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Exploring the Impact of Different Durations of Foam Rolling as a Recovery Technique following Intense Exercise in College-aged Males

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Exploring the Impact of Different Durations of Foam Rolling as a Recovery Technique following Intense Exercise in College-aged Males

By

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APPROVAL OF SUCCESSFUL DEFENSE

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Doctoral Candidate, Connor M. Saker, has successfully defended and made required modifications to the text of the doctoral dissertation for the Ph.D. during the Fall 2022 semester.

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Dedications

This dissertation is dedicated to my parents, Patty and Glenn. You provided Kate, AJ, and I a childhood that was second to none filled with love, compassion, and support. To make that possible you made endless sacrifices of which we never understood their immensity. Now a grown man, a husband, and a father, I truly understand the gravity of those sacrifices made to allow the three of us to grow up happy, healthy, and able to follow our dreams. It was your sacrifices and love that have allowed me to become the man I am today. Were it not for you providing me the opportunity to go to college and pursue my dreams, I would not be here dedicating my dissertation to you both. You are role models for who I strive to be as a human, a spouse, and a parent. Thank you both for everything you have done and continue to do. I am truly blessed to call you my parents.

I love you.

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Abstract

Background: Foam rolling (FR) for recovery from delayed onset muscle soreness (DOMS) and exercise induced muscle damage (EIMD) has received considerable attention because the technique is being a relatively inexpensive and is self-performed. However, there are currently no FR guidelines and the available literature assessing the impact of FR for recovery of muscle soreness is heterogeneous and offers conflicting results. Assessing different FR durations and their impact on recovery may help provide insight to the effectiveness of this technique for recovery from EIMD and DOMS. ***Purpose:*** To explore the impact of two different acute durations of FR for the recovery of vertical jump (VJ), sprint speed (SS), agility, range of motion (ROM), and pain/soreness following high intensity exercise. ***Methods:*** An experimental, randomized cross-over design was used consisting of twelve college-aged males were randomly assigned to a one- or two-minute FR group (EXP) (N = 6 per group) and served as their own control (CON). Participants completed a familiarization and baseline measure session before completing two, 4-session testing weeks (1-week EXP, 1-week CON) separated by a 1-week washout period. Session one employed the EIMD protocol and immediate post exercise measures taken. Sessions 2-4 were 24, 48, and 72 hr. post measures. FR (either 1 or 2-minutes) was completed during the EXP week on each lower extremity muscle group following the immediate post exercise measures, whereas CON did not complete FR. ***Results:*** No significant difference was seen between EXP groups at any time point post exercise for recovery of jump height (F=.007, P=.933), agility (F=.171, P=.681), sprint speed (F=.024, P=.876), ROM (F=.013, P=1.000), or pain/soreness (F=.000, P=.909). ***Conclusion:*** Foam rolling for either 1 or 2-minutes per muscle group immediately post exercise did not significantly aid in recovery of muscle soreness as measured by its impact on performance and non-performance outcomes. Therefore, FR using the protocol applied in this study, in the lower extremities immediately following high-intensity exercise may not be beneficial for recovering from DOMS in college-aged males.

Keywords: Delayed onset muscle soreness, Exercise induced muscle damage, Foam Rolling

CHAPTER I

Introduction

Physically active individuals, whether elite athletes or recreationally active, spend more time in a recovery phase than they do training (Bishop et al., 2008). Recovery is a vital aspect to any training program to ensure the individual is ready for the following training session and/or competition. Following an intense bout of exercise, an individual may experience exercise induced muscle damage (EIMD) that results in delayed onset muscle soreness (DOMS) (Drinkwater et al., 2019). When assessing the impact of EIMD and DOMs on performance, both can severely decrease performance variables such as vertical jump, broad jump, agility, squat repetition, sprint time, and force output (MacDonald et al., 2014; Pearcey et al., 2015; Rey et al., 2017). Although there are many techniques used to promote recovery (Barnett, 2006), there seems to be no 'gold standard' when assessing recovery from EIMD and DOMS. Additionally, some techniques can be costly and/or require additional personnel to perform. For the average, recreationally active individual this may leave few techniques to choose from.

A cost effective, self-performed modality of recovery that has received considerable attention in the past decade is that of self-myofascial release (SMR) using a foam roller (FR). SMR is an intensive self-treatment that mimics manual therapy techniques aiming to combat dysfunctions of both the skeletal muscle and connective tissue (Krause et al., 2017). The SMR using a FR technique requires individuals to use their bodyweight while rolling a specific body region over a dense foam cylinder placing pressure on the tissue (Aboodarda et al., 2015). Though the exact mechanism(s) associated with the specific use of FR to promote MR are unknown, a proposed mechanism is that it may aid in recovery through the restoration of connective tissue disrupted during exercise (MacDoanld et al., 2014). Through FR, a decrease in pain perception/soreness (D'Amico et al., 2020; Pearcey et al., 2015; Rey et al., 2017; Laffaye et al., 2019) may allow for an increase in range of motion (ROM) (Phillips et al., 2018; MacDonald et al., 2014) and greater utilization of the series elastic component

(SEC) and stretch reflex. Though this may be a viable mechanism, past research assessing the overall impact of using a FR for recovery from EIMD and DOMs is inconclusive (Hendricks et al., 2019; Wiewelhove et al., 2019).

Research assessing SMR using a FR as a recovery tool for DOMS is still inconclusive. When assessing recovery, studies have utilized performance-based measures including vertical jump (VJ)/ countermovement jump (CMJ), agility, sprint speed (ss) and force output (MacDonald et al., 2014; Drinkwater et al., 2019; Romero-Moraleda et al., 2019; Rey et al., 2017; D'Amico et al., 2019, 2020; Laffaye et al., 2019; Pearcey et al., 2015). However, the findings for each of the variables have showed varying results. Other non-performance-based variables assessed include muscle soreness and pain perception (PP) with studies showing FR's ability to decrease both variables (Macdonald et al., 2014; D'Amico et al., 2020; Laffaye et al., 2019; Rey et al., 2017; Drinkwater et al., 2019). While further research is warranted to fully understand the effects of SMR using FR for recovery, there are deficiencies within the current literature that need to be addressed to provide a direction for future research endeavors.

Gaps in the Literature

Current literature assessing the impact of FR on recovery is very heterogeneous with a common difference amongst studies being the duration in which FR is performed. Durations have ranged from as little as 45-seconds per muscle group (Pearcey et al., 2015) up to 5-minutes per muscle group (Romero-Moraleda et al., 2019). Yet, there seems to be a dearth of literature that has directly assessed the impact of two different durations of SMR using a FR and their impact on recovery. Assessing whether there is a duration-dose response will provide recreationally active individuals, athletes, and practitioners a better understanding as to whether SMR using a FR is beneficial for recovery as well as the appropriate duration one should FR for recovery. Additionally, there seems to be no clear understanding as to the best type of FR to use, if there is a specific amount of pressure that should be applied to the FR, and how frequently an individual should FR when recovering.

Purpose of the Study

The purpose of this experimental study was to explore the impact of two different durations of SMR using a FR as a technique for recovery in recreationally active, college-aged males. The independent variable of foam rolling requires individuals to utilize their own bodyweight to apply pressure to the musculature while foam rolling the muscle from proximal to distal and then distal to proximal for a specified duration. The dependent variable, recovery, is defined as the degree to which performance measures (vertical jump, agility, and sprint speed), ROM, and pain perception/soreness return to baseline values after performing a foam rolling SMR protocol following the completion of an exercise designed to elicit EIMD and DOMS.

Research Questions

1. Is there a difference in vertical jump performance based upon the performance of different durations of foam rolling?
2. If there a difference in agility performance based upon the performance of different durations of foam rolling?
3. Is there a difference in sprint speed based upon the performance of different durations of foam rolling?
4. Is there a difference in range of motion based upon the performance of different durations of foam rolling?
5. Is there a difference in pain perception/soreness based upon the performance of different durations of foam rolling?

Hypothesis

H_o1. There will be no difference in recovery of vertical jump performance following the completion of two different acute durations of foam rolling.

H_a1. There will be an increase in recovery of vertical jump performance following the completion of two different acute durations of foam rolling.

H_o2. There will be no difference in recovery of agility performance following the completion of two different acute durations of foam rolling.

H_a2. There will be an increase in recovery of agility performance following the completion of two different acute durations of foam rolling.

H_o3. There will be no difference in recovery of sprint speed performance following the completion of two different acute durations of foam rolling.

H_a3. There will be an increase in recovery of sprint speed performance following the completion of two different acute durations of foam rolling.

H_o4. There will be no difference in recovery of knee range of motion following the completion of two different acute durations of foam rolling.

H_a4. There will be an increase in recovery of knee range of motion following the completion of two different acute durations of foam rolling.

H_o5. There will be no difference in recovery of pain perception/soreness following the completion of two different acute durations of foam rolling.

H_a5. There will be an increase in recovery of pain perception/soreness following the completion of two different acute durations of foam rolling.

CHAPTER II

Review of Literature

The focus of this section is to provide a brief explanation of the symptoms associated with EIMD/DOMS. Exercise-induced muscle damage is a common result of an intense bout of exercise that is characterized by muscular soreness, swelling, a reduction in muscular strength, and a decrease in ROM (Torres et al., 2012). In addition, this section will discuss some of the proposed mechanism behind DOMS. While seeking to understand the mechanisms leading to EIMD and DOMS were not the focus of this study, it is important to discuss some of the well-known causes and symptoms.

Exercise Induced Muscle Damage and Delayed Onset Muscle Soreness

DOMS is a condition experienced by almost every athlete and individual who partakes in routine exercise or physical activity. Though it is well understood that exercise can aid in sport performance by increasing lean body mass, decreasing fat mass, and increasing cardiorespiratory fitness (Vo2), the training utilized to elicit these desired adaptations can cause EIMD that results in DOMS. DOMS has been defined as “the sensation of discomfort or pain in the skeletal muscles that occurs following unaccustomed muscular exertion” (Armstrong, 1984). DOMS is typically experienced by individuals, whether competitive athletes or recreationally active individuals, who are returning to training following reduced activity (Cheung et al., 2003) or by individuals who partake in intense bouts of exercise. The degree to which DOMS impacts an individual can vary depending on training variables such as the intensity and duration of activity (Cheung et al., 2003). Typically, DOMS increases within the first 24 hours post exercise and peaks anywhere from 48 – 72 hours post exercise. It is characterized by symptoms such as pain, swelling, and decreases in ROM (Armstrong, 1984). Although DOMS is a side effect of high intensity training, little is known about the mechanism(s) responsible for DOMS. To date, there have been various proposed mechanisms that try to physiologically explain the cause of DOMS. However, these proposed mechanisms are speculative with some having already been disregarded leaving the exact mechanism to still be determined.

Proposed DOMS Mechanisms

The mechanism responsible for DOMS is still a widely debated and researched topic. There are a total of six theories within the literature that discuss the potential cause of DOMS including the spasm, lactic acid, muscle damage, inflammation, enzyme efflux, and connective tissue theories. Though the purpose of the current study is not to determine the mechanism(s) of DOMS, it is important that each of these proposed theories are discussed as they offer a lens to potentially understand the mechanism(s) that may be responsible for the cause of DOMS.

Spasm Theory

The Spasm Theory was first proposed by De Vries (1961). It centers on the belief that the pain associated with DOMS is caused by ischemia resulting from exercise that releases a pain substance into the muscle stimulating nerve endings (de Vries, 1966). When the nerve endings are stimulated, they result in repeated activation of the motor units (spasms) causing the ischemia to be prolonged thus repeating the process initiating a “vicious cycle” (De Vries, 1966). However, some investigations have assessed this idea and shown that there were no increases in muscle activity (spasms) while pain was present (Abraham, 1977; Newham, Mills, Quigley, & Edwards, 1983; Talag, 1973). As a result of inconsistent findings this theory has mostly been rejected.

Lactic Acid Theory

The Lactic Acid Theory has mostly been disregarded as a possible cause for DOMS. Lactic acid (LA) is a byproduct of metabolism that is continuously produced with greater production and accumulation seen during high intensity bouts of exercise. It was believed that this metabolic waste is toxic to the working musculature and causes pain to the site of accumulation (Armstrong, 1984). However, blood lactate typically returns to pre-exercise levels within 1-hr following exercise and symptoms of DOMS are typically within 24 hr post exercise. Also, if lactic acid were the cause of DOMS then it would make sense that symptoms would be experienced throughout the entire body rather than localized to the musculature used during activity. When assessing this theory Amussen (1956) found that while substantial LA accumulation was seen following a bout of exercise, the amount of pain associated with it was fairly small. Schwane, Watrous, Johnson, & Armstrong, (1983) also found that when comparing level surface running to downhill running, downhill runners experienced lower LA accumulation and greater DOMS, while level surface runners saw greater LA accumulation and less DOMS. Therefore, though lactic acid is produced during physical activity, it does not appear to serve as a sound mechanism for DOMS.

