therefore, the two participants that reported diagnosed chronic conditions of the lower extremity had greater baseline SLB contractions of the gluteus medius and were not potentiated but did in fact reach their peak level of activation more quickly following the IWW PAP protocol. This could lead one to conclude the IWW PAP protocol was too fatiguing for these chronically injured individuals in particular, however, their significantly higher baseline SLB mean and peak values raise questions regarding the presence of muscular imbalances, contribution of muscular versus neural contributors and effective prescription of PAP to chronically injured athletic populations.

A major limitation to the present study is the previously discussed inconsistency in PAP prescription parameters as well as the lack of agreement on physiological mechanisms causing this increase in muscle activation. Multiple factors have been proposed to enhance the production and attenuation of PAP and PAPE from both neural and muscular contributors. Within the scope of the current study, no testing was conducted to confirm or deny the presence of true PAP via myosin regulatory light chain phosphorylation from a molecular standpoint. Another limitation is the assumption of maximal effort during all exercises from all participants throughout their sessions. Participants were not asked to refrain from competition, training, or lower-extremity lift sessions throughout the study in efforts to mimic "real-life" collegiate athlete schedules, level of muscle soreness and fatigue. Throughout the study, two participants reported dominant leg hamstring muscle spasm during the study between repetitions of the SLB and stated they had been sore that day. General muscle soreness and fatigue could have affected the level of effort and therefore muscle contraction observed in some sessions.

Continuous research is warranted to identify preferred prescription parameters for PAP and PAPE in a classic strength and conditioning setting to improve upon the translation of those parameters to the rehabilitation setting. Future research on PAP in the collegiate athletic rehabilitation setting should prioritize the prescription of an effective but non-fatiguing pre-conditioning stimulus as well as a performance task that allows for a larger magnitude of improvement in muscle activation outcomes. The pre-conditioning stimulus contraction may need to be modified to increase or decrease the muscle activation to find the right balance of muscular potentiation and fatigue when the performance task begins based on the individuals in the study population. The outcome measures for the present study were mean, peak and time to peak muscle activation however, for a more comprehensive representation of the amount of muscle activity within the target muscle, area under the curve may be a more beneficial statistical analysis of the effectiveness of PAP in future studies. Conducting a similar study of PAP in a rehabilitation setting involving participants with diagnosed and confirmed muscular imbalances could offer further insight to the true nature of their baseline muscular activation values and to better identify the optimal “window of opportunity” for potentiation in these individuals. Further studies could investigate the effect of PAP or PAPE in successive sets and repetitions of various exercise throughout a mock rehabilitation session as it has been hypothesized that successive contractions would potentiate the muscle even further.

In conclusion, the primary findings of the present study are 1) in a population of 10 female collegiate athletes, a postactivation potentiation protocol consisting of an isometric pre-conditioning stimulus and a gluteus medius rehabilitation exercise performance task showed no statistically significant differences in peak, mean and time to peak muscle activation in the first 10 seconds following pre-stimulus contraction and 2) isometric wall warrior and single leg glute bridge exercises appear to successfully target activation of the gluteus medius when performed in the dominant leg. Despite not achieving a level of significance, all muscle activation outcome measures revealed favorable trends approaching the original hypothesis as mean, peak and time to peak muscle activation all had improved following the implementation of a PAP protocol. PAP and PAPE are undefined and highly controversial therefore, more research with larger and more controlled populations, prescription parameters and enhanced data analysis is warranted to determine the true applicability of potentiation protocols in the collegiate athlete rehabilitation setting.

Practical Applications

The intended applicability within the current study was to determine the effectiveness of implementing a postactivation potentiation protocol in the collegiate athletic rehabilitation setting by sports medicine clinicians such as athletic trainers and physical therapists. This hypothesis was taken a step further as this was the first study, to our knowledge, that investigated the effect of PAP specifically within a stabilizer muscle. With the primary outcome of the present study being an insignificant yet favorable trend toward improvements in mean, peak and time to peak muscle activation following a PAP protocol within the first 10 seconds following pre-conditioning stimulus, one could conclude there is no harm done to the patient in implementing a PAP protocol for a lower-extremity rehabilitation in collegiate athletics however, the protocol may or may not be effective for that particular individual and could possibly result in fatigue. If a clinician decides to implement a PAP protocol within their rehabilitation session, they should ensure the pre-conditioning stimulus does not cause excessive fatigue prior to performing the remaining exercises. The clinician should also ensure that it is safe for the patient to be attempting a near maximal effort isometric contraction to satisfy the pre-stimulus contraction requirement. This type of contraction may not be safe if the patient is recovering from an acute muscular strain. The present study also concludes the isometric wall warrior and single leg glute bridge are effective exercises for the gluteus medius therefore, clinicians can implement these exercises when attempting to target this muscle for purposes of lower extremity stabilization. Although more research is warranted in the applicability of PAP for a sports medicine clinician, the present study demonstrates potential for expansion on tools clinicians can utilize to enhance muscle activation in efforts to correct muscular imbalances, create injury prevention programs or rehabilitate athletic injuries.

