Acute Effects of Moist Heat and Foam Rolling on Dynamic Hamstrings Flexibility and Hip Joint Range of Motion in NCAA Division II Female Lacrosse Athletes

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Matthew Robert Flattery

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ACUTE EFFECTS OF MOIST HEAT AND FOAM ROLLING ON DYNAMIC HAMSTRINGS FLEXIBILITY AND HIP JOINT RANGE OF MOTION IN NCAA DIVISION II FEMALE LACROSSE ATHLETES

A thesis prepared by Matthew Robert Flattery, ATC

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

Penny Sanders 6.19-17

Dr. Penny Sanders Date
Director of Graduate School

Tracey L Robinson 6-19-17

Dr. Tracey Robinson Date
Chairman of Thesis Committee

Thesis Committee Members:

Tracey L Robinson
Tracey Robinson, PhD

B M Zuleger
Brian Zuleger, PhD

D Oranchuk
Dustin Oranchuk, MS

Abstract

While there are many methods used by athletes to decrease muscle tightness and thus increase range of motion (heating, stretching, joint mobilizations), one of the newest and least studied methods is foam rolling. While purported to increase range of motion, decrease delayed onset muscle soreness (DOMS), and increase athletic performance, there is very little scientific research to date on the validity of these claims, particularly increasing range of motion, which is how it is most commonly used. **Purpose:** The purpose of this study was to compare the acute effects of moist heat, foam rolling, and a combination of both methods on hip joint range of motion. **Methods**: Eleven NCAA Division II female lacrosse athletes volunteered for the study. The participants had a mean height, body weight, age, and years of lacrosse experience of 163.43 ± 8.5 cm, 62.15 ± 9.0 kg, 19.9 ± 1.51 years, and 6.55 ± 3.83 years of experience, respectively. A pre-season baseline measurement of active hip flexion range of motion was taken before the beginning of the lacrosse season. Participants reported for testing at the same time of day on the Monday of three consecutive weeks. Athletes began each day by having baseline active hip flexion range of motion measured, followed by one of three interventions in a randomized order: application of a moist hot pack for 10 minutes, foam rolling the hamstrings for three sets of 60 seconds with sets separated by 15 seconds, or a combination of heating followed by foam rolling. Immediately following the intervention, participants had range of motion measured again using the same protocols. All measurements were taken three times and then averaged. **Results:** A two-way repeated measures ANOVA showed that all three interventions significantly increased range of motion ($p < 0.001$) from pre-post intervention, however no intervention

increased range of motion more than any other intervention by a statistically significant margin ($p > 0.05$). Despite the lack of statistical significance, effect sizes indicated that the combination intervention had the largest magnitude of practical effect with a large effect size ($d = 0.85$), while heating and foam rolling had medium effect sizes ($d = 0.54$, $d = 0.41$ respectively). Heating increased range of motion by a mean of 8.14 ± 3.17 degrees, while foam rolling and the combination increased range of motion by means of 5.93 ± 3.9 degrees and 9.91 ± 6.83 degrees, respectively. **Conclusions:** These results indicate that heating, foam rolling, and a combination of both can all be effective in acutely increasing range of motion. However, the combination of both treatments may be most effective, time and resources allowing. Further studies may wish to investigate the effects that foam rolling on consecutive days has on range of motion, or other combinations, such as heating, stretching, and foam rolling with a larger, more diverse population of participants. Future studies could also investigate the effects of heating and foam rolling on different muscles or joints. **Practical Applications:** Oftentimes, those in the sports medicine community are short on time and must help multiple athletes at once. The results show that athletes can perform heating and foam rolling on their own and see significant increases in range of motion. Findings also indicate that, if limited on time, athletes can either heat or foam roll and have a decrease in muscle tightness. Athletic departments with a minimal budget can also invest in a hydrocollator with hot packs and foam rollers and potentially see similar results as more expensive treatments options.

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Chapter I

Introduction

Aside from traumatic, acute injuries, the most common complaint heard in the sports medicine community from athletes is that their muscles feel tight. One of the most commonly tight muscle groups is the hamstrings, which can also lead to lower back pain if untreated (Sairyo et al., 2013). There are various causes for this tightness, from overuse to biomechanical imbalances (Prentice, 2004). Though muscles tend to loosen up on their own, and tightness may not reoccur once the athlete is accustomed to the amount of activity they are doing, some muscles can be chronically tight in athletes (Clark, 2016). If muscles become chronically tight, it can lead to more injuries throughout the kinetic chain, or even lead to tears in the muscles or tendons (Clark, 2016). In order to combat tight muscles, there are many treatments that athletic trainers suggest, such as stretching, massage, moist hot packs, ultrasound therapy, or shortwave diathermy (Prentice, 2004). Heating is perhaps the most common, due to the simplicity and the fact that athletes can often do it themselves without the aid of an athletic trainer (Starkey, 2004). The application of heat modalities have been shown to, among other things, increase rate of cellular metabolism, increase elasticity of tissues, decrease muscle spasm and decrease pain (Starkey, 2004). While these methods have been shown to be effective, some (ultrasound, shortwave diathermy) are quite expensive and not a viable option for schools with small budgets, or to the average person who suffers from tight muscles.

One of the newest methods to be introduced in the past decade is foam rolling (Boyle, 2016). Certified athletic trainer and strength and conditioning coach Michael Boyle writes that it was first introduced into the athletic and sports medicine world approximately a decade ago (Boyle, 2016). He credits physical therapist Michael Clark for helping to bring foam rolling to the mainstream, altering the focus of physical therapy and rehabilitation to soft-tissue care, instead of electrical modalities and isokinetic exercises (Boyle, 2016).