Muscle Damage Theory

The Muscle Damage Theory indicates that pain associated with DOMS is caused by a rupture within the muscle (Hough, 1900). Specifically, it is believed that the disruption comes from within the z-lines of the sarcomere following a bout of eccentric exercise (Friden et al., 1984; Newham, Jones, & Edwards, 1983; Armstrong, 1983). During an eccentric contraction the tension curve is greater while the number of active motor units is decreased allowing the muscle to elongate. As a result, the structure of the z-lines, specifically those within type II fibers, is disrupted (Cheung et al., 2003). Schwane, Johnson, Vandenakker, & Armstrong, (1983) found that individuals who completed a downhill running protocol, which places greater strain on the muscle during the lengthening (eccentric) phase, saw a greater degree of DOMS when compared to individuals running on level ground. This theory appears plausible as greater DOMS has been seen following exercise that places greater emphasis on eccentric contractions (Cheung et al. 2003). A method of assessing muscle damage is through creatine kinase (CK) as has been known to be an increased enzyme following exercise (Callegari et al., 2017). When Newham, Jones, & Edwards, (1983) assessed CK levels following a stepping exercise, it was found that while a number of the participants saw an increase in CK within 24 hours post exercise, others did not experience elevated CK until 4-5 days post exercise. Knowing that DOMS is dominant between 24 and 72 hours post exercise, CK levels alone cannot support this theory.

Inflammation Theory

Inflammation is a natural response by the body to injury and can either be acute or chronic in duration. The main purpose of inflammation is to aid in the healing of the injured site. When muscle is broken down, like seen following a bout of exercise, it triggers the release of proteolytic enzymes that begin breaking down protein and lipids (Cheung et al., 2003). As a result, neutrophils and monocytes are attracted to the injured area (Smith, L., 1991), which causes both swelling and increased pressure (Friden, Sfakianos, and Hargens, A., 1986). It is thought that the increased pressure may stimulate group IV sensory neurons ultimately resulting in a degree of pain (Friden et al., 1986). Following this idea, it would seem that a greater degree of damage would cause more inflammation and result in greater pain. However, a study by Schwane, Johnson, Vandenakker, and Armstrong, (1983) did not see an increase in swelling or neutrophil accumulation following downhill running even though soreness was present. Similarly, Bobbert et al., (1986) also did not see an increase in inflammation while pain was present following exercise. It was believed that macrophages are largely present in the area between 24 and 48 hours following damage and may relieve the pain by sensitizing the nerve endings (Smith, 1991). Therefore, due to inconsistent findings, it still remains unclear as to whether or not inflammation serves as a viable mechanism to explain DOMS.

Enzyme Efflux Theory

The Enzyme theory, like some of the previously discussed theories, centers on stimulation of nerve endings that result in pain. In this theory it is believed that calcium accumulation is a result of damaged muscle (Armstrong, 1984). Although calcium is usually housed within the sarcoplasmic reticulum (SR), it is believed that accumulation of calcium happens outside of the SR when muscle is damaged. Adenosine triphosphate (ATP) regeneration is then slowed causing an inability of calcium to get back into the SR as ATP is needed for this process to occur (Cheung et al., 2003). Calcium also increases levels of proteases and phospholipases causing further injury to the sarcolemma such as the z-lines (Armstrong, 1984). When this protein is broken down it then stimulates nerve endings resulting in pain (Cheung et al., 2003).

Connective Tissue

The Connective Tissue Theory was proposed by Hough (1900). It focuses on DOMS resulting from a disruption in the connective tissue elements of the muscle, particularly that of surrounding sheaths of the individual bundles of muscle fibers (Cheung et al., 2003). To support this idea, studies by Asmussen et al., (1956), as well as Komi et al., (1972), also believe that DOMS may be a result of the disruptions to contractile components within the connective tissue. When it comes to the muscle fibers encapsulated by the connective tissue, there is a difference in composition of type I (slow twitch) and type II (fast twitch) muscle fiber. Specifically, type II fibers do not exhibit as strong of a connective tissue as that of type I fibers. As a result, damage from being over stretched is much more likely for type II fibers than that of type I fibers (Stauber, W. M., 1989). Stauber (1989) also speculated that considering pain receptors are housed within the connective tissue between fibers, then pain may appear when either the connective tissue alone, or a combination of the connective tissue and fibers, are damaged. To assess damage of the connective tissue, measures of hydroxyproline, a known marker of connective tissue (specifically collagen) degradation, can be measured within urine. Abraham (1977) found that individuals who exhibited muscle soreness had high amounts of hydroxyproline following an eccentric exercise. This idea seems rational considering DOMS is experienced to greater degrees following eccentric (lengthening) muscle contractions than concentric or isometric contractions. However, like many of the other proposed DOMS theories, this theory has not been fully supported and therefore requires additional research.

Although many theories have proposed a potential mechanism(s) responsible for DOMS, no single theory has been agreed upon. In the literature it has also been proposed that a combination of multiple mechanisms may be responsible for DOMS rather than one single cause. With the exact mechanism(s) of DOMS not fully understood, it has been challenging for professionals and recreationally active individuals to find the most efficient way of recovering from DOMS. Although many methods have been assessed, no single one has shown to be more effective than the others.

Fascia

The term 'fascia' has been defined and explained in vary ways depending on the scope of research in which it is being assessed or referred to (Fede et al., 2021). As a result, there is no single agreed upon definition to describe this anatomical structure. Fascia seemingly appears as a continuous connective web spanning the entire body from head to toe. Depending on the area being assessed it is comprised of different layers all of which serve different purposes. Within certain regions of the body these layers are noticeably separate, while in others they seemingly combine to become one layer (Stecco et al., 2009). Although more research is still needed to better understand fascia and be able to provide a single definition, it is important to briefly discuss what is currently known about fascia and its layers.

Fascia is described as being composed of two different layers with the first being the superficial layer (SF). This first layer serves as a barrier to what is referred to as the superficial adipose tissue (SAT) and the deep adipose tissue (DAT) (Lancerotto et al., 2011; Stecco et al., 2013). The SF is shaped by the subcutaneous adipose tissues (SAT and DAT) and the septa, which holds this three-dimensional component together (Stecco et al., 2013). This layer is composed of loosely packed collagen fibers as well as elastic fibers that are woven together (Lancerotto et al., 2011; Stecco et al., 2011; Stecco et al., 2013). Due to the elastic fibers found within, the SF has the ability to stretch when under stress. It also serves as a structural support for vital cardiovascular components such as veins (Stecco et al., 2011; Stecco et al., 2013) and arteries of the hypodermal plexus (Stecco et al., 2013), as well as nervous fibers (Stecco et al., 2011). In the areas where these structures are seen the SF will split into two layers providing a sheath to surround them.

The deep fascial (DF) layer lies below the DAT just above the muscle and is separated by a layer of loose connective tissue that possesses a gel-like substance allowing the muscles to slide during movement (Stecco et al., 2008). In the limbs, the fascia is composed of two to three layers of collagen fibers that are separated by the connective tissue (Stecco et al., 2009; Benetazzo et al., 2011). Although fascia surrounds the entire muscle bundle posing as a protective sheath, the epimysium separates the fascia from having direct contact with the muscle itself. An abundance of nerves and free nerve endings have also been identified in the deep fascia of the upper limbs (Stecco et al., 2007). Both Ruffini and Pacini corpuscles are present within the DF, as well as muscle spindles. Ruffini corpuscles are receptors said to respond to long-term pressure exhibited by slow, deep massage techniques (Schliep, 2003). Pacini corpuscles differ in that they change more rapidly to pressure such as high velocity thrust manipulations and techniques including vibration (Schleip, 2003). Muscle spindles are proprioceptive organs that are sensitive to the rate and magnitude of stretch. Yahai et al., (1992) found that both Ruffini and Pacini receptors were also located within the fascia of the thoracolumbar. The discovering of nerves and free nerve endings within the DF signify that fascia may serve a much larger function than simply holding muscles and organs in place.

From the findings discussed it is believed that fascia is directly involved with the autonomic nervous system (Schleip, 2003; Stecco et al., 2008; Fede et al., 2021). With the high involvement of free nerve endings and receptors within the fascia it is possible that SMR using a FR may decrease pain associated with DOMS through inhibition of these receptors. Though the purpose of this study is not to directly assess the fascia itself, it is important to recognize that nerve and nerve endings are abundantly seen throughout the fascia. Considering that pain is a common symptom of DOMS and that SMR using a FR is known to decreases pain/soreness, these findings may aid in understanding the potential mechanism(s) for SMR using a FR.

Myofascial Release

The term 'myofascial release' (MR) is regarded as an umbrella term due to the various techniques by which it can be performed (McKenney et al., 2013). During direct myofascial release pressure is applied to the area of concern by a practitioner's hands, elbows, or additional tools. The objective of the undulating pressure is to change the overall structure of the myofascia by either stretching it, lengthening the fascia all together, or mobilizing adhesive tissue (Shah et al., 2012). Though MR has been used in treating a wide array of conditions (Shah et al., 2012), it requires a trained professional to administer the treatment. The feasibility of receiving direct MR as a recovery technique to address DOMS is often limited after general physical activity, unless the individual either pays for the treatment or is part of a program (sports team, organizations, etc.) and has immediate access to a practitioner who is trained in MR. For recreationally active individuals, receiving this form of treatment can be both costly and require additional time and resources. With MR being a passive treatment requiring the assistance of a trained professional, a self-administered modified version of the technique has gained greater attention in practice over the past decade thereby eliminating the need for assistance.

Self-myofascial Release

Self-myofascial release (SMR) encompasses the same principals as that of MR. However, SMR relies on the individual to utilize a piece of equipment or object to manually roll over the targeted area using their own bodyweight to administer the force (Aboodarda et al., 2015). Various tools, like that of a small ball (i.e., tennis, golf, lacrosse), have been effectively utilized to perform SMR as their size makes them much more versatile and able to focus on specified spots while also working in a three-dimensional fashion (Kalichman et la., 2017). Grieve et al., (2014) investigated the immediate impact of SMR using a tennis ball on hamstring and lumbar spine flexibility. Applying as much pressure as possible, subjects rolled a tennis ball from the head of the metatarsals to the heel while dominantly focusing on rolling over the medial arch for two minutes. The researchers found that the two-minute tennis ball SMR increased flexibility as assessed through a sit-and-reach test in the thirty-three participants tested. Another tool used for SMR is that of a roller massager (RM). A RM is described as a small, stick-like piece of plastic that is wrapped with a thin layer of foam (Kalichman et al., 2017). Using a RM, Jay et al., (2014) found that performing a 10-minute RM treatment 48 hours after the completion of an exercise designed to elicit DOMS decreased perceived pain and increased pressure pain threshold. Additionally, Halperin et al., (2014) found that the use of a RM helped to increase maximal force output when compared to traditional static stretching. While the popularity and use of SMR has grown exponentially, there are few studies that utilize both a ball or roller massage to administer the SMR and assesses its impact on dynamic movements.

Jump Height

SMR has been performed using various tools including those previously discussed. However, a common tool used to assess the impact of SMR, especially that of SMR on recovery from EIMD and DOMS, is a foam roller (FR). Within a practical setting, Cheatham (2019) found that of the 1,042 professionals surveyed including athletic trainers, physical therapists, and fitness professionals, 81% (n =840) prefer to use a foam roller within their practice over other tools. With a FR being a highly chosen tool by practicing professionals, this further warrants the need for more research to better understand the impact of SMR using a FR on recovery as well as if there is a dosage response. It should be noted that the consensus of FR as a recovery mechanism is inconclusive as there are conflicting results throughout the literature. Within the literature many of the performance-based movements that have been used to measure recovery using a FR have been those that incorporate the use of the series elastic component (SEC) and stretch reflex. One of the commonly used field-based measures is that of the vertical jump (VJ)/ countermovement jump (CMJ). A study conducted by MacDonald et al., (2014) used a 10 x 10 back squat protocol at 60% 1RM to elicit EIMD and DOMS on twenty physically active resistance-trained males. Upon completion of the exercise, the experimental (EXP) group used a custom-made FR constructed out of a 10.16-cm outer diameter and 0.5-cm polychloride pipe wrapped with 1-cm thickness neoprene. Participants rolled each of the lower extremity muscle groups for two 60-s bouts. When VJ was reassessed post exercise, the EXP group saw substantial benefits in performance at 48 hours post exercise compared to control (CON). Similarly, Drinkwater et al., (2019) assessed the impact of FR for 3-minutes on each of the targeted, lower extremity muscle groups after the completion of a 6 x 25 leg extension protocol designed to elicit muscle damage. All variables, one of which was a CMJ, for both the EXP and CON groups were measured immediately, 24, 48, and 72 hours post exercise. Results of the CMJ showed significant increases at 72 hours. with small to moderate effects seen post training and 48 hr. In addition to both MacDonald et al., (2014) and Drinkwater et al., (2019), Romero-Moraleda et al., (2019) had a group of 32 individuals perform a 10 x 10 back squat protocol to elicit EIMD using a gravity-free training flywheel. When CMJ was reassessed 48 h post exercise, the EIMD protocol resulted in a decrease in CMJ by 9% compared to baseline measures. Individuals were then asked to perform a FR protocol rolling each of the lower limb muscle groups for two 60-s bouts. Upon completion of the FR protocol participants were reassessed. A significant increase in CMJ of 5.18% was seen when compared to pre-treatment measures. The findings of these studies indicate that SMR using a FR can have a positive impact in the recovery of VJ/CMJ, a movement utilized in various sports, from EIMD and DOMS. However, while the aforementioned studies showed positive impacts of FR on jump height, studies like Rey et al., (2017) did not see any difference in CMJ when reassessed 24 h following FR. Similar findings were also seen by Laffaye et al., (2019) who reassessed CMJ immediately, 24, and 48 hours following a FR protocol.