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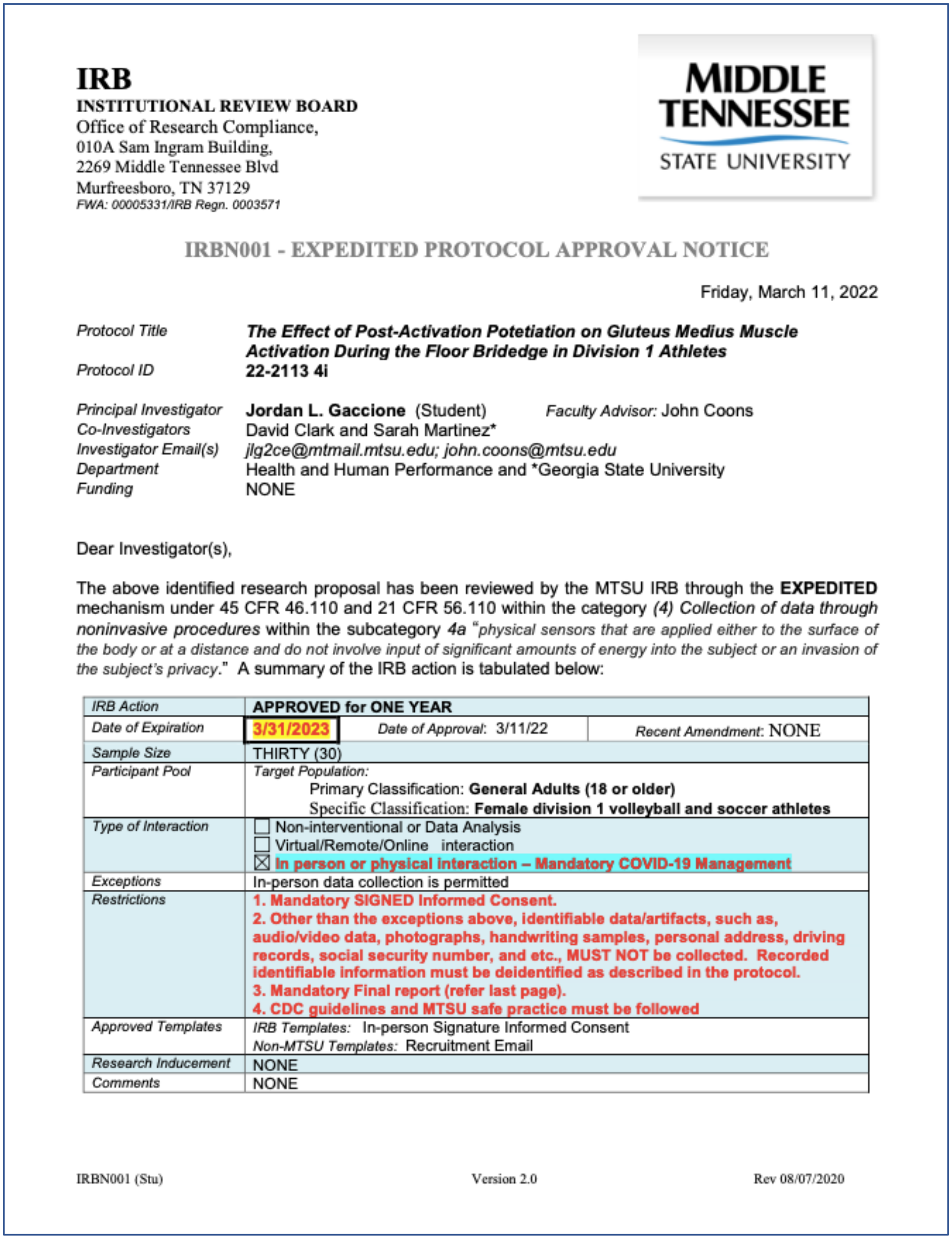
APPENDICES