Since its inception, foam rolling has been associated with many positive effects for athletes; it is purported to solve nearly every issue, including increasing range of motion, decreasing delayed onset muscle soreness (DOMS), and even aiding power output, lowering injury risk, and relieving joint stress (Boyle, 2016; TP Therapy, 2017). Since it is such a relatively new method, there are questions regarding how effective it is, how its effects can be best utilized and whether or not the effects are cumulative or go away after a short period time, etc. One persistent question heard by athletic trainers is what duration of rolling is necessary to have a beneficial effect; research thus far points to longer being superior to shorter, however the upper limit appears to be approximately 60 seconds per set (Bradbury-Squires et al., 2015; Sullivan, J. Silvey, Button, & Behm, 2013). Those selling the product recommend using it every day you exercise in order to see a more substantial of an effect, believing that the effects may be lost if a person goes too many days without foam rolling (TP Therapy, 2017). Those in the sports medicine field are taught that a combination of methods can be effectively used to ease tightness and increase range of motion: one of the more common combinations is heating, stretching and foam rolling (Prentice, 2004).

Purpose of the Study

The purpose of this study was to test the efficacy of foam rolling to decrease hamstrings tightness in athletes. Hamstrings tightness was tested by the amount of active hip flexion range of motion. Because many in the active population use a foam roller in order to decrease muscle tightness or increase range of motion, those purported effects of foam rolling were the focus of the study. The efficacy was compared to that of moist heat packs, which is one of the most common modalities used by athletic trainers to ease muscle tightness and increase range of motion. While the hamstrings was the muscle group in question, this study aimed to see the effects on muscles in general, as a proof of concept for foam rolling and heating to increase range of motion around a joint, which may be limited due to muscular tightness. Hamstrings were chosen for the ease of both the participants and the researcher, as well as for their importance in many sports. A secondary purpose of this study was to use a Likert scale survey to find which intervention the participants felt was most effective at decreasing hamstrings tightness.

Hypotheses

It was hypothesized that both foam rolling and heating alone would be enough to acutely decrease hamstrings tightness (and thus increase range of motion) when compared with the baseline measurement. It was also hypothesized that the combination of foam rolling and heating would be more effective than each individual treatment alone at decreasing hamstrings tightness and increasing range of motion compared to the baseline measurement of either condition alone.

Research Questions

1. Will foam rolling alone significantly decrease hamstrings tightness and therefore increase hip flexion range of motion?
2. Will heat alone be enough to significantly decrease hamstrings tightness and therefore increase hip flexion range of motion?
3. Will the combination of heating and foam rolling significantly decrease hamstrings tightness and therefore increase hip flexion range of motion more than foam rolling or heat separately?
4. Which intervention will the participants feel is most effective decreasing hamstrings tightness and increasing hip flexion range of motion?

Delimitations

Only female lacrosse athletes, from 18 to 22 years old, from a small, rural Division II university were asked to participate in this study. The team had a good rapport with the researcher who carried out this study, and as a result they were more likely to comply than other teams. Range of motion of the hip joint was determined via goniometer, as opposed to other methods, such as a bubble inclinometer. Goniometers are a common and accurate method for measuring range motion (Prentice, 2004), and were readily available at the testing site. The researcher also had six years of experience using this tool. Foam rolling was limited to three sets of 60 seconds per session, as this appears to be the point where the largest effects are seen from foam rolling (Bradbury-Squires et al., 2015; Sullivan et al., 2013). Volunteers with any lower extremity injury within the past 12 months that caused them to miss at least three practices or one competition were disqualified from participation. This was to ensure that any difference in range of motion, either pre-treatment or post-treatment, was not due to a past injury. Foam rolling was delimited to comparison to only heat in order to decrease muscle tightness and increase range of motion, as opposed to other methods of increasing range of motion such as stretching, joint mobilizations, or massage. The method of heating was delimited to moist heat instead of other methods such as ultrasound or shortwave diathermy. Heating was limited to 10 minutes per participant, as this was the duration which lets the heat penetrate the muscle tissue and have physiological effects (Starkey, 2004).

Limitations

Foam rolling can be very uncomfortable and even painful for some participants, and as a result they may use less than optimal pressure when rolling out, which may have decreased efficacy (Bradbury-Squires et al., 2015; Sullivan et al., 2013). While the hydrocollators were kept at a constant temperature, the temperature of each individual hot pack may have varied slightly. The athletes' diets, hydration status, and activities were not controlled outside of the laboratory setting; however it was requested that they maintain their normal activity levels and diets throughout the duration of the study. Athletes were in season during the study, and as a result, may have been tired or sore from the previous week's practices. Athletes were instructed to avoid any method to increase range of motion (massage, heating, foam rolling) on the rest days in between testing. A copy of their practice log from the week of the study is included in the appendix. A goniometer may not have been the most accurate instrument to measure range of motion, however it was the method that the researcher had the most experience in using, and was the only measurement tool readily available.

Assumptions

All participants were instructed to give full effort throughout all testing, and full effort was assumed when analyzing and interpreting all results. It was assumed that all athletes would remain injury-free outside of the laboratory setting, and would alert the researcher to any changes in their health. It was assumed that the angle reading given by the goniometer was accurate. It was also assumed that the correct anatomical landmarks were used and that the measurements were consistently taken in all trials with all participants. It was assumed that 10 minutes was a sufficient time of application for a moist hot pack to have an effect on range of motion. It was also assumed that three sets of 60s of foam rolling was enough to increase range of motion. It was assumed that the participants complied with instructions to not use any modality to help decrease muscle tightness during the study, and maintained their normal diet and hydration status. It was assumed that the time of day and nutrition of different participants had a minimal effect on their measurements.

Definition of Terms

Fascia: a thin sheath of fibrous tissue enclosing a muscle or other organ (Venes & Taber, 2005).

Flexion: a bending movement around a joint in a limb (as the knee or elbow) that decreases the angle between the bones of the limb at the joint (Venes & Taber, 2005).

Foam Rolling: a self-myofascial release technique that is used by athletes and physical therapists to inhibit overactive muscles and increase range of motion, using a foam cylinder of various sizes and densities (Venes & Taber, 2005).

Goniometer: an instrument for the precise measurement of joint angles (see Figure 1: Appendix II) (Venes & Taber, 2005).