D'Amico et al., (2019; 2020) also did not show any significant impacts of FR on jump height. Speculation as to why improvements in jump height were not seen for D'Amico et al., (2019; 2020) could be that these studies assessed jump height utilizing a squat jump (SJ) rather than a CMJ. A proposed mechanism to explain how FR may aid in recovery is through the recovery of connective tissue disrupted during intense exercise. A squat jump requires the individual to pause at the end of the eccentric loading phase before concentrically contracting. This pause negates the use of the stretch shortening cycle (SSC) and therefore relies solely on the muscles ability to produce power to perform the movement. If FR is indeed beneficial in recovery of connective tissue, then utilizing a CMJ may have been more appropriate to assess recovery as the series elastic component (SEC) and stretch reflex are housed within tendons of the connective tissue. However, this rationale does not apply to Rey et al., (2017) and Laffaye et al., (2019) who used a CMJ to assess jump height. While a VJ/CMJ is a good test of power and a movement commonly seen in various sports, it is only one of a few performance-based measurements that have been used when assessing a FR on recovery.

Sprint Speed and Agility

Sprint speed and agility are two key skills utilized in a multitude of sports. However, both movements have shown to be negatively impacted due to EIMD and DOMS (Highton et al., 2009; Pearcey et al., 2015), which can result in decreased performance. When assessing the ability of SMR using a FR to aid in recovery of speed and agility, there is limited research. Two studies that did assess both speed and agility were that of Pearcey et al., (2015) and Rey et al., (2017). Pearcey et al. (2015) had eight healthy males complete a EIMD protocol consisting of ten sets with ten repositions (10 x 10) back squats at 60% 1RM with a 4-second eccentric contraction, a 1-second concentric contractions, and a 2-minute rest period between sets. To assess both speed and agility (referred to as 'change in direction speed' within the study) the researchers used a 30-m sprint and a 'T-test'. Post exercise measurements were taken immediately, 24, 48, and 72 hours after the exercise protocol.

During these times, the EXP group also performed a FR protocol after each session while the CON did not. Using a FR similar to that of MacDonald et al., (2014), the EXP group rolled each of the lower extremity muscle groups one time for a total duration of 45-seconds per muscle group. Results indicated that speed was substantially less affected at both 24 and 72 hours post exercise following FR whereas FR did not have an impact on agility performance. The results indicate that SMR using a FR may aid in recovery of movements requiring acceleration in a single direction, whereas movements requiring accelerations, decelerations, and lateral changes in direction are not positively impacted. In contrast to these results, Rey et al., (2017) found that a 1.5-minute FR protocol had a significant impact on agility performance 24 hours following FR, while no difference was seen in 5 or 10m sprinting. Similarly, D'Amico et al., (2019) assessed the impact of FR on recovery through measures of physical performance of which a T-test was used to assess agility. Thirty-seven healthy, college-aged males were placed into either an EXP (FR) or CON group. Using a sprint protocol to elicit EIMD, each participant completed 40, 15 m sprints with a 5 m deceleration zone. Immediately upon completion the EXP group performed a FR protocol using a high-density FR focusing on the anterior, posterior, lateral, and medial sides of the thighs, the glutes, and the gastrocnemius. In contrast, the CON sat quietly during this time. Upon completion of the FR protocol, both groups completed the post exercise performance measures. Over the next four days both groups completed the performance measures with the EXP group using a FR prior to each assessment. Results indicated that the EXP group saw a lesser impairment in agility performance compared to the CON. With regards to the impact of SMR using a FR on agility performance, these findings are in direct opposition to those of Pearcey et al., (2015), but also in agreement with Rey et al., (2017).

All the movements discussed above are key skills necessary to compete in various sports such as basketball, volleyball, soccer, football, lacrosse, and field hockey. With conflicting results seen amongst the various performance measures, further research is warranted on the ability of FR to aid in recovery to give both recreationally active individuals, as well as practitioners and fitness professionals, a better understanding as to whether SMR using a FR is a viable option for recovery of muscle pain/soreness.

Pain and Soreness

Pain and soreness are two non-performance based variables that have been assessed regarding the impact of SMR using a FR on recovery from EIMD and DOMS. Within the literature, the ability of SMR using a FR to decrease these sensations have been referred to as 'soreness', 'perceived pain' (PP), and/or 'pain pressure threshold' (PPT). However, they were all assessing the ability of a FR to decrease sensations of pain commonly seen with EIMD and DOMS. A variety of tools have been utilized to assess these variables ranging from visual scales to algometers. However, many studies have shown that SMR using a FR is helpful in alleviating these symptoms. Perceived pain was assessed by Laffaye et al., (2019) using a visual analog scale that ranges from "0" being defined as "absolutely no pain" to "10" being "the worst pain ever felt". Results indicated that DOMS decreased by 50% in the EXP compared to a 20% decrease in the CON. Studies performed by Pearcey et al., (2015) and Drinkwater et al., (2019) both assessed PPT using an algometer after using a FR to perform SMR. Results of both studies indicate that FR was beneficial in increasing PPT with Pearcey et al., (2015) seeing an increase in PPT of the quadriceps at 24 and 48 hours post exercise and Drinkwater et al., (2019) seeing a near significant increase in PPT immediately post training, 24, 48, and 72 hours Rey et al., (2017) saw a significant decrease in soreness 24 hours following a 1.5-minute FR protocol focusing on the quadriceps, hamstrings, adductors, glutes, and gastrocnemius. Finally, both MacDonald et al., (2014) and D'Amico et al., (2020) assessed soreness following SMR using a FR on recovery from EIMD. The former study assessed soreness using a numerical rating scale and found that muscle soreness was substantially lower in the FR group at 24, 48, and 72 hours post exercise compared to CON. The latter study, utilizing an algometer to assess soreness, found that the average soreness value was lower at all time points for the EXP group. The findings of the studies discussed above give a better understanding to the ability of SMR using a FR to decrease pain and soreness. Yet, while the above studies showed a decrease in pain and soreness after using a FR, the same studies had conflicting results on the ability of FR to aid in the recovery of performance measures, as previously discussed. Therefore, more research is warranted to see if a decrease in pain and/or soreness is accompanied by a recovery in performance-based measures.

Range of Motion/Flexibility

Hip

Range of motion and flexibility are important for any athlete and recreationally active individual alike. With a decrease in ROM being a common side effect associated with DOMS (Armstrong, 1984), multiple studies have assessed the impact of SMR using a FR to increase ROM. Literature has found that FR, utilizing varying dosages, can have a positive impact on ROM. MacDonald et al., (2014) assessed ROM of the hamstrings and quadriceps by measuring hip and knee joint angles. When assessed 24, 48, and 72 hours post FR, it was seen the there was a difference in quadricep ROM at both 24 and 48 hours. For the hamstrings, a difference in dynamic ROM was seen 24 hours post FR while a difference in passive ROM was seen 72 h post. Utilizing the same FR protocol, Laffaye et al., (2019) also saw a significant increase in hip ROM when FR targeted the tensor fascia latae, sartorius, and rectus femoris. Ironically, D’Amico et al., (2019) also used the same 2-minute FR protocol targeting the hamstrings, quadriceps, glutes, and gastrocnemius. However, unlike the previous studies, no difference was seen when ROM was reassessed immediately, 24, and 48 hours post intervention. Although the same muscles were targeted in this study as that of MacDonald et al., (2014), it was speculated that the use of a more vigorous, dynamic warm-up may have increased ROM prior to the FR intervention. Romero-Moraleda et al., (2019) also evaluated both active and passive ROM about the hip and found that FR the quadriceps for 5-minutes had a significant impact on ROM. Finally, a study completed by Mohr, Goad, and Long, (2014) also assessed changes in ROM at the hip following FR. Participants had their pre-FR ROM tested, completed a bout of FR, and were then immediately re-tasted. It was found that FR the hamstrings for 3-minutes significantly increased ROM as measured using an inclinometer.

Studies performed by Smith, Pridgeon et al., (2018), as well as Rey et al., (2017), assessed the impact of FR on flexibility as measured through a sit and reach test. Smith et al., (2018) had participants FR for 1.5-minutes focusing on the hamstrings, quadriceps, glutes, and gastrocnemius. When flexibility was reassessed upon completion of FR, it was found that FR produced a significant change in sit and reach measurements. Likewise, Rey et al., (2017) also utilized a 1.5-minutes FR protocol using a high-density FR. Immediately upon completion of physical activity, FR was completed on the quadriceps, hamstrings, adductors, glutes, and gastrocnemius. Differing from Smith et al., (2018), this study reassessed participants 24 hours post FR rather than immediately after FR. When sit-and-reach was reassessed, it was found that there was no difference in flexibility between the EXP and CON groups.

Knee

In addition to evaluating changes in ROM at the hip following FR, research has also looked at changes in ROM at the knee joint as well. MacDonald et al., (2013) used 2, 1-minute bouts of FR focusing on the quadricep muscles. When reassessed at 2 and 10-minutes post FR, knee flexion was significantly greater at both times when compared to the CON group. Cheatham and Stull (2018) also had participants FR the quadriceps for two minutes. However, within this study participants were assigned to one of three groups that used a different type of FR; soft, medium, or hard. When FR was completed, participants were immediately reassessed. Post intervention values showed that knee flexion was not significantly different between the groups indicating that the type of FR used did not have different impacts on knee flexion. However, all groups exhibited a significant difference in ROM when compared to pre-intervention values. Romero-Moraleda et al., (2019) found similar results in knee flexion following FR, however FR duration and the time of reassessment was different than previous studies. Forty-eight hours after the completion of an EIMD protocol, participants returned to have measurements reassessed and then immediately completed a FR protocol comprised of 5, 60-second bouts. Once completed, participants were again re-tested. Results showed that a significant difference in knee flexion was seen when compared to pre-intervention measures. While the previously discussed studies showed significant difference in knee flexion, some studies on knee flexion following FR had differing results.

Studies by Laffaye et al., (2019) and Drinkwater et al., (2019) saw different results in knee flexion following FR than those previously discussed. Laffaye et al., (2019) saw no significant difference in knee flexion when reassessed immediately, 24, and 48 hourspost intervention. Additionally, Drinkwater et al., (2019) utilized a 3-minute (per muscle group) FR protocol focusing on the quadriceps, hamstrings, adductors, iliotibial band, and glutes. Findings showed that there was no significant difference in knee flexion immediately, 24, 48, and 72 hours post intervention.

From the studies reported in the literature there is general supports for the use of a FR to increase ROM within the lower extremities. Although significant differences were seen amongst multiple studies, it should be noted that varying FR protocols were used. Within the topic of SMR using a FR, there does not appear to be a specific identified dose-response making it difficult to determine just how long an individual should FR to achieve desired changes in ROM.

Foam Rolling Duration

When it comes to physical activity such as resistance training, endurance training, flexibility, or plyometrics, there are recommended dosage guidelines to follow to achieve the desired outcomes. These dosages can come in various forms including sets, reps, frequency, and duration. Specific modes of exercise, like that of resistance training, have specific dosage guidelines that should be followed to help meet the desired goal(s) or need(s) of the individual(s) (i.e., hypertrophy, power, strength, muscular endurance). However, with regards to FR, while it is gaining much more interest as a recovery technique, there does not appear to be dosage guidelines in the literature. Additionally, past literature assessing the impact of FR on the recovery from DOMS have used varying dosages ranging from as short as one, 45-second bout per muscle up to 5, 60-second bouts per muscle/muscle group and have seen varying results thus requiring further investigation.

Less than One Minute

The shortest duration of FR found to be used for recovery from DOMS was conducted by Pearcey et al., (2015). Recovery was assessed through varying performance-based measures including sprint speed and change of direction speed (agility), as well as a pressure-pain threshold. A single 45-second (total) bout performed at a cadence on 50-beats per minute (BPM) was chosen focusing on the lower extremity muscle groups including the quadriceps, hamstrings, adductors, iliotibial band, and gluteus. When reassessing participants pain threshold at 24, 48, and 72 hours post FR, it was seen that the FR group had substantially less pain at only 48 hours post intervention, with no substantial differences seen at post 24 and 72 hours Sprint times were also found to be substantially lower at 24 and 72 hours following FR, while change-of-direction speed (agility) was not significantly impacted by FR at any post treatment measurements.

One – Two Minutes

Many of the FR dosages seen within the literature were durations ranging from 1-2 minutes per targeted area. Using a high-density foam roller, Rey et al., (2017) had participants FR the lower extremities for two, 45-second bouts (1.5 minutes of total FR per muscle) focusing on the quadriceps, hamstrings, adductors, gluteus, and gastrocnemius. When participants were re-tested 24 hours following FR, it was found that there was no difference in both the 5m and 10m sprint speed between the FR and CON group. Additionally, there was no difference in ROM, measured through sit and reach, at the lumbar and hamstrings. When both agility and muscle soreness were re-evaluated, it was found that agility performance was significantly different for the FR group, while it was also seen that the FR group had a significant decrease in muscle soreness.

The most commonly seen FR dosage employed and reported in the literature was that of two, 60-second bouts (2-minutes per muscle) performed on a single occasion. MacDonald et al., (2014) was the first to use this dosage with Laffaye et al., (2019), D'Amico et al., (2019), and D'Amico et al., (2020) later adopting the same protocol. In the earliest of these studies, MacDonald et al., (2014) had participants roll the anterior, posterior, medial, and lateral aspect of the thigh as well as the glutes at no specific cadence for recovery from an EIMD protocol. When participants were re-tested, it was found that the EXP group experienced a decrease in muscle soreness at both 48 and 72 hours post treatment. When performance was assessed, the EXP group saw a difference in countermovement jump height at 48 hours post treatment when compared to the CON group. FR individuals also exhibited an increase in ROM in both the hamstrings as well as the quadriceps.