APPENDIX A: UNIVERSITY INSTITUTIONAL REVIEW BOARD APPROVAL DOCUMENT



IRB
INSTITUTIONAL REVIEW BOARD
Office of Research Compliance,
010A Sam Ingram Building,
2269 Middle Tennessee Blvd
Murfreesboro, TN 37129
FWA: 00005331/IRB Regn. 0003571

MIDDLE TENNESSEE STATE UNIVERSITY

IRBN001 - EXPEDITED PROTOCOL APPROVAL NOTICE

Friday, March 11, 2022

Protocol Title ***The Effect of Post-Activation Potetiation on Gluteus Medius Muscle Activation During the Floor Bridedge in Division 1 Athletes***
Protocol ID **22-2113 4i**

Principal Investigator **Jordan L. Gaccione** (Student) *Faculty Advisor:* John Coons
Co-Investigators David Clark and Sarah Martinez*
Investigator Email(s) *jlg2ce@mtmail.mtsu.edu; john.coons@mtsu.edu*
Department Health and Human Performance and *Georgia State University
Funding NONE

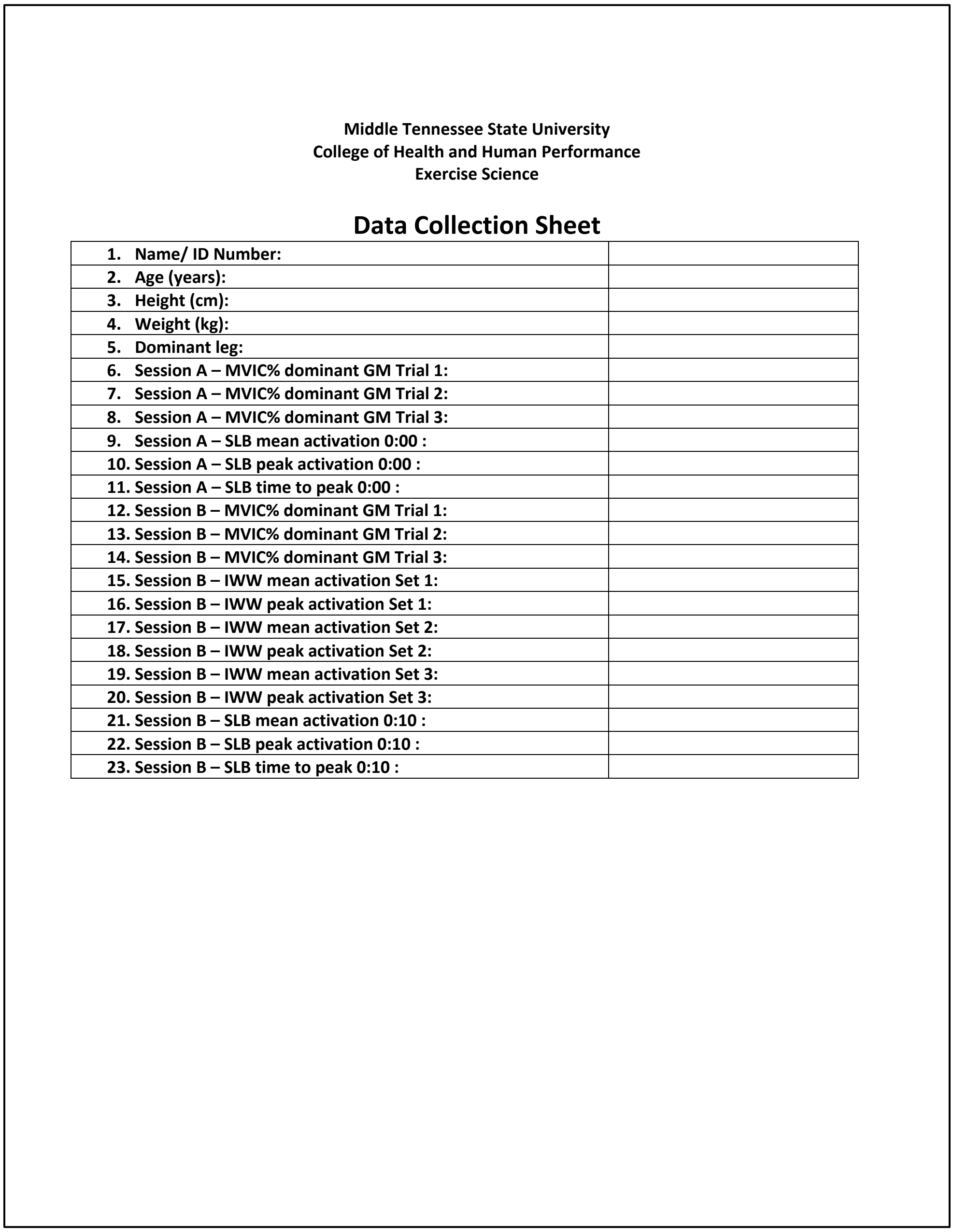
Dear Investigator(s),

The above identified research proposal has been reviewed by the MTSU IRB through the **EXPEDITED** mechanism under 45 CFR 46.110 and 21 CFR 56.110 within the category *(4) Collection of data through noninvasive procedures* within the subcategory *4a* "*physical sensors that are applied either to the surface of the body or at a distance and do not involve input of significant amounts of energy into the subject or an invasion of the subject's privacy*." A summary of the IRB action is tabulated below:

IRB Action	**APPROVED for ONE YEAR**
Date of Expiration	**3/31/2023** *Date of Approval*: 3/11/22 *Recent Amendment*: NONE
Sample Size	THIRTY (30)
Participant Pool	*Target Population:* Primary Classification: **General Adults (18 or older)** Specific Classification: **Female division 1 volleyball and soccer athletes**
Type of Interaction	☐ Non-interventional or Data Analysis ☐ Virtual/Remote/Online interaction ☒ **In person or physical interaction – Mandatory COVID-19 Management**
Exceptions	In-person data collection is permitted
Restrictions	**1. Mandatory SIGNED Informed Consent.** **2. Other than the exceptions above, identifiable data/artifacts, such as, audio/video data, photographs, handwriting samples, personal address, driving records, social security number, and etc., MUST NOT be collected. Recorded identifiable information must be deidentified as described in the protocol.** **3. Mandatory Final report (refer last page).** **4. CDC guidelines and MTSU safe practice must be followed**
Approved Templates	*IRB Templates:* In-person Signature Informed Consent *Non-MTSU Templates:* Recruitment Email
Research Inducement	NONE
Comments	NONE