Greater Trochanter: a large, irregular, quadrilateral eminence of the lateral femur (see Figure 2: Appendix II) (Venes & Taber, 2005).

Hamstrings: the muscle group on the posterior thigh comprised of the semitendinosus, semimembranosus, and biceps femoris muscles, involved in knee flexion and hip extension (see Figure 3: Appendix II) (Venes & Taber, 2005).

Joint Mobilizations: a manual therapy technique involving slow, passive movement of a joint's articulating surfaces, used to regain normal active joint range of motion, restore normal passive motions that occur about a joint, reposition or realign a joint, or reduce pain (Venes & Taber, 2005).

Lateral Epicondyle: a small, bony protrusion located on the lateral side of the distal femur (see Figure 2: Appendix II) (Venes & Taber, 2005).

Range of Motion (ROM): the measurement of movement around a specific joint or body part (Venes & Taber, 2005); in this study, ROM is measured specifically at the hip joint, by the angle between a person's raised leg (with knee fully extended) and their trunk while keeping their back flat on the treatment table (see Figure 4: Appendix II).

Self-myofascial release (SMR): a manipulative treatment that attempts to release tension in the fascia due to trauma, posture, or inflammation (Venes & Taber, 2005).

Shortwave Diathermy: a therapeutic elevation of temperature in the tissues by means of an oscillating electric current of extremely high frequency (10–100 million Hz) and short wavelength of 3–30 meters (Starkey, 2004).

Ultrasound: a therapeutic modality emitting ultrasonic waves to decrease muscle spasms by reducing the mechanical and chemical triggers that cause the pain-spasm-pain cycle (Starkey, 2004).

Chapter II

Review of the Literature

Since foam rolling has gained popularity recently in the past decade, the literature is severely lacking; therefore further scientific research must be done to test its efficacy. As a result, the review of literature was expanded to include other methods commonly used in the sports medicine community to restore or increase a joint's range of motion and decrease muscle tightness. While not all of these methods will be tested in this experiment, they are relevant to muscle tightness resulting in a lack of range of motion of a joint. The hamstrings muscle group, as a long, powerful muscle group on the posterior thigh, plays a large role in sports (Fujii, Sato, & Takahira, 2012; Ghandi, Thakkar, & Shah, 2015; Nigg, MacIntosh, & Mester, 2000). As a result, they can be prone to tightness in athletes which in turn can lead to sports injuries, disorders of the lumbar spine, or lower back pain (Ghandi et al., 2015). Due to the importance of the hamstrings muscle group in athletics and the problems that can arise when they are tight (Lempainen et al., 2015), this was the focus of the current study. Literature pertaining to the underlying cause of muscle tightness was also investigated. The hamstrings are also an easy muscle group to roll out, and the range of motion of the group is easily measured, which should increase the accuracy of interventions and measurements in this study.

Hamstrings

Being such a large, powerful muscle group, the hamstrings are a crucial component in basically any lower extremity athletic movement. Because the hamstrings are such an active muscle group in so many different activities, they are one of the more commonly tight muscles, as well as one of the most common muscles to suffer from strains (Felser et al., 2016; Kalli & Dimitrios, 2016; Lempainen et al., 2015).

One of the most important actions of the hamstrings (specifically the biceps femoris muscle), is to prevent excessive internal rotation of the tibia (Fujii et al., 2012). Fujii and colleagues (2012) investigated internal rotation of the tibia in 10 collegiate basketball players (5 male and 5 female). Participants performed a single-leg drop landing from a 25 cm height, while measuring internal rotation of the tibia (measured by 3D motion tracking software), hamstrings activation (via EMG), and ground reaction forces (Fujii et al., 2012). Results indicated that there was a positive correlation between decreased tibial rotation and lateral hamstrings (biceps femoris) activation (Fujii et al., 2012). These results led the researchers to conclude that a fully functioning biceps femoris muscle is crucial in preventing excessive tibial internal rotation during closed-kinetic chain activities, which in turn can help prevent injuries such as anterior cruciate ligament (ACL) or medial collateral ligament (MCL) tears (Fujii et al., 2012). Fujii et al. (2012) found more significant differences between biceps fremoris activation and tibial internal rotation in the female participants, leading them to believe that increasing biceps femoris strength in young female athletes could help prevent ACL tears (Fujii et al., 2012, Prentice, 2004).

There are many risk factors that are thought to contribute to hamstrings strains, however one of the most common appears to be tightness in the muscle (Lempainen et al., 2015). Lempainen et al. (2015) reviewed relevant literature regarding hamstrings strains, in order to better understand risk factors associated with them, as well as possible preventative measures and treatments for sports medicine practitioners. The most common cause of hamstrings strains was found to be forceful hip flexion, combined with ipsilateral knee extension (Lempainen et al., 2015). This mechanism puts the hamstrings on a stretch; stretching too far, or too quickly, will cause the fibers to tear, resulting in a muscle strain (Lempainen et al., 2015). Among the most effective methods of prevention of these injuries were found to be strengthening of the hamstrings, proprioceptive, sport-specific training, proper warm-up/cool-down, and increasing range of motion at the hip/knee joints (Lempainen et al., 2015). While the first three methods are very common in most sports, the authors believe that methods to increase range of motion and flexibility in the hamstrings are generally lacking; research points to flexibility being a very effective method to lower the prevalence of this injury (Lempainen et al., 2015).

Kalli and Dimitros (2016) also investigated decreasing tightness of the hamstrings (increasing hip and knee range of motion) to decrease the prevalence of hamstrings injury. Their methods included searching various medical databases for any randomized, controlled trials investigating the prevention and care of hamstrings injury (Kalli & Dimitrios, 2016). Results were combined and analyzed to find the most effective treatments and preventative measures for these injuries (Kalli & Dimitrios, 2016). Fourteen studies in all were used when compiling this review (Kalli & Dimitrios, 2016). Results tended to agree with those given by Lempainen et al. (2015). The most common ways to prevent hamstrings strains include proper strengthening of the muscle itself, proper warm-up before activities, and methods to decrease tightness of the muscle and increase the joint's range of motion, whether it be heating before activity, stretching, or

SMR (Kalli & Dimitrios, 2016). When rehabilitating from hamstrings injury, the authors found that eccentric strengthening and light stretching to avoid losses of range of motion could also be effective in restoring full function (Kalli & Dimitrios, 2016).