Using the same protocol, D'Amico et al., (2019; 2020) had participants roll the anterior, posterior, medial, and lateral aspects of the thigh, glutes, and the gastrocnemius at a cadence of 5-sec per roll. Upon re-testing, similarities and differences were seen between the two studies. For both studies there was no difference in jump performance between conditions, which is in opposition to that of MacDonald et al., (2014). For agility, a difference in (T-test) performance was seen in D'Amico et al., (2019), whereas D'Amico et al., (2020) saw no difference between groups. Similarly, differences in muscle soreness were also seen between both studies with D'Amico et al., (2019) seeing no significant difference in muscle soreness between conditions while D'Amico et al., (2020) saw a decrease in muscle soreness at all post measures. Finally, when assessing ROM, D'Amico et al., (2020) found that FR did not have an impact on ROM about the hip or in the length of the hamstring. Given that both studies discussed here used the same 2 x 60-s FR dosage, it is rather interesting that differences were seen amongst the two studies for the same variables.

The fourth study using the two, 60-second bouts was conducted by Laffaye et al., (2019). This study focused on FR of the tensor fasciae latae, sartorius, and rectus femoris with a cadence requiring participants to complete their rolling movement from proximal to distal (hip to knee) in 2-seconds. Following FR it was found that the EXP group saw a significant difference in soreness at both 24 and 48 hours post treatment. However, no difference was seen in either squat jump or counter movement jump following massage, which also differs from the findings of MacDonald et al., (2014). Additionally, when ROM was reassessed at the hip, knee, and ankle, no significant differences were seen between groups.

Three - Five Minutes

Some of the longer dosages of FR were used by Drinkwater et al., (2019) and Romero-Moraleda et al., (2019). The first of the two used a protocol requiring individuals to roll each targeted area for a total of 3-minutes. The muscles/muscle groups included the quadriceps, adductors, iliotibial band, glutes, and hamstrings. Immediately following, 24, 48, and 72 hours post FR, the individuals were reassessed for CMJ height, knee flexion, and pressure-pain threshold. Results showed that a significant difference in CMJ height was only seen 72 hours post FR. A difference in pressure-pain threshold was also seen in the EXP group at 48 hours post FR, but not at any other time frames. Finally, there was no significant difference in knee flexion ROM seen between either group following FR.

Romero-Moraleda et al., (2019) used the longest dosage found within the literature. Using a protocol consisting of 5, 60-second bouts per muscle group, participants were asked to roll the quadriceps from the most proximal portion down to their patellae. At the conclusion of each 1-minute repetition, participants were given a 30-second break before completing the ensuing repetition. When participants were reassessed, CMJ height was significantly different compared to pretreatment values. There was also a difference in both active and passive ROM at the hip, as well as active ROM at the knee. However, this study was one of the few that did not see a difference in pain-pressure threshold when following FR.

Given that multiple dosages of SMR using a FR have been investigated and reported in the literature with varying results both between and within the different dosages, more research on dosage-responses is warranted in order to determine an appropriate duration that an individual should FR to recover from DOMS.

Conceptual Framework

Though the exact mechanism as to how SMR works are uncertain it has been proposed that its effects may be achieved through a neurophysiological mechanism. The fascia is highly innervated with a large number of mechanoreceptors, of which it is believed the interstitial receptors, that are highly abundant within the fascia, and the Ruffini organs play an intricate role (Schleip, 2003). Ruffini organs, which are sensitive to tangential forces and lateral stretch, have shown to be stimulated when a slow, deep massage is applied to a specific area (Schleip, 2003). When this happens, the central nervous system (CNS) may signal the motor units within the area being massaged to decrease their firing rate thus resulting in a decrease in the muscle tonus (Schleip, 2003). In addition to decreased muscle tonus, SMR has also shown to decrease muscular pain/soreness (MacDonald et al., 2014; Pearcey et al., 2015; Cheatham et al., 2018; Laffaye et al., 2019; Drinkwater et al., 2019; D’Amico et al., 2020), which may result from decreased nociceptor (pain receptor) activation. The decreases in both pain/soreness and muscle tonus may be what allows for the greater ROM that has been seen following SMR using a FR (MacDonald et al., 2013a, 2013b; Mohr et al., 2014; Cheatham et al., 2018; Laffaye et al., 2019; Romero-Moraledo et al., 2019). Foam rolling may also help to lengthen the fascia and/or stretch it (Sheh et al, 2012), further leading to increases in ROM.

Self-myofascial release and other forms of massage have shown to have physiological impacts. It was found that a bout of FR can decrease arterial stiffness while also increasing plasma nitric oxide (NO) concentration (Okamoto et al., 2014). Foam rolling has also shown to increase blood flow by 73.6% immediately after and 52.7% 30-minutes following a bout of FR when compared to baseline (Hotfiel et al., 2017). The combination of increased arterial function and vasodilation from the increases in NO concentration may allow for more blood flow to the injured site aiding in healing through the delivery of key nutrients and proteins. Massage following a bout of strenuous exercise may also increase mitochondrial biogenesis (Crane et al., 2012) and decrease levels of serum creatine kinase, an indirect measurement of muscle damage (Smith et al., 1994). Understanding that a proposed mechanism to DOMS is that of muscle damage, it may be possible that massage helps to decrease the degree of muscular breakdown while also aiding in the healing process through increased blood flow and increased mitochondrial biogenesis.

Through the processes previously discussed it is possible that increases in ROM, decreases in muscular pain/soreness, and increased healing of the injured site could potentially allow for greater utilization of the series elastic component (SEC) and stretch reflex. During eccentric muscle contractions the SEC is stretched generating potential energy (Haff and Triplett, 2016). During a sport specific movement, such as a vertical jump, this potential energy can be utilized to help create force and assist in the movement. Additionally, when a muscle goes through a rapid eccentric contraction, the stretch reflex is activated through the stimulation of muscle spindles. These proprioceptive organs are sensitive to the rate and magnitude of stretch meaning the more rapid of a change they experience, the greater of a reflex will occur. When stimulated, they send an afferent signal to the CNS about the experienced change within the muscle that results in an efferent signal being sent to the agonist muscle causing the reflexive action (contraction) (Haff and Triplett, 2016). This muscular contraction allowing work (movement) to be performed may be the result of both the neurophysiological and mechanical processes.

Muscular contraction is a multistep process that is ultimately achieved by the binding of myosin heads to actin allowing the sarcomeres, the basic unit of muscular contraction from z-line to z-line, to be pulled closer to one another. The process of muscular contraction is explained through the Sliding Filament Theory (SFT). For the myosin and actin to bind together an electrical stimulus must reach the muscle cell and transverse the t-tubules allowing the stimulus to get inside of the cell. When this is achieved the stimulus causes calcium (Ca^{2+}) release from the sarcoplasmic reticulum (SR) into the sarcoplasm. The Ca^{2+} will bind to the troponin proteins and result in tropomyosin being moved from binding sites on the actin filament. When these binding sites are revealed it will allow the myosin heads to bind to these sites allowing for the crossbridge cycle to occur. The myosin heads will then release energy through the hydrolysis of adenosine tri-phosphate (ATP) allowing for them to move (in a 'wrenching' motion) pulling on the actin. This part of the SFT is known at the 'powerstroke' and is the distinct moment at which the actin from both ends of the sarcomere are being pulled towards one another allowing the z-lines to come closer to each other and the shortening of the sarcomere. This process is repeatedly performed until the Ca^{2+} goes back into the SR awaiting the next stimulus to appear allowing for the process to repeat itself.

CHAPTER III

Methodology

The purpose of this chapter is to explain the methodologies related to this experimental, cross-over design study. The following sections will be explained and thoroughly defined in detail: operational definitions, participants, experimental procedures, independent and dependent variables, statistical analysis, delimitations, and limitations.

Operational Definitions:

Recreationally active - Partaking in routine physical activity at least 3x/week for 30-minutes at an intensity high enough to cause sweating and fatigue.

College-aged- Between the ages of 18-26 years, typically seen in most collegiate undergraduate through master's programs.

Muscle Damage Protocol – 5-minute dynamic warm-up followed by 10 sets of 10 repetitions (10 x 10) maximal vertical jumps with 1-minute of passive recovery between sets.

Study Design, Protocols, Instrumentation

Study Design - This study employed a 3-group, randomized experimental cross-over design, including 4 experimental sessions to compare the impact of SMR using a foam roller as a recovery modality for the recovery of vertical jump, sprint speed, agility, soreness/pain perception, and range of motion. All variables were assessed immediately, 24, 48, and 72-hours following the completion of an exercise designed to elicit muscle damage and DOMS.

Participants **-** Twelve adult males participated in this study. Participants were an average of 21 years old, 178.8cm tall, and weighed 83.25 kg's. To partake in the study participants were to be college-aged males, recreationally active following ACSM guidelines, and were currently free from any lower extremity musculoskeletal injuries. Upon meeting inclusion criteria, participants were randomly assigned to one of two foam rolling groups: 1-minute per muscle group or 2-minutes per muscle group. There were a total of six males in each foam rolling group and all participants served as their own control.

Procedures - Upon obtaining IRB approval from both East Stroudsburg University (ESU) and Seton Hall University (SHU), participants were solicited from undergraduate and graduate level courses in the Department of Exercise Science (EXSCI) at East Stroudsburg University of Pennsylvania (ESU) via direct, in-class solicitation. The class was informed of the purpose of the study and a brief background of the problem. The primary investigator (PI) ensured that potential participants signing up met the study inclusion criteria by confirming the following: all volunteers were to be college-aged (18-26) males, were recreationally active following ACSM guidelines, and were currently free from any lower extremity musculoskeletal injuries. Participants were informed that this study would take place over a 2-week period and that all testing would be completed in the Human Performance Lab (HPL) of the ESU EXSCI department, as well as the arena of Koehler Fieldhouse on the ESU campus. A sign-up sheet was then passed around the room asking for those interested to provide their name and contact information in which they would receive an email from the PI. All individuals on the sign-up sheet were then sent an email asking for their availability to attend a familiarization session. Upon scheduling a time, participants were asked to refrain from performing any physical activity or consuming alcohol 24 hours prior to attending the familiarization session.

Upon arrival to the familiarization session, participants were again informed of the inclusion criteria to ensure they met the requirements. They were then given the IRB approved letter of informed consent to read and sign as well as a physical activity readiness questionnaire (PAR-Q) which the PI immediately reviewed before beginning any familiarization. Individuals were randomly assigned to a FR group (either 1 or 2-minutes) based off the numerical order in which they were recruited. All ‘odd numbered’ participants (1,3,5,7,etc.) were placed in one FR group while the ‘even numbered’ participants (2,4,6,8,etc.) were placed in the other FR group. Based upon an A*Priori G-Power calculation of three groups (1-minute, 2-minute, CON) with a total of 5 measurements taken, a total of six males were assigned to each of the two foam rolling groups. Each participant also served as their own control. Participants were then put through a 5-minute “down and back” dynamic warm-up covering a 10-m distance comprised of the following movements: knee-to-chest, alternating quad stretch, high knees, butt kicks, carioca, power skips, and side-shuffles. This warm-up was performed prior to each testing session. Following the warm-up, participants were given a thorough explanation of each test, a demonstration of the tests by the PI, and then were asked to perform each test two times while the PI evaluated their form and made any necessary corrections. Following the NSCA guidelines for a battery of tests, tests were performed in the following order during the familiarization and testing days: vertical jump, agility, sprint, ROM, and soreness/pain perception. Following the familiarization of each test, baseline measures were collected. Participants performed 3-vertical jumps, two 10-meter sprints, three agility tests, and had their soreness/pain perception and range of motion measured once. For performance variables, the highest jump and fastest sprint and agility times were recorded. Specifically for sprint speed, the fastest times for both 5-and-10 meters were recorded and used for baseline values. Following baseline measures, individuals were given a demonstration of the foam rolling protocol by the PI. This foam rolling demonstration was completed after baseline testing to ensure that it did not have any impact on baseline measures. Participants were asked to place as much pressure as tolerable on the FR and complete the foam rolling protocol by rolling the following muscles in corresponding order: thigh (anterior, posterior, lateral, and medial), the gluteus maximus, and the gastrocnemius. Each targeted area was rolled for 1-minute at a cadence of 5-seconds per repetition (2.5-seconds down from proximal to distal, 2.5-seconds back up from distal to proximal) in one fluent motion without any undulations. Following FR familiarization, participants were asked of their availability to schedule their first testing session. Before leaving the lab, participants were again asked to refrain from any physical activity and consumption of alcohol 24 hours prior to the beginning of testing as well as during the 4 days of testing. They were also asked to refrain from performing any additional recovery techniques outside of testing or taking any pain relief medications (Tylenol®, Aleve®, etc.) during testing weeks. A reminder email was sent to all participants 24 hours prior to their first testing session.

Within a week of completion of the familiarization session, participants arrived back at the lab for their first week of testing. Each participant completed two testing weeks (4-days for EXP group, 4-days for CON) with a 7-day washout period between testing weeks. Re-test times were immediately, 24, 48, and 72 hours post exercise. Each participant completed their testing sessions at the same time of day to minimize any impact that diurnal variation may have on performance. The PI maintained a testing time log to ensure that each participant was testing at the same time of day as they had done in the previous day(s)/week. On the first day of testing the participants completed the 5-minute dynamic warm-up prior to completing a muscle damage protocol. The muscle damage protocol consisted of 10 x 10 maximal vertical jumps with a 1-minute passive recovery between sets. Upon completion, participants were immediately re-tested for all variables (vertical jump, agility, sprint speed, soreness/pain perception, ROM). During the EXP week, participants then completed the foam rolling protocol for their prescribed time (1 or 2 minutes per muscle group). Upon completion, participants were allowed to leave the lab and reminded that they would be returning with 24 hours for retesting. On testing days 2-4 during the EXP and CON weeks, participants only completed the battery of tests (no FR was completed). An overview of the study design can be seen in Figure 1.