IRBN001 (Stu) Version 2.0 Rev 08/07/2020

APPENDIX B: DATA COLLECTION FORM

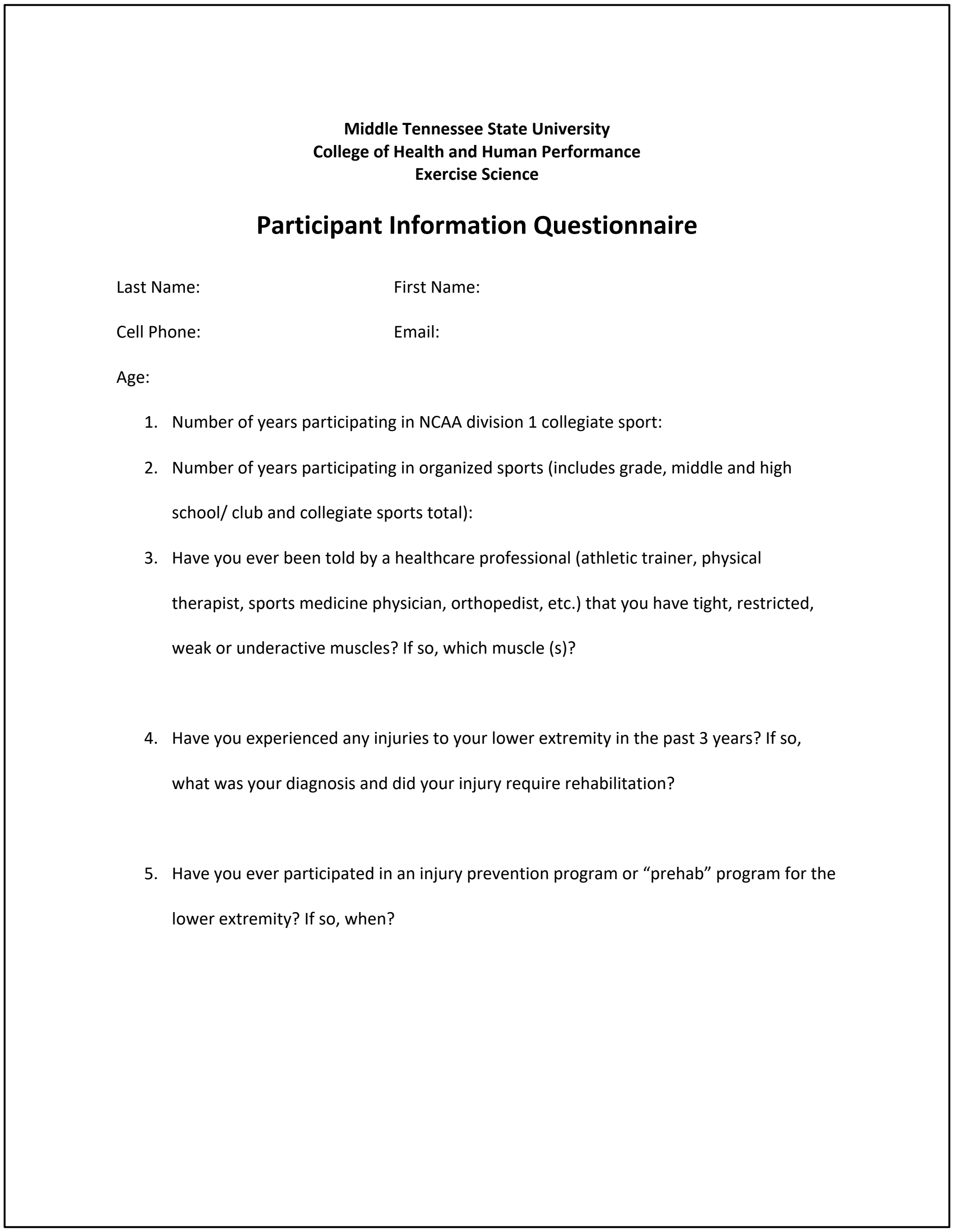


Middle Tennessee State University
College of Health and Human Performance
Exercise Science

Data Collection Sheet

1. Name/ ID Number:	
2. Age (years):	
3. Height (cm):	
4. Weight (kg):	
5. Dominant leg:	
6. Session A – MVIC% dominant GM Trial 1:	
7. Session A – MVIC% dominant GM Trial 2:	
8. Session A – MVIC% dominant GM Trial 3:	
9. Session A – SLB mean activation 0:00 :	
10. Session A – SLB peak activation 0:00 :	
11. Session A – SLB time to peak 0:00 :	
12. Session B – MVIC% dominant GM Trial 1:	
13. Session B – MVIC% dominant GM Trial 2:	
14. Session B – MVIC% dominant GM Trial 3:	
15. Session B – IWW mean activation Set 1:	
16. Session B – IWW peak activation Set 1:	
17. Session B – IWW mean activation Set 2:	
18. Session B – IWW peak activation Set 2:	
19. Session B – IWW mean activation Set 3:	
20. Session B – IWW peak activation Set 3:	
21. Session B – SLB mean activation 0:10 :	
22. Session B – SLB peak activation 0:10 :	
23. Session B – SLB time to peak 0:10 :	

APPENDIX C: PARTICIPANT INFORMATION AND QUESTIONNAIRE FORM



Middle Tennessee State University
College of Health and Human Performance
Exercise Science

Participant Information Questionnaire

Last Name: First Name:

Cell Phone: Email:

Age:

1. Number of years participating in NCAA division 1 collegiate sport:
2. Number of years participating in organized sports (includes grade, middle and high school/ club and collegiate sports total):
3. Have you ever been told by a healthcare professional (athletic trainer, physical therapist, sports medicine physician, orthopedist, etc.) that you have tight, restricted, weak or underactive muscles? If so, which muscle (s)?
4. Have you experienced any injuries to your lower extremity in the past 3 years? If so, what was your diagnosis and did your injury require rehabilitation?
5. Have you ever participated in an injury prevention program or “prehab” program for the lower extremity? If so, when?