Hamstrings flexibility was again a crucial component in returning to play following a hamstrings injury as demonstrated by Delvaux et al. (2014). Thirty-seven team physicians from French and Belgian professional soccer leagues were interviewed on the criteria that they use in order to clear an athlete to return to practice/competition following hamstrings injury (Delvaux et al., 2014). While there were various criteria used by each practitioner, hamstrings muscle strength and hamstrings flexibility were mentioned by all of them (Delvaux et al., 2014). Consistent with previous research, Delvaux et al. (2014) also noted a positive correlation between limited hamstrings flexibility and a higher chance of hamstrings injury.

Muscle Tightness

Athletic performance depends on many different factors, but one of the biggest factors is musculoskeletal health which is often addressed with strength training (Sullivan, Silvey, Button, & Behm, 2013). Another crucial factor in maximizing musculoskeletal health is appropriate range of motion (Sullivan et al., 2013). Flexibility of a muscle may be hindered for a number of reasons, but the main cause appears to be fascial restrictions (or adhesions) (Morton, Oikawa, Phillips, Devries, & Mitchell, 2016; Sullivan et al., 2013).

Fascial restrictions can occur in any fascia found in the body, and are generally caused by injury, disease, inactivity, inflammation, or intense physical exercise (Morton et al., 2016; Sullivan et al., 2013). These issues can cause the fascia surrounding the muscle fibers to adhere together, restricting the muscle's contraction mechanics and inhibiting the muscle from contracting or relaxing through the full range of motion (Morton et al., 2016; Prentice, 2004; Sullivan et al., 2013). These restrictions can end up reducing flexibility, range of motion, strength, motor coordination, and be part of the cause of soreness following exercise (Sullivan et al., 2013). Foam rolling is believed to increase range of motion by directly combatting these fascial restrictions (Morton et al., 2016; Sullivan et al., 2013; TP Therapy, 2017). The mechanism behind this is believed to be the pressure exerted on the muscle fibers by the foam roller, combined with the rolling action along the muscle fibers in order to 'smooth' out the adhesions (TP Therapy, 2017).

While there were randomized control trial studies found that specifically looked at the causes of muscle tightness, many studies investigating ways to alleviate it mentioned potential causes in their introductions (Morton et al., 2016; Sullivan et al., 2013). The prevailing cause is believed to be myofascial restrictions (Morton et al., 2016; Sullivan et al., 2013). Due to the physiological mechanism behind muscle tightness, it appears that foam rolling would be effective in combatting these adhesions; heat may also help to loosen the tissue (Morton et al., 2016; Sullivan et al., 2013; TP Therapy, 2017).

Heating

In the athletic training field, heating is one of the more common modalities used to decrease muscular spasm or tightness. The application of heat has been shown to accelerate metabolic rate, decrease muscle spasm, elongate tissues and reduce scar tissue (Starkey, 2004). Practitioners try to raise the temperature of the treated area by 1°C to

4°C to receive the most benefits (Starkey, 2004). Superficial heat modalities (moist hot packs, warm whirlpools) have a depth of heat penetration of less than 2 centimeters, which can limit their efficacy for deeper tissues (Starkey, 2004). Other common heating modalities, such as ultrasound and shortwave diathermy, are deep heating modalities and can heat tissues to depths greater than 2 cm (Starkey, 2004). This difference is significant, as a deeper effect of heating can make it possible to treat muscles that are deeper than two cm below the skin, or muscle knots that may be deeper in the belly of the muscle (Starkey 2004).

Moist Heat

Although some studies find that different forms of heat can be effective (Hanson & Day, 2012; Katsuyuki, Yuka, Hisayoshi, & Takayuki, 2014), others have found that it may not be as effective in returning range of motion or joint function as it was previously thought (Warner, Kyung-Min, Hart, & Saliba, 2013). Hanson and Day (2012) looked at different forms of heating tissue and the effect on range of motion. Forty-four subjects (24 male and 20 female) applied heat for 10 minutes each (Hanson & Day, 2012). Subjects were then tested for passive range of motion for hip flexion, and repeated for three trials (Hanson & Day, 2012). Heat via exercise, warm whirlpool and a moist hot pack were utilized in the research, and researchers found that all of the subjects increased hip flexion angle from the pre-intervention measure, although the exercise had the greatest mean change of 3.8 degrees when compared to warm whirlpool and moist hot pack (1.6 and 1.8 degrees, respectively) (Hanson & Day, 2012). Katsuyuki et al. (2014) used ultrasound as a different, potentially deeper, form of heat and found that 10 minutes of ultrasound was sufficient to increase range of motion of the muscle fibers of the upper trapezius, compared to the control and placebo groups.

In another study using moist heat, researchers investigated range of motion along with grip strength, pressure pain threshold, and wrist extension strength on 28 healthy male college students (Khamwong, Nosaka, Pirunsan, & Paungmali, 2012). Fourteen of the 28 subjects had a moist hot pack applied to their wrist as an intervention, while the other half served as the control and received no intervention (Khamwong et al., 2012). While there were some positive results from the hot pack group, they were limited (Khamwong et al., 2012). Heating increased both passive and active wrist flexion range of motion, as well as increased pressure pain threshold; however it was not significant compared to the control group ($p = 0.593$) (Khamwong et al., 2012).

Warner et al. (2013) investigated 12 subjects with a history of knee-joint pathology and arthrogenic muscle inhibition. Subjects received three applications of a moist heat pack on the affected knee for 15 minutes each (Warner et al., 2013). An isokinetic dynamometer was used to assess knee torque, and a skin EMG was used to assess quadriceps function (Warner et al., 2013). After the treatments, there was no evidence of moist heat packs adding to quadriceps function or knee torque created (Warner et al., 2013). All participants began the experiment will full knee extension range of motion, and as a result no effects from the moist heat were seen (Warner et al., 2013).