Muscle Damage Protocol **-** To elicit EIMD and DOMS, participants performed a 10 x 10 maximal countermovement vertical jump protocol using a Vertec (Jump USA, Sunnyvale, CA) with each set separated by a 1-minute passive recovery. The Vertec height was set so that the first vane was just above the individuals standing reach height. Once set, participants were asked to complete one maximal jump and hit the highest vane possible. This mark was then used as a target point for the participant to reach for on each subsequent jump to encourage maximal effort and help maintain jump height during the protocol.

During the landing phase of each jump the participants were instructed to obtain a 90° angle at the knee to promote muscle damage due to the increase in eccentric loading upon landing. This protocol has successfully shown to induce muscle damage in previous studies (Twist and Eston, 2005; Highton et al., 2009).

Foam Rolling - During the EXP group, foam rolling was completed immediately following the completion of the EIMD/DOMS protocol. During the CON week, participants did not complete FR, but went immediately into the 'immediate post' measurements. The FR protocol used was adapted from D'Amico et al., (2019). Using a TheraBand® (Theraband, Hygienic Corporation, Akron, OH) high-density foam roller, participants rolled the thigh (anterior, posterior, medial, and lateral), gluteus maximus, and the gastrocnemius for either 1 or 2-minutes depending upon their assigned foam rolling duration. Examples showing the positioning for FR each of the targeted muscles can be found in Appendix D. Participants were asked to place as much body mass (BM) as tolerable on the FR at all times. A metronome was set at 47-bpm to control the cadence allowing for 5-seconds per roll from proximal to distal (2.5-seconds) and back up again (2.5-seconds). The cadence allowed for 12 complete repetitions within 1-minute (24 repetitions for 2-minute FR group). For FR of the thigh, participants were instructed to start with the FR at the proximal end of the thigh and roll in one fluent motion distally towards the knee. Once reached, they were to reverse the motion rolling back towards the proximal end of the thigh in one fluent motion. This same process was completed for all four sides of the thigh. For the gluteus maximus, participants were instructed to sit on top of the FR with their hands behind them aiding as a support and crossing their left/right leg over their right/left leg allowing their weight to be placed directly on the gluteus maximus. The rolling motion was to be continuous from the origin of the muscle (outer surface of ilium, posterior lumbar fascia, lateral sacrum, sacrotuberous ligament and coccyx) to the insertion (deepest quarter in gluteal tuberosity of femur and three quarters into iliotibial tract). Finally, for the gastrocnemius, participants placed the FR at the proximal end of the muscle, crossed their left/right leg over their right/left leg, and placed their hands behind them as a support. They proceeded to roll in one fluent motion from proximal to distal and back up at the specified cadence. Foam rolling was performed for all muscle groups on one leg before switching to the other. For the 2-minute foam rolling group, they completed 1 x 60-second bout of foam rolling on all muscles on one leg, switched to the other leg completing 1 x 60-second bout of FR on all muscle groups, and then started over again on the first leg completing the second, one-minute bout for each muscle. All FR protocols were monitored to ensure participants were keeping pace with the metronome, were rolling the entire muscle from proximal to distal, and that their form was correct.

Vertical Jump - Three countermovement jumps (CMJ) were utilized to determine vertical jump height as previously used by Moir et al., (2008). A jump mat (Just Jump, Probotics, Huntsville, AL) was used to record jump height. The same instructions were given during each testing session. Prior to stepping on the mat, participants were reminded that they were performing a CMJ and therefore should not pause between the eccentric and concentric movement. They were also reminded to refrain from tucking their legs during the jump. When ready, the participants stepped onto the mat and placed their hands around their neck to avoid using their arms during the jump. The depth and speed of the eccentric loading phase were not controlled to allow the movement to be as natural as possible. A total of three CMJ's were performed, separated by a 1.5-minute rest period. Each jump was rounded to the nearest 0.25 inch with the highest jump recorded being used for analysis. The ICC for three CMJ's is 0.87 – 0.93 (Moir et al., 2008).

Agility - A T-test protocol was adapted from Raya et al., (2013). Single-beam, electronic photocells (TCI System, Brower Training System, Draper, UT) were placed at the starting line. When ready, participants (1) sprinted 10 meters as quickly as possible to the center cone, (2) side shuffled 5 meters either left or right (based on their preference) to a cone, (3) sidestepped 10 meters to the cone on the opposite side of the 'T', (4) sidestepped 5 meters back to the center cone, and (5) back peddled all the way through the finish line.

Participants completed the test three times separated by a 60-second passive recovery. The fastest of the three times was used for analysis. ICC for the T-Test is 0.83 (Raya et al., 2013).

Sprint Speed - Using a protocol adapted from Highton et al., (2009), participants performed two, 10-meter sprints from a standing start on an indoor track with a 3-minute passive rest between sprints. Sprint times were recorded using single-beam, electronic photocells (TCI System, Brower Training System, Draper, UT) placed at 0 (start), 5-meters, and 10-meters (finish). Sprint times for 0 to 5 meters and 5 meters to 10 meters were rounded to the nearest 0.01 second. The fastest times recorded over the 5-and-10-meter distance were used for analysis. ICC for 10-meter sprint is 0.92 (Duthie et al., 2006).

Muscle Pain/Soreness - Muscular pain/soreness was measured using a 0-10 Numerical Rating Scale (NRS). The NRS ranges from “0” indicating the individual is experiencing “No pain” to “10” indicating they were experiencing the “Worst pain possible”. As previously completed by MacDonald et al., (2013), participants were asked to perform a bodyweight squat eccentrically loading until their thighs were parallel to the ground. When the individuals were in the appropriate position, they were asked to rate their pain/soreness using the NRS. The NRS ICC for pain measurement is 0.99 (Gallash et al., 2007).

Range of Motion - Range of motion was assessed at the knee joint using a long-arm goniometer (JAMAR, Jackson, MI) while individuals laid in a prone position on a cushioned treatment table (Cheatham et al., 2018; Drinkwater et al., 2019). The fulcrum of the goniometer was positioned against the lateral epicondyle of the femur, the stationary arm in line with greater trochanter of the femur, and the movement arm in line with the lateral malleolus. Holding the ankle, the researcher moved the knee through a passive ROM until the initial sensation of pain was experienced by the participant or until the point where the knee could no longer be passively moved. During passive ROM, the researcher was also monitoring the pelvis to ensure that the hips did not lift off the table. The measurement was then taken and recorded. Measurements were taken a total of three times with the greatest

ROM used for analysis. The ICC for long arm goniometry for knee flexion is 0.996 (Hancock et al., 2018).

Statistical Analysis - A 2x5 ANOVA (1-min. group, 2-min group x baseline, immediate, 24, 48, 72hrs post) was used. Differences in the mean delta (Δ) changes between groups were determined for each dependent variable at all measurement times using a repeated measures within – between interaction analysis of variance. Precision of differences were expressed with 95% confidence interval (CI), an effect size of 0.5, and significance set at $P < 0.05$. Statistical analysis was performed using SPSS (version 27; IBM statistics).

Limitations

1. Participants were required to refrain from partaking in additional recovery techniques or from consuming any pain relief medications following the muscle damage protocol. Other than verbal questioning there was no way to assess whether these requirements were met.
2. Recovery was indirectly measured through performance, kinematic, and perceptual measurements. Direct, physiological measures were not assessed.
3. During FR, participants were required to place as much BM as tolerable on the FR at all times. Due to the fact that pressure placed on the FR was not directly assessed, pressures may have varied from repetition-to-repetition, set-to-set, and/or day-to-day.

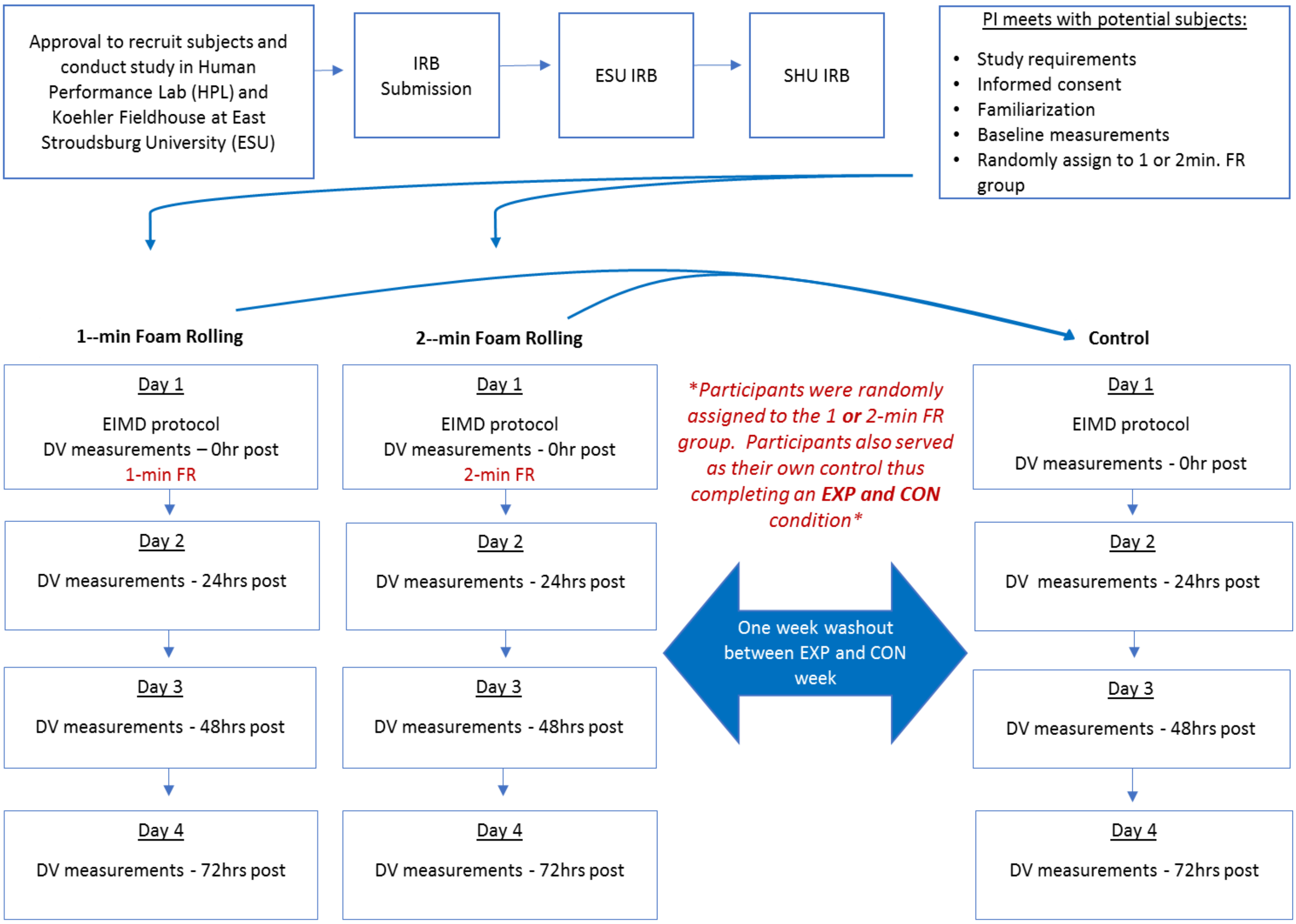
Delimitations

1. Male undergraduate and graduate students from the Department of EXSCI at ESU.
2. College-aged, ages 18-26.
3. A sample size of 12 participants.
4. Participants currently recreationally active per ACSM guidelines
5. Participants currently free from any lower body musculoskeletal injuries.

6. Participants were healthy, active, and able to complete a 10 x 10 vertical jump EIMD protocol.
7. Participants who completed the PAR-Q and informed consent forms.

Figure 1.

Visual Overview of Study Design



Note. Participants only completed the FR protocol they were randomly assigned too.

Chapter IV

Results

This study aimed to explore the impact of two different acute, single bout durations of self-myofascial release (SMR) using a foam roller (FR) as an intervention for recovery, defined as the degree to which values returned back to baseline measures, of vertical jump, sprint speed, agility speed, knee ROM, and pain/soreness from DOMS in recreationally active college-aged males. Specifically, this study assessed the recovery of performance-based variables including CMJ height, agility speed, and sprint speed, as well as non-performance-based variables including pain/soreness and knee range of motion (ROM). Twelve participants volunteered for this study and were randomly assigned to one of two EXP FR groups (1 or 2-minutes per muscle group), while also serving as their own control.