Moist heat packs also had no effect on pain or range of motion when combined with scapular mobilizations in 66 participants with subacromial impingement syndrome, referred to the researchers by their treating physicians (Aytar et al., 2015). In the study by Aytar et al. (2015), the 66 participants were split into three groups, including scapular mobilizations, sham scapular mobilizations, and the group who only performed strengthening exercises (Aytar et al., 2015). Moist heat was applied to all participants prior to their specific intervention (Aytar et al., 2015). There was no significant change in pain between the intervention groups; however range of motion was increased with the combination of heat, strengthening and scapular mobilizations, while there were limited increases with the sham scapular mobilizations (Aytar et al., 2015).

Ultrasound

As a deep heating modality, ultrasound can penetrate superficial tissues to apply heat to deeper tissues; however its area of effect is smaller (only twice the diameter of the ultrasound head, or up to 4cm) than that of moist heat, and requires a practitioner to perform it (Starkey, 2004). As a result, it is less often used in the athletic training setting (Starkey, 2004).

Ultrasound can be used to decrease muscle spasm by reducing the mechanical and chemical triggers that cause the pain-spasm-pain cycle to continue (Starkey, 2004). Multiple studies have found that ultrasound is effective on its own at increasing range of motion in various levels of participants, and can also be used in conjunction with other modalities to further enhance these improvements (Draper, 2010; Jeong, Yong-Nam, & Hyun, 2014; Katsuyuki et al., 2014). One study tried to take advantage of these facts and investigated using low-intensity pulsed ultrasound with cryotherapy to return a knee's full function following a total replacement surgery (Jeong, Yong-Nam, & Hyun, 2014). The researchers observed that all experimental groups (ultrasound, cryotherapy, or both), experienced significant progress in overall knee function over a three-week testing period; however the combination of the two was most effective, and the ultrasound alone was least effective (Jeong, Yong-Nam, & Hyun, 2014).

Katsuyuki et al. (2014) focused solely on ultrasound as a method to increase range of motion and decrease stretch pain (Katsuyuki et al., 2014). The study consisted of 15 males, split into three groups: a group receiving ultrasound (n=5), a placebo group receiving unpowered ultrasound (n=5), and a control group that just rested (n=5) (Katsuyuki et al., 2014). Ultrasound was applied to the upper fibers of the trapezius muscle, found at the midpoint between the acromion process of the ipsilateral clavicle and the spinous process of C7 (Katsuyuki et al., 2014). Each group received a 10-minute treatment session either with the powered ultrasound at 3MHz and 100% duty cycle, an unpowered ultrasound (both with transducing gel), or the control group receiving just the transducing gel (Katsuyuki et al., 2014). The study's results showed that 20 minutes following the 10 minutes of ultrasound, both passive and active range of motion increased much more than the placebo or control group (Katsuyuki et al., 2014). The mechanical and heating effects of the ultrasound were believed to be the main reasons behind the range of motion increases, as well as an explanation as to why the placebo and control groups did not receive any increases (Katsuyuki et al., 2014). In agreement with Katsuyuki et al. (2014), Draper (2010) found that after six treatments of ultrasound and joint mobilizations to the wrist, five of the six participants had achieved normal flexion active range of motion. All of the participants achieved full extension active range of motion compared to their uninjured wrist, as well as a return to normal activities of daily life (Draper, 2010).

Shortwave Diathermy

Like ultrasound, shortwave diathermy (SWD) is a deep heating modality, and has a larger area of effect than ultrasound (Starkey, 2004). However, it is very expensive compared to an ultrasound machine or moist hot packs and, like ultrasound, needs an athletic trainer or physical therapist to operate it. Due to these factors, and the fact that any patient with metal implants are contraindicated from using the machine, it is very rarely found in the athletic training community (Draper, 2013; Starkey, 2004).

Microwave diathermy (same concept with different wavelengths than SWD) has been shown to be effective in heating tissues (Draper, 2013). Shortwave diathermy involves placing a patient within the device's magnetic field and allowing their body to act like a radio receiver, converting the energy into heat (Starkey, 2004). A pulse width of 200 milliseconds and a pulse rate of 800 pulses per second have been shown to help treat pain syndromes, muscle spasms and chronic inflammation (Starkey, 2004).

Martínez-Rodríguez and colleagues in 2014 investigated the heating effects that a session of shortwave diathermy (SWD) could have on hamstrings extensibility (Martínez-Rodríguez, Bello, Yañez-Brage, & Turner, 2014). Twenty participants (10 female, 10 male) volunteered, with a mean age of 24.78 years (Martínez-Rodríguez et al., 2014). All participants suffered from tight hamstrings, defined by a knee extension of less than 150 °, and were randomly assigned into a control group and an experimental group (Martínez-Rodríguez et al., 2014). Following a pre-treatment test of passive and active range of motion, the experimental group received a 15-minute treatment of SWD, while the control group received no intervention (Martínez-Rodríguez et al., 2014). Following the 15 minutes, passive and active range of motion were again measured for all participants

(Martínez-Rodríguez et al., 2014). They found that there were no increases in passive or active range of motion immediately following one 15-minute session of SWD (Martínez-Rodríguez et al., 2014). However, it was theorized that repeated sessions with stretching could help restore full knee extension to the participants, due to cumulative effects of SWD (Martínez-Rodríguez et al., 2014). The researchers' hypothesis was supported by Draper and VanPatten (2010), where two weeks of daily SWD treatment, combined with joint mobilizations three times a week, was able to return full knee extension in ACL rehabilitation (Draper & VanPatten, 2010).

Stretching

Unlike heating modalities, which use chemical processes to elongate tissues, stretching consists of mechanically elongating muscle fibers in an attempt to lengthen the muscle overall (Starkey, 2004). Stretching is usually one of the first and most simple methods an athlete suffering from tight muscles turns to (Prentice, 2004). However, since some stretches need a partner to be most effective (Prentice, 2004), it can be difficult for a single athletic trainer or physical therapist to stretch every athlete in need.

Static and Dynamic

Stretching usually comes in two forms: static and dynamic (Starkey, 2004). Static stretching consists of passively moving the joint up to a point where it feels uncomfortable, and holding it for a predetermined amount of time, generally ranging from 15 to 30 seconds (Starkey, 2004). Dynamic stretching can be either active or passive and involves utilizing momentum from motion, or the momentum from static-passive stretching in an effort to propel the muscle into an extended range of motion not exceeding one's static-passive stretching ability (Starkey, 2004).

While stretching is a commonly used prophylactic measure, one study found that neither static nor dynamic stretching were effective in preventing injuries (Zakaria, Kiningham, & Sen, 2015). Zakaria et al. (2015) recruited 465 participants from multiple local high schools. They split them into two groups: 10 high schools consisting of 214 participants performed a static stretching routine before soccer matches in their varsity and JV teams, while 251 participants in 12 high schools performed a dynamic stretching regimen before their soccer matches (Zakaria et al., 2015). After a season of these interventions, researchers did not find any significant discrepancy in the number of injuries that each team suffered throughout the season as the quantity of injuries for all teams were comparable (17 injuries for the static stretching protocol, 20 for the dynamic stretching protocol) (Zakaria et al., 2015). However, the study did not control for the playing surfaces, nor did they supervise the athletes to see if they were performing the stretching interventions correctly, which they theorize could have contributed to the lack of significant results (Zakaria et al., 2015).

Static stretching has been found to decrease muscle stiffness in the biceps brachii of women's basketball players (Veevo, Ereline, Riso, Gapeyeva, & Pääsuke, 2012). However, there were minimal decreases in muscle stiffness following the dynamic stretching (Veevo et al., 2012). Muscle stiffness in the women's basketball participants was measured via a myotonometer, while the isometric contraction strength was measured by a dynamometer (Veevo et al., 2012). While muscle stiffness decreased after static stretching but not dynamic stretching, neither intervention had any effect on the isometric contraction strength of the participants (Veevo et al., 2012).

Egan, Cramer, Masser, and Marek (2006) tested whether or not there is a loss in peak torque or mean force output in Division I athletes following static stretching. Eleven Division I women's basketball players participated in the study (Egan et al., 2006). All participants performed a baseline isokinetic test to find their peak torque and mean force output (Egan et al., 2006). Following the baseline test, the participants' dominant leg extensors were statically stretched with one unassisted and three assisted static stretches for 30 seconds each and a 20-second rest between sets (Egan et al., 2006). Further isokinetic testing was done at 5, 15, 30, and 45 minutes post-stretching (Egan et al., 2006). Results showed that there was no significant loss of force output or peak torque in any of the participants at any time period (Egan et al., 2006). The results of Egan et al.'s (2006) study contradicts other research that has shown decreases in strength and power from static stretching (Jarbas da Silva et al., 2015). However, Egan et al. (2006) hypothesized that the differences in results may be attributed to the high level athletes used in their study (Egan et al., 2006; Jarbas da Silva et al., 2015).

Jarbas da Silva et al. (2015) examined 17 young men who were active, but not participants in any organized athletics. All participants performed a single leg bounce drop jump (SLBDJ) on both the control leg and the stretched leg (Jarbas da Silva et al., 2015). A randomly assigned leg of each participant was given six sets of 45 seconds on - 15 seconds off static stretch to the plantar flexor muscle group (Jarbas da Silva et al., 2015). Peak force and jump height were tested immediately, 10 minutes, and 20 minutes following the stretching protocol (Jarbas da Silva et al., 2015). The researchers found that both peak force and jump height were decreased immediately following static stretching, and got back to baseline compared to the un-stretched leg following 20 minutes (Jarbas da Silva et al., 2015). However, passive ankle dorsiflexion range of motion increased with stretching (Jarbas da Silva et al., 2015).

In another stretching study, researchers recruited sixty healthy university students to investigate the effect that passive stretching of the hamstrings had on cervical spine range of motion and balance (In & Jong, 2013). Split into two equal groups, 30 participants received three 30-second hamstrings stretches with ankle dorsiflexion, while the other group received the hamstrings stretch without the dorsiflexion (In & Jong, 2013). The researchers found that ankle dorsiflexion combined with passive hamstrings stretching immediately increased the range of motion and stability of the participants' cervical spine (In & Jong, 2013). The authors attribute this result to the theory that all of the muscles of the body are connected via fascia, and that applying force and stretching at one part of the kinetic chain has effects on body parts farther up the chain (In & Jong, 2013).

While there are multiple studies that looked at the efficacy of static stretching, only one study found investigated whether or not the rest intervals between stretching repetitions changes how effective the stretch becomes (Freitas et al., 2015). Frietas et al's (2015) hypothesis was that too long of a rest period may cause stretched muscles to tighten up again; and shorter rest intervals may allow greater stretch angles during subsequent sets. In two different protocols, participants either had a 30-second rest between stretch sets, or no rest at all (Freitas et al., 2015). Each participant performed five sets of static stretches for a duration of 90 seconds each (Freitas et al., 2015). They found that the addition of the 30-second rest decreased the range of motion, as well as the peak torque of the joints (Freitas et al., 2015).

Another form of static stretching called 'hold-relax', was tested by Ahmed, Iqbal, Anwer, & Alghadir (2015). Hold-relax stretching is where the muscle is held in isometric contraction, for at least seven seconds, followed by the usual static stretch (Starkey, 2004). The researchers compared both to see how they can affect the extensibility of the hamstrings compared to a control group (Ahmed et al., 2015). Forty-five people were split equally into three groups, all with similar mean heights, weights and body mass indices (BMI) (Ahmed et al., 2015). One group received moist heat and static stretching, one group received moist heat and the modified hold-relax stretching, and the control and received only moist heat (Ahmed et al., 2015). Subjects came in every day for a 10-minute session of their intervention, with measurements being taken at the baseline, as well as one, three, and five days following intervention (Ahmed et al., 2015). The researchers found that both stretching interventions combined with heat were equally effective, as well as far more effective on hamstrings extensibility than doing nothing besides applying heat (Ahmed et al., 2015).