Changes in Dependent Variables

Countermovement Jump

Two-way ANOVA of mean Δ values showed there was no significant difference between EXP groups for the recovery of CMJ performance (*F* =.007; *P* = .933) at any time point post exercise (*F* = .931; *P* = .453)

Table 1

Test of Between-Subject Effects of FR for Recovery of CMJ.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Time	7.104	4	1.776	.931	.453
FRDuration	.014	1	.014	.007	.933

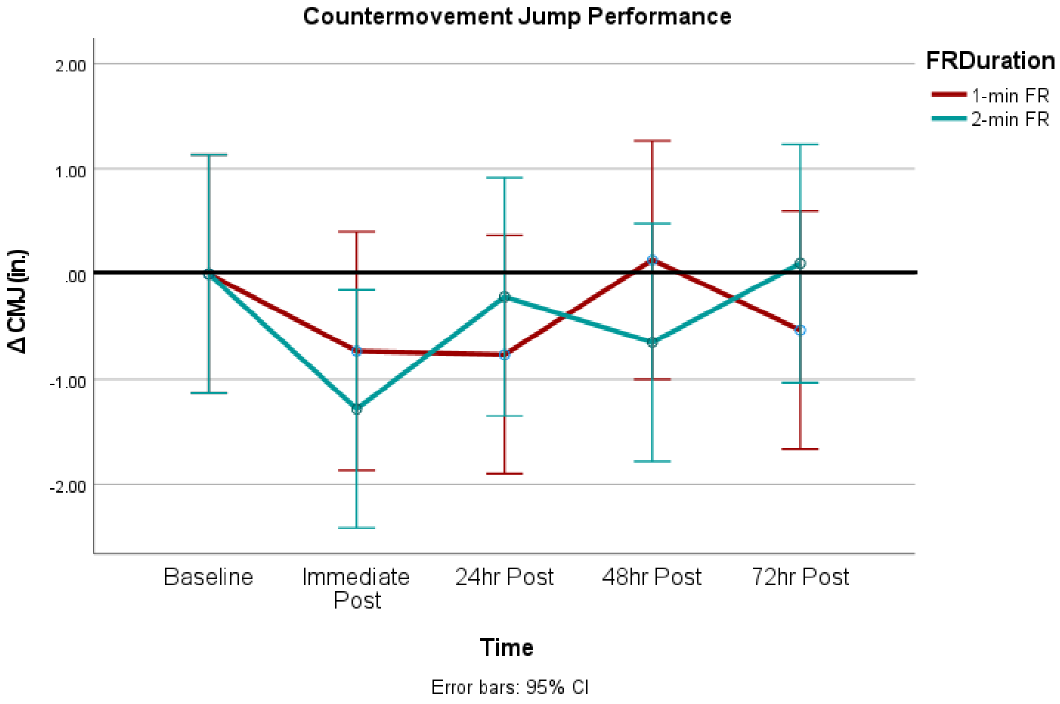
Note. Time = DV measurement times. FRDuration = duration of FR performed.

When assessing recovery between both EXP groups, results indicate that there was no significant difference in recovery of jump performance between EXP groups at any time point post exercise. A negative mean Δ in CMJ performance indicates participants in both

EXP groups experienced a lesser decrease in jump performance during the CON week than during the FR week, whereas a positive Δ indicates better performance during EXP week than the CON week (Figure 2).

Figure 2

Difference in Mean Changes in CMJ between Foam Rolling Durations.



Note. X-axis represents assessment times of DV. Solid black line = baseline.

Agility

Two-way ANOVA of mean Δ values showed there was a significant difference in post exercise measures of agility performance when comparing baseline to post exercise measurement times (F = .3.612; P = .012). However, there was no significant difference in agility performance between EXP groups at any post exercise measure (F = .171; P = .681) (Table 2).

Table 2

Test of Between-Subject Effects for recovery of Agility Time.

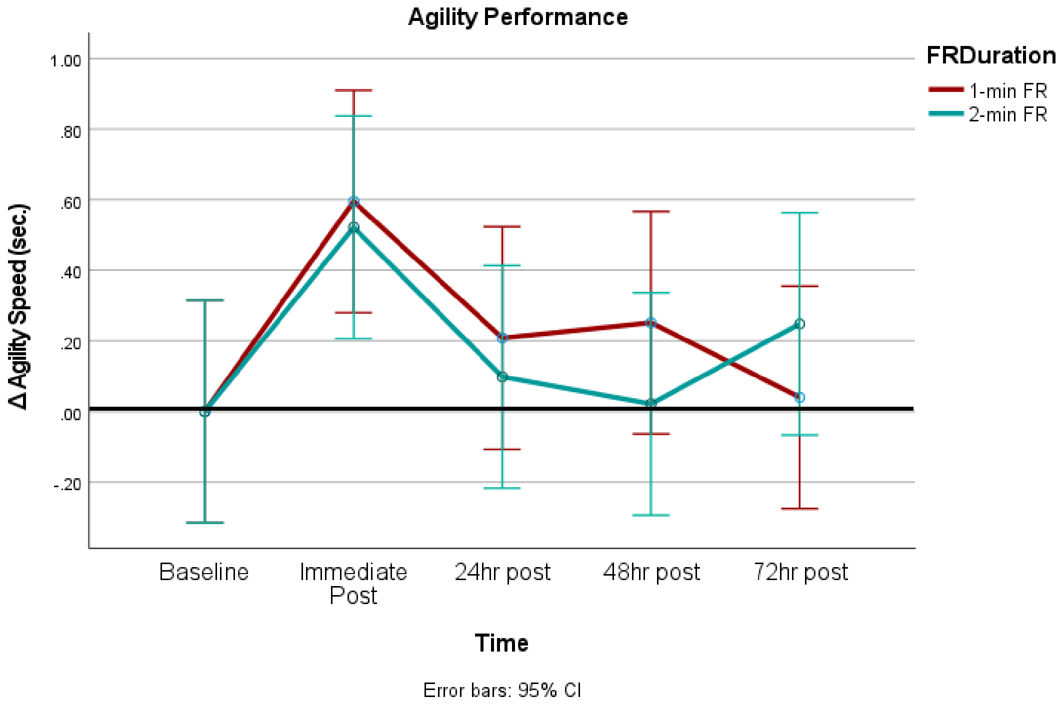
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Time	2.132	4	.533	3.612	.012
FRDuration	.025	1	.025	.171	.681

Note. P = <.05 considered significant. Time = DV measurement times. FRDuration = duration of FR performed. Significance = *p* <.05.

A significant difference in agility performance was only seen between baseline (1.00) and immedicate post exercise measures (2.00) for both EXP groups (*F* = 3.612, *P* = .012), indicating the exercise significantly decreased agility performance (increased time). However, this difference in performance may be more attributed to fatigue more than DOMS. When assessing recovery, a positive mean Δ in agility performance indicates individuals experienced a lesser decrease in agility performance during the CON week than the EXP, whereas a negative Δ indicates better performance during EXP week than the CON week. The 2-min FR duration did exhibit a greater return closer to baseline values for both 24 and 48-hr post exercise when compared to 1-min FR, however there was no significant difference between EXP groups for the recovery of agility performance (Figure 3).

Figure 3

Difference in Mean Changes in Agility Time between Foam Rolling Durations.



Note. X-axis represents assessment times of DV. Solid black line = baseline.

Sprint Speed

Two-way ANOVA of mean Δ values showed there was no significant difference between EXP groups for the recovery of sprint performance (F = .024; P = .876) at any time points post exercise (F = *.660;* P = .623) (Table 3).

Table 3

Test of Between-Subject Effects of FR for recovery of Sprint Time.

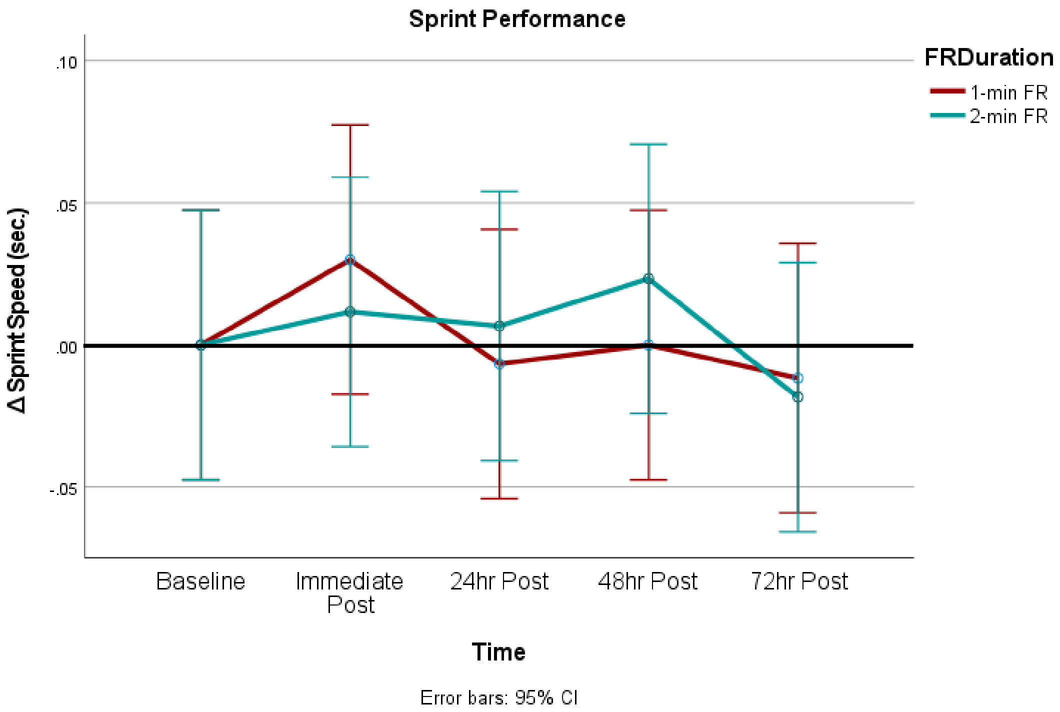
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Time	.009	4	.002	.660	.623
FRDuration	8.167E-5	1	8.167E-5	.024	.876

Note. Time = DV measurement times. FRDuration = duration of FR performed. Significance = p <.05.

When assessing recovery between EXP groups there was no significant difference in recovery of sprint performance between EXP groups at any time point post exercise. A positive mean Δ in sprint performance indicates participants in both EXP groups experienced a lesser decrease in sprint performance during the CON week than during the FR week. (Figure 4).

Figure 4

Difference in Mean Changes in Sprint Time between Foam Rolling Durations.



Note. X-axis represents assessment times of DV. Solid black line = baseline.

Pain/Soreness

Two-way ANOVA of mean Δ values showed there was no significant difference between EXP groups for the recovery of pain perception/soreness (*F* = .013; *P* = .909) at any time point post exercise (*F* = .464; *P* = .762) (Table 4).

Table 4

Test of Between-Subject Effects of FR for recovery of Pain perception/Soreness.

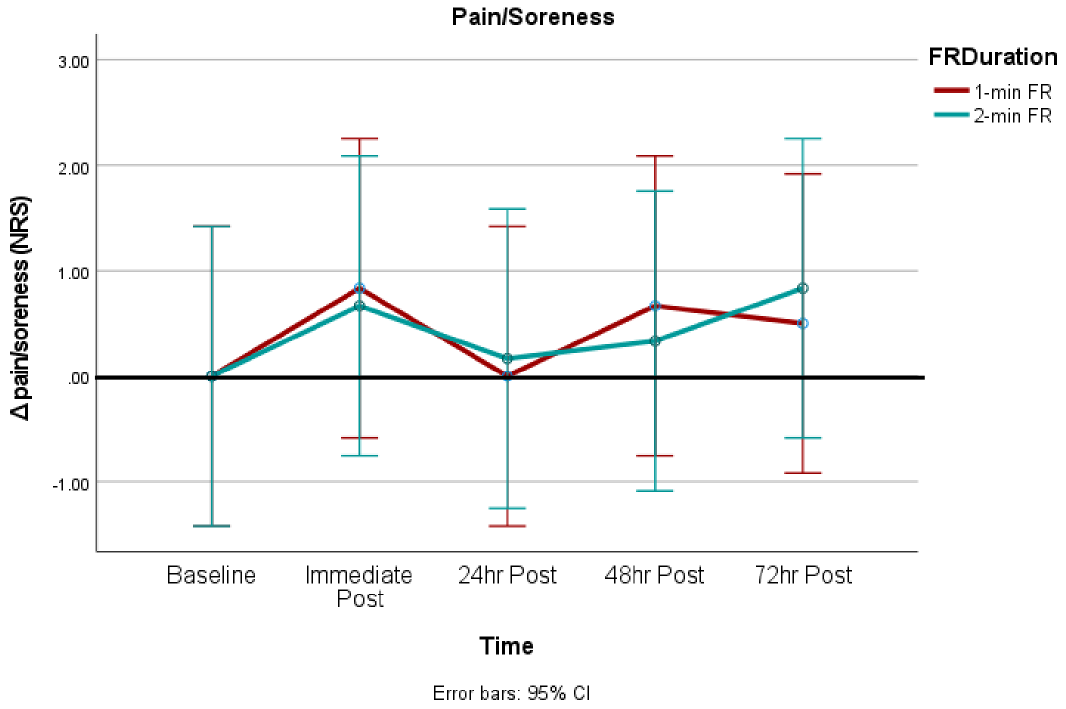
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Time	5.567	4	1.392	.464	.762
FRDuration	.000	1	.000	.000	1.000

Note. Time = DV measurement times. FRDuration = duration of FR performed. Significance = *p* <.05.

When assessing recovery between both EXP groups, results indicate that there was no significant difference in recovery of pain/soreness between EXP groups at any time point post exercise. A positive mean Δ in pain/soreness indicates participants in both EXP groups experienced a lesser increase in pain/soreness during the CON week than during the FR week, whereas a negative Δ indicates less pain/soreness during EXP week than the CON week (Figure 5)

Figure 5

Difference in Mean Changes in Pain/Soreness between Foam Rolling Durations.



Note. X-axis represents assessment times of DV. Solid black line = baseline.