Proprioceptive Neuromuscular Facilitation

A third type of stretching that is less well-known than static and dynamic is proprioceptive neuromuscular facilitation, or PNF (Kwak & Ryu, 2015). PNF stretching is explained by Sherrington's muscle facilitation and inhibition concept, in which it's believed that a muscular contraction can lead to antagonistic relaxation, which can then be used to increase the range of motion of the joint (Kwak & Ryu, 2015). Sixty participants were split into four groups: three experimental groups and one control group

(Kwak & Ryu, 2015). The control group received no intervention, while the three experimental groups were given the PNF stretching technique at three different intensities: 20%, 60%, and 100% of the maximum voluntary isometric contraction (Kwak & Ryu, 2015). Knee extension angle was taken before and after the interventions (Kwak & Ryu, 2015). The researchers found that all three contraction intensities (20%, 60% or 100% MVC) were effective in increasing the angle of knee extension more than the control group (Kwak & Ryu, 2015). However, there was no significant difference between the three intensities, so increasing the force of the muscular contraction may not necessarily lead to a greater gain in ranges of motion (Kwak & Ryu, 2015).

PNF stretching was also tested to see if it caused any deficits in force output (Cengiz, 2015). Ten physically active males tested their bilateral 3-second maximum voluntary isometric contraction (MVC) strength against a force transducer as a baseline measurement; EMG analysis of the wrist-flexor muscles was also performed (Cengiz, 2015). Following a bout of PNF stretching, there were significant deficits in both EMG and peak MVC (Cengiz, 2015). Although PNF stretching is effective in increasing a joint's range of motion (Kwak & Ryu, 2015), Cengiz (2015) suggested that it may not be the ideal choice for increasing range of motion prior to athletic activities due to subsequent losses in force output.

Massage

Much like stretching, massage is a treatment modality that tries to physically elongate tissues that may be tight. Much like some stretching techniques and ultrasound/shortwave diathermy, massage needs a sports medicine practitioner to perform it on an athlete; therefore, it may not be the most time-efficient treatment for an athletic trainer/physical therapist working with a large team. Massage is a form of manual therapy in which the tissues are manipulated to produce the desired effects (Starkey, 2004; Thomson, Gupta, Arundell, & Crosbie, 2015). Massage is an effective treatment method for promoting local and system relaxation or invigoration, increasing local blood flow, breaking down adhesions, and promoting venous return (Starkey, 2004). While there are many forms of massage that can serve many different functions, for this literature review only massage methods with the aim of relieving myofascial adhesions and tight musculature to help range of motion was considered.

One study in particular looked at 60 (43 women, 17 men) orthopedic patients at a hospital, and massage's effect on posterior shoulder tightness (Yang, Chen, Hsieh, & Lin, 2012). A physical therapist provided deep tissue massage to the participant's infraspinatus, teres minor, and posterior deltoid for six minutes per muscle (Yang et al., 2012). The control group received a light hand touch (Yang et al., 2012). The researchers found that there was a significant decrease in posterior shoulder tightness and increased range of motion in the massage group as compared to the control (Yang et al., 2012).

Another study looked at the effects of a massage in back pain experienced by office workers (Šiško, Videmšek, & Karpljuk, 2011). The 19 participants were seated in a specially designed ergonomic chair and given a 15-minute massage by a massage therapist twice a week for a month (Šiško et al., 2011). Before and after the intervention, a muscular discomfort questionnaire was given, and range of motion measurements of the participants' cervical flexion, cervical lateral flexion, cervical extension, lumbar extension, and lumbar flexion were taken (Šiško et al., 2011). The results showed that there were significant decreases in musculoskeletal discomfort as well as significant gains in range of motion in all participants in all directions (Šiško et al., 2011).

While the studies by Šiško et al. (2011) and Yang et al. (2012) found evidence supporting the use of massage in improving range of motion, an additional study by Thomson et al. (2015) found very few effects of deep tissue massage on passive mechanical properties of calf muscle. This study consisted of 29 participants (17 male and 12 female) all receiving an intervention, with their contralateral legs receiving no intervention to serve as the control (Thomson et al., 2015). The interventions included a 10-minute application of a moist hot pack, or a 10-minute deep tissue massage (Thomson et al., 2015). Both interventions were given to all participants, with a washout period between both (Thomson et al., 2015). In the second intervention, the leg that served as the control in the first trial served as the test leg in the second trial, and vice versa (Thomson et al., 2015). The authors found no significant differences in ankle dorsiflexion torque or dynamic muscle stiffness (defined as the change in force per change in muscle tendon unit length over the total joint's ROM) between any of the interventions when compared to the control (Thomson et al., 2015). The researchers believed that a measure of dynamic muscle stiffness gives a better idea of the changes to tissues following a massage, as ROM can be limited by many other factors besides muscle tightness (Thomson et al., 2015).

Massage has also been utilized to decrease muscle soreness following intense physical activity (Jay et al., 2014). A participant group of 22 untrained men were recruited for the study (Jay et al., 2014). The participants visited the testing center twice, separated by 48 hours (Jay et al., 2014). Their demographic measurements (height, weight, age, etc.) were taken at the first session, as well as a baseline measurement of visual analog scale for pain (VAS), pressure-pain threshold (PPT) and hamstrings range of motion (ROM) (Jay et al., 2014). Following the first visit, all participants trained to elicit the symptoms of DOMS (Jay et al., 2014). On the second visit, 48 hours following the strenuous workout to elicit DOMS symptoms, the intervention groups were randomly chosen with the interventions, either 10 minutes of a massage on one leg (with the contralateral leg serving as a control) or 10 minutes of rest with no intervention (Jay et al., 2014). Post-treatment measurements of soreness, PPT and ROM were taken immediately, 10 minutes, 30 minutes and 60 minutes post-treatment (Jay et al., 2014). The results showed that 10 minutes after treatment, there was a significant reduction in muscle soreness, as well as gains in range of motion and an increase in pressure-pain threshold when compared to the pre-intervention and control measurements (Jay et al., 2014). These effects appeared to be lost at 30 minutes post-treatment (Jay et al., 2014).