Knee Range of Motion

Two-way ANOVA of mean Δ values showed there was no significant difference between EXP groups for the recovery of range of motion (*F* = .000; *P* = 1.000) at any time point post exercise (*F* = .474; *P* = .755) (Table 5).

Table 5

Test of Between-Subject Effects of FR for recovery of Knee Range of Motion.

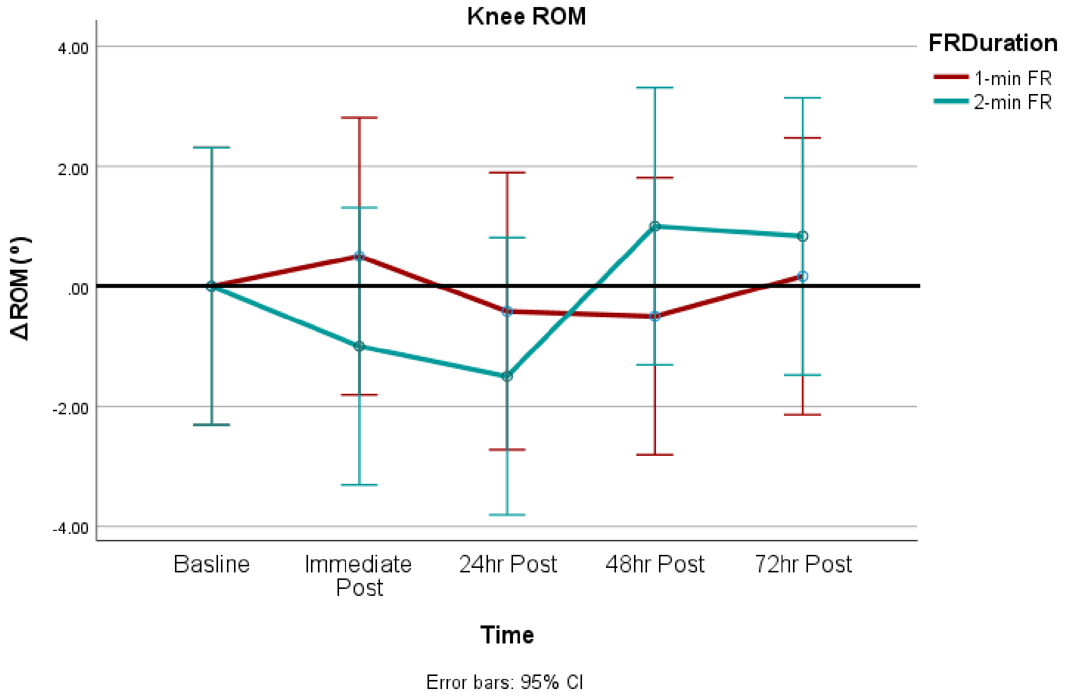
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Time	15.017	4	3.754	.474	.755
FRDuration	.104	1	.104	.013	.909

Note. Time = DV measurement times. FRDuration = duration of FR performed. Significance = *p* <.05.

When assessing recovery between both EXP groups, results showed that there was no significant difference in recovery of knee ROM between EXP groups at any time point post exercise. A negative mean Δ in ROM indicates participants experienced a lesser decrease in ROM during the CON week than during the FR week, whereas a positive Δ indicates a greater decrease in ROM during EXP week than the CON week (Figure 6).

Figure 6

Difference in Mean Changes in Knee Range of Motion between Foam Rolling Durations.



Note. X-axis represents assessment times of DV. Solid black line = baseline.

In summation, when assessing the recovery on performance-based variables, the only significance difference seen was in agility performance between baseline and the immediate post-exercise measures for both EXP groups, with no significant differences seen at any other time point. Though significant, it is believed these findings were mostly attributed to post-exercise fatigue, rather than DOMS. When assessing recovery of jump and sprint performance, there were no significant differences seen at any time point post exercise. Assessing the recovery of non-performance-based variables showed that there were no significant differences seen for pain perception/soreness or range of motion at any time points post exercise.

CHAPTER V

Discussion

The aim of this study was to explore the impact of two different acute, single bout durations of self-myofascial release (SMR) using a foam roller (FR) as an intervention for recovery from delayed-onset muscle soreness in recreationally active, college-aged males. Specifically, recovery was defined as the degree to which values returned back to baseline measures and was assessed through both performance-based variables (vertical jump height, sprint speed, agility speed) and non-performance-based variables (knee ROM and pain perception/soreness). Though this scope of research has gained significant interest within the past decade, the literature is fairly heterogeneous with some research supporting the use of FR for recovery from DOMS, while others are in opposition. Additionally, to the best of the PI's knowledge, no literature has directly compared two different acute durations of FR in order to determine a duration-dose response.

Past literature has focused on the use of a FR for the recovery of varying performance-based movements with one of the more commonly assessed movements being a vertical jump. Of the seven previous studies found to have assessed jump performance, four showed no significant difference in recovery of jump height. Rey et al., (2017) who utilized a 2 x 45sec. FR protocol found no significant difference in jump height 24 hours post exercise. The current study is also consistent with other studies who utilized a 2 x 60-sec FR protocol and found no significant difference in jump performance immediately post exercise (Laffaye et al., 2019) and immediately, 24, 48, 72, and 96 hours post exercise (D'Amico et al., 2019, 2020), respectively. The findings of the current study are similar to those previously discussed in that FR had no significant difference in the recovery of jump performance for either FR group at any time point post exercise. However, studies by MacDonald et al. (2014), Drinkwater et al., (2019), and Romero-Moraleda et al., (2019) did find FR to significantly aid in the recovery of jump performance. It is possible that the sample sizes used within Macdonald et al., (2014) (20 participants) and Romero-Moraleda et al., (2019) (32 participants) may have been large enough to account for any potential outliers. However, the idea of sample size having an impact on result was previously argued by Drinkwater et al., (2019) who used a similar sample size (11 participants) to that of the current study and found a significant difference. It is also unlikely that the type of FR used (High-density FR) impacted the results considering Drinkwater et al. (2019) and Romero-Moraleda et al., (2019) both used a FR similar to the one used in the current study and found significant results. With the current literature on using a FR for the recovery of jump performance being fairly divided, more research is warranted to provide more insight on the use of a FR for recovery of vertical jump performance.

Agility is a skill that is required in various sports and training programs, but has been shown to be negatively impacted by DOMS. To date only 4 studies have directly assessed FR's impact on the recovery of this movement following exercise, with two of the studies supporting FR for recovery of agility performance and the remaining two not supporting it. The findings of this study parallels the findings of Pearcey et al., (2015) and D'Amico et al., (2020) and found that neither a 1 nor 2-min. FR protocol had a significant impact on the recovery of agility performance at any time post exercise. Pearcey et al., (2015) who used a 1 x 45sec. FR protocol following a bout of repeat squats, while D'Amico et al., (2020) utilized a 2 x 60sec. protocol following a repeat sprint exercise. The findings of these studies are in opposition to that of Rey et al., (2017), who used a 2 x 45sec. FR protocol, and D'Amico et al., (2019), who used a 2 x 60sec FR protocol, and found a significant difference in recovery of agility performance. It is possible that the study by D'Amico et al., (2019), which required participants to complete a bout of FR immediately, 24, 48, 72, and 96 hours post exercise, may have resulted in a significant difference in agility performance when compared to the current study due to greater FR frequency. However, this could be argued by citing D'Amico et al., (2020) who utilized the same FR protocol and frequency and saw no significant difference in agility performance. As a result of the conflicting findings in the literature, in addition to a lack of literature assessing FR for recovery of agility performance, more research is warranted to better understand the impact of FR for the recovery of agility performance.

When assessing FR for the recovery of sprint performance, the current study found that sprint performance was not significantly impacted by either a 1 or 2-min. FR protocol. With only two previous studies found to have assessed the recovery of sprint performance using a FR, these findings are only consistent with one, Rey et al., (2017), who found no significant difference in recovery of sprint performance in male soccer players 24 hours following a bout of FR. In contrast, Pearcey et al., (2015) found a 1 x 45sec. bout of FR to significantly aid in the recovery of sprint performance. Differences in findings between studies could be attributed to FR frequencies and protocols employed. Pearcey and colleagues required participants to FR at various time points (immediately, 24, and 48 hours post exercise) equating to multiple sessions of FR, whereas as participants in Rey et al., (2017) and the current study only performed a single bout of FR that was completed immediately post exercise. With the literature unclear as to whether there is a frequency-dose response, it is possible that FR more frequently, as done in Pearcey et al., (2015), may result in greater recovery. However, additional research is needed to determine if there is a frequency-dose response. With limited literature having assessed sprint performance as a measure of recovery from DOMS, more research is warranted to better understand if FR can be considered a viable technique to use in individuals experiencing a decrease in sprint performance as a result of DOMS.

Range of Motion (ROM) is a non-performance-based variable commonly assessed with regards to FR. However, the literature is divided on whether FR aids in the recovery of ROM following DOMS. Within the current study, recovery of ROM at the knee joint was not significantly different between either EXP groups at any time point following exercise. These findings are consistent with Drinkwater et al., (2019) who also saw no significant difference in knee joint ROM following a 1 x 3min. bout of FR. However, they are in direct opposition of MacDonald et al., (2014) and Romero-Moraleda et al., (2019) who both found FR to significantly increase knee ROM following a 2 x 60sec. (MacDonald et al., 2014) and 5 x 60sec. (Romero-Moraleda et al., 2019) bout of FR, respectively. Differences in results may be a result of FR frequency and/or timing. Macdonald and colleagues had participants FR at each post exercise time point, whereas the current study only required FR immediately post exercise. Therefore, it is possible that a greater frequency of FR may result in better recovery. Additionally, the timing of FR may impact results. Romero-Moraleda et al., (2019) required participants to perform a bout of exercise to elicit DOMS before reassessing participants' 48 hours post exercise. During this session individuals were reassessed, completed a bout of FR, and were then immediately reassessed for a second time. Although this study does indicate that FR may aid in increase ROM immediately post FR, it makes it difficult to determine the impact of FR on recovery of ROM for any time other than immediately post FR. With such variability in findings and within methodologies used to assess recovery of ROM, it is difficult to determine FR's impact on recovery of ROM from DOMS.

Increased pain/soreness is another nonperformance measure and is the most common symptom associated with DOMS. Past literature is largely supportive of the use of FR to decrease pain/soreness associated with DOMS. However, within the current study, no significant difference was seen in pain/soreness between either EXP groups at any time point following exercise. These findings are consistent with only two other studies (D'Amico et al., 2019; Romero-Moraleda et al., 2019). When trying to determine why the current study findings are in opposition to the bulk of the literature, one might argue that the exercise protocol used in the current study may not have been vigorous enough to significantly elicit DOMS within the particular sample. When comparing the pain/soreness values of the baseline time point for both EXP groups to the 24, 48, and 72 hours post exercise measures (time points where DOMS is known to be most prevalent post exercise) it was found the there was no significant difference is pain/soreness values at any time point for either EXP group. While the repeat jump protocol used has shown to significantly impact performance in past literature (Twist and Eston, 2005; Highton, Twist, and Eston, 2009), it appears to have not been vigorous enough for the sample used in the current study.

As previously discussed, the topic of FR for the recovery from DOMS has received considerable attention within the past decade. While more research is warranted for the use of FR for recovery from DOMS, better understanding of the phenomena of DOMS itself may help to progress this line of research more directly. Within the current literature many different exercise protocols have been utilized to elicit DOMS including repeat back squats (MacDonald et al., 2014; Pearcey et al., 2015; Romero-Moraleda et al., 2019), leg extensions (Drinkwater et al., 2019), sprints (D'Amico et al., 2019, 2020), a 60-minute soccer practice (Rey et al., 2017), and Tabata (Laffaye et al., 2019). Though each of the protocols used was demonstrated to elicit DOMS, the precise mechanism as to what causes DOMS is not clearly known. As a result, it is possible that different modes of exercise may elicit DOMS differently (i.e., muscle damage vs. connective tissue damage vs. inflammation) and therefore may not be impacted by FR in the same manner. Using a consistent exercise protocol to elicit DOMS, while also measuring physiological biomarkers associated with DOMS (i.e., creatine kinase), may help to better understand not only if FR is beneficial for recovery of DOMS, but also what type of DOMS-inducing exercise FR may most benefit considering the mechanism causing DOMS may not be the same for all types of training. Though this is purely speculation, it may be beneficial in helping practitioners and consumers alike to better understand what types of athletes/active individuals would benefit most from using a FR for recovery from DOMS.

Practical Application

The current study found that there were no significant difference for any performance and non-performance-based variables at any time point between the two different FR groups. As previously discussed, that the 10x10 repeat jump exercise may not have been vigorous enough to elicit DOMS within the population used. Although physiological variables (i.e. creatine kinase) were not used to directly assess DOMS, pain/soreness (a variable shown to increase with the onset of DOMS) was not significantly elevated at any time point post exercise suggesting the DOMS was not present. Therefore, the impact of a single bout of 1 or 2-minutes of FR for the recovery from DOMS could not thoroughly be assessed.

Study Limitations

As within all studies there were several limitations within the study that are worthy of being noted. The first limitation would be the exercise protocol used to elicit DOMS. The 10x10 repeated vertical jump has shown to induce DOMS in past literature and decrease performance (Twist and Eston, 2005; Highton, Twist, and Eston, 2009). However, for the sample used in the current study, the protocol appeared to not be vigorous enough to elicit significant DOMS and therefore did not significantly impact individual's performance. As a result, the impact of FR for recovery from DOMS could not fully be assessed. The second limitation would be the sample used. Though the sample size calculated from the A*Priori analyses was met, it may not have been large enough to compensate for potential outliers seen within the data. Additionally, the results of the study can also only be generalized to the population assessed within the study and for recovery from a repeat jump-based exercise. Another limitation was the way in which DOMS and recovery were assessed. Both were assessed using performance, kinematic, and perceptual measurements rather than physiological measures (i.e., creatine kinase) (CK). Measuring CK, a well-known biomarker of muscle breakdown, could have helped to determine the overall level of muscle breakdown following exercise to determine if EIMD and DOMS was elicited. CK could have also been reassessed during the recovery phase to see if FR has an impact on CK levels, thus potentially indicating FR helps decrease CK levels aiding in muscular recovery. The final limitation is that while participants were asked during the familiarization/orientations session, and continuously reminded after each testing session, to refrain from any additional exercise and/or recovery techniques outside of testing, it is possible that participants may not have adhered to this request. If not followed, this could have altered the data. The only way of completely limiting participants from doing any additional exercise and/or recovery would be to have them stay within the lab for 72-hours under continuous surveillance.

Future Research

Based upon the findings of the current investigation, there are still some unknowns within this topic that future research endeavors should focus on. First, a larger sample size should be utilized to be better able to thoroughly compare the impact of different durations of FR for the recovery from DOMS. Next, while this was the first study, to the knowledge of the primary investigator, to directly compare the impact of two different durations of FR for recovery from DOMS, future studies should focus on completion of more than one bout of FR to see if greater frequency of FR impacts the rate of recovery. Additionally, different FR durations should be compared to better understand the most appropriate protocol (duration, pressure, and frequency) one should complete for recovery from DOMS. With regards to DOMS, future studies should assess the impact of 1 and 2-min of FR on the recovery from DOMS that is elicited via endurance-based training. With the exact mechanisms of DOMS not completely understood, it is possible that different types of training elicits DOMS via different mechanisms and therefore FR for one type of training may not be suitable for recovering from a different type of training.

Conclusion

Timely recovery from EIMD and DOMS is vital for recreationally active individual and competitive athletes alike, yet there is no ‘gold standard’ technique for recovering from DOMS noted in the literature to date. While it is yet to be determined if there is a frequency and/or dose-duration relationship for FR for recovery from EIMD and DOMS and specifically what type of FR is most appropriate to use, the findings of the current study indicate that FR the lower extremities for either 1 or 2-minutes is not beneficial for recovery from DOMS within recreationally active, college-aged males using a high-density foam roller. However, with FR being readily available, variables in terms of type of FR, cost-effective and self-performed, in addition to the literature assessing its impact on recovery from DOMS being very conflicting, more research is warranted to better determine if FR can be considered a viable option for those looking to recover from EIMD and DOMS.

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Appendix A

IRB Approval

EAST STROUDSBURG UNIVERSITY

East Stroudsburg University Institutional Review Board
Human Research Review
Protocol # **ESU-IRB-0900-2021**

Date: **July 20, 2021**
To: **Connor Saker and Chad Witmer**
From: **Shala E. Davis, Ph.D., IRB Chair**
Proposal Title: **"Exploring the Impact of Different Acute Durations of Foam Rolling as a Recovery Technique following Intense Exercise"**

Review Requested:	Exempted **X**	Expedited	Full Review
Review Approved:	Exempted **X**	Expedited	Full Review

FULL RESEARCH

__**X**_ Your full review research proposal has been approved by the University IRB (12months). Please provide the University IRB a copy of your Final Report at the completion of your research.

_____ Your full review research proposal has been approved with recommendations by the University IRB. Please review recommendations provided by the reviewers and **submit necessary documentation for full approval.**

_____ Your full review research proposal has not been approved by the University IRB. Please review recommendations provided by the reviewers and resubmit.

EXEMPTED RESEARCH

_____ Your exempted review research proposal has been approved by the University IRB (12 months). Please provide the University IRB a copy of your Final Report at the completion of your research.

_____ Your exempted review research proposal has been approved with recommendations by the University IRB. Please review recommendations provided by the reviewers and **submit necessary documentation for full approval.**

_____ Your exempted review research proposal has not been approved by the University IRB. Please review recommendations provided by the reviewers and resubmit, if appropriate.

EXPEDITED RESEARCH

_____ Your expedited review research proposal has been approved by the University IRB (12months). Please provide the University IRB a copy of your Final Report at the completion of your research.

_____ Your expedited review research proposal has been approved with recommendations by the University IRB. Please review recommendations provided by the reviewers and **submit necessary documentation for full approval.**

_____ Your expedited review research proposal has not been approved by the University IRB. Please review recommendations provided by the reviewers and resubmit, if appropriate.

Appendix B

Institutional Review Board (IRB) Authorization Agreement

Institution or Organization Providing IRB Review: **East Stroudsburg University of Pennsylvania**

IRB Registration #: **00004767**

Federal-wide Assurance (FWA)#, if any: **00008733**

Institution Relying on the Designated IRB: **Seton Hall University**

FWA#: __FWA00001223____

The Officials signing below agree that **Seton Hall University** may rely on the designated IRB for review and continuing oversight of its human subjects research descried below: (check one):

(___) This agreement applies to all human subjects research covered by the institution B's FWA.

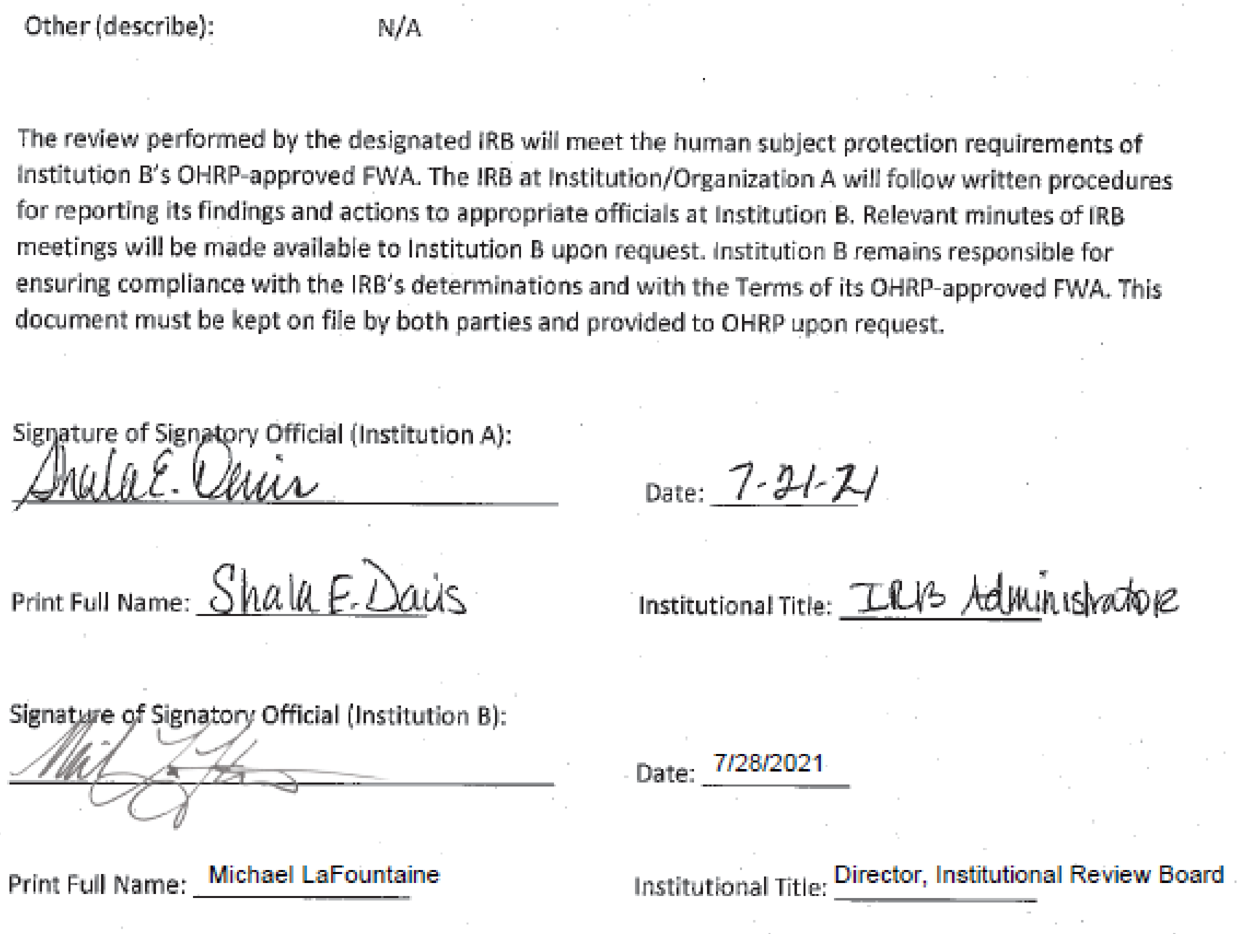
(_X__) This agreement is limited to the following specific protocol(s):

Name of Research Project: **"Exploring the impact of Different Acute Durations of Foam Rolling as a Recovery Technique following Intense Exercise"**

Name of Principal Investigator: Connor Saker, ABD

Sponsor of Funding Agency: N/A

Award Number, if any: N/A



Other (describe): N/A

The review performed by the designated IRB will meet the human subject protection requirements of Institution B's OHRP-approved FWA. The IRB at Institution/Organization A will follow written procedures for reporting its findings and actions to appropriate officials at Institution B. Relevant minutes of IRB meetings will be made available to Institution B upon request. Institution B remains responsible for ensuring compliance with the IRB's determinations and with the Terms of its OHRP-approved FWA. This document must be kept on file by both parties and provided to OHRP upon request.

Signature of Signatory Official (Institution A): Shala E. Davis

Date: 7-21-21

Print Full Name: Shala E. Davis

Institutional Title: IRB Administrator

Signature of Signatory Official (Institution B):

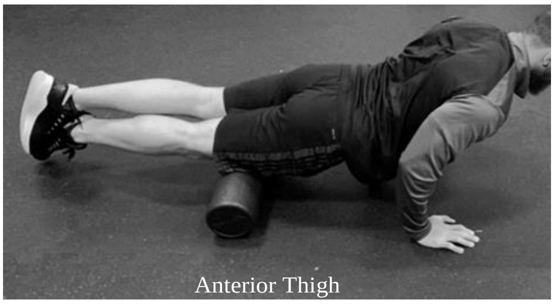
Date: 7/28/2021

Print Full Name: Michael LaFountaine

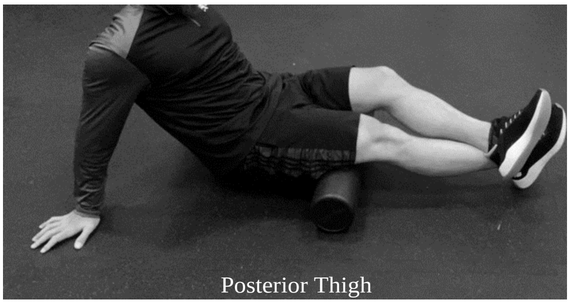
Institutional Title: Director, Institutional Review Board

Appendix C

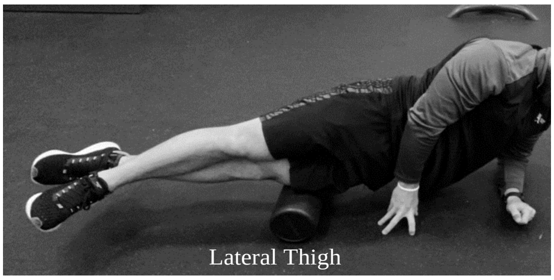
Foam Rolling Positioning



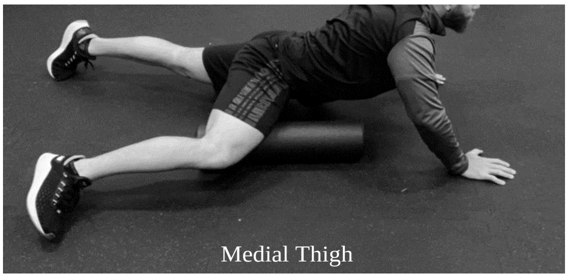
Anterior Thigh



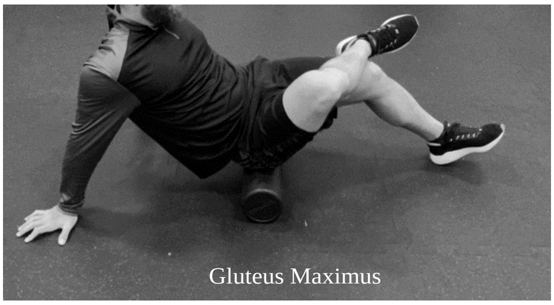
Posterior Thigh



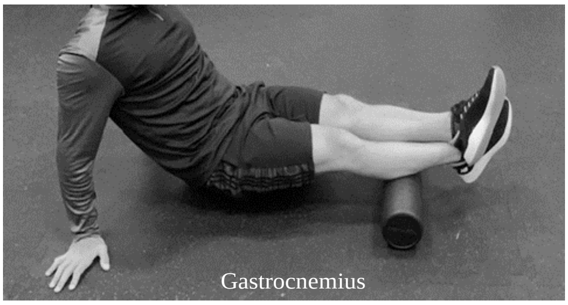
Lateral Thigh



Medial Thigh



Gluteus Maximus



Gastrocnemius