Massage was further shown to be effective in relieving tight muscles in a study looking at the massage of the longus colli (deep neck flexor) muscle versus the superficial neck flexor muscles (Wontae, Giduck, & Jongho, 2012). The study split the 60 participants into two groups: one received massage and active release of the longus colli, while the other group received massage and active release of the trapezius, levator scapulae, and posterior cervical muscles (Wontae Gong et al., 2012). The study showed that the massage and active release combination increased range of motion of the cervical spine, although the longus colli massage was significantly more effective than the massage of the other muscles (Wontae et al., 2012). They believe that being a deep neck flexor, the longus colli may be more likely to be overlooked, and thus may limit cervical range of motion even if other, more superficial muscles are massaged (Wontae et al., 2012).

Joint Mobilizations

Joint mobilizations are less well known and less utilized when compared to heating, massage and stretching when it comes to improving range of motion (Prentice, 2004). Joint mobilization is a manual therapy technique that involves the slow, passive movement of the joint's articulating surfaces (Prentice, 2004). The techniques are used to regain normal active range of motion, restore normal, passive movements that occur around a joint, reposition or realign a joint, and/or reduce pain (Prentice, 2004).

There are usually two methods of joint mobilizations: Maitland and Kaltenborn (Gui, Jin, Da, & Tae, 2015, Prentice, 2004). While both methods use similar movements on joints, Maitland utilizes oscillation movements, whereas Kaltenborn techniques perform a sustained movement on a joint (Gui Do Moon et al., 2015; Prentice, 2014). One study compared their effectiveness in improving pain and range of motion in patients with frozen shoulder (Gui Do Moon et al., 2015). Frozen shoulder is also known as adhesive capsulitis, which causes tissue degeneration, joint capsule thickening, and decreased glenohumoral cavity volume (Gui Do Moon et al., 2015). Researchers did not find any significant differences between the two methods, but both were significantly effective in improving both range of motion and pain in the participants (Gui Do Moon et al., 2015).

Aytar et al. (2015) used joint mobilizations and a placebo in their study of shoulder range of motion. While all participants received hot packs and electrical stimulation, one group received scapular mobilizations, one group received a placebo scapular mobilization, and the last group received just heat and electrical stimulation (Aytar et al., 2015). Placebo scapular mobilizations were applied with different hand positions and less pressure, and involved moving the scapula in random directions (Aytar et al., 2015). The researchers found that the scapular joint mobilizations were effective in increasing shoulder range of motion and decreasing pain, although it was not significantly more effective than either the stretching or placebo mobilization groups (Aytar et al., 2015).

Min-Hyeok and colleagues examined how gastrocnemius stretching could be combined with talocrural joint mobilizations to increase ankle range of motion (Min-Hyeok, Dong-Kyu, Soo-Yong, Jun-Seok, & Jae-Seop, 2015). Min-Hyeok et al.'s (2015) study consisted of 11 male participants, all of which had bilateral limited dorsiflexion range of motion. All participants received the same intervention of talocrural (ankle) joint mobilizations as well as gastrocnemius stretching, with a bubble inclinometer measuring their passive dorsiflexion range of motion before and after the intervention (Min-Hyeok Kang et al., 2015). For the stretching portion, the participants would do a lunge position against the wall, with the back leg in dorsiflexion until a stretch in the gastrocnemius was felt (Min-Hyeok Kang et al., 2015). While participants were in this position, the researcher would provide a gliding anterior-posterior force to the talus for 30 seconds to mobilize the talocrucal joint (Min-Hyeok et al., 2015). After three trials, the post-intervention measurement of range of motion was taken (Min-Hyeok et al., 2015). Findings demonstrated that the combination of talocrural joint mobilizations and static stretching of the gastrocnemius yielded significant increases in passive ankle dorsiflexion in all participants compared to their baseline measurements (Min-Hyeok et al., 2015).

Joint mobilizations can be combined with heating modalities as well stretching (Draper & VanPatten, 2010). Six individuals participated, all of whom had limited elbow range of motion due to previous trauma (Draper & VanPatten, 2010). Active elbow extension range of motion was taken after every treatment session, which consisted of 20 minutes of pulsed shortwave diathermy applied to the cubital fossa of the elbow, followed by 7-8 minutes of elbow joint mobilizations (Draper & VanPatten, 2010). Immediately following treatment, ice was applied to the area for 30 minutes and the participants rested (Draper & VanPatten, 2010). Interventions were applied three times a week for four to six treatments total per participant (Draper & VanPatten, 2010). At the end of the treatments, all participants but one had restored full range of motion in the affected elbow when compared with the contralateral side (Draper & VanPatten, 2010).

Ultrasound has also been used as a method of heating in combination with either anterior or posterior glides of the glenohumeral joint (Joshi & Jagad, 2013). The thirty participants were split equally into the anterior and posterior glide groups, with all receiving the same ultrasound treatment as well as shoulder exercises (Joshi & Jagad, 2013). Effectiveness was determined by changes in external rotation range of motion in the affected shoulder, as well as a visual analog scale (VAS) of pain (Joshi & Jagad, 2013). After six treatments for each participant, the post-intervention measurements of range of motion and VAS were taken and compared to the pre-intervention measurements (Joshi & Jagad, 2013). Researchers found that anterior glides were significantly more effective in decreasing pain and increasing range of motion, although both glide groups made significant progress compared to their pre-intervention measures (Joshi & Jagad, 2013).

Foam Rolling

There are many methods used by the sports medicine community to relieve tight muscles and restore range of motion with a variety of findings indicating which may be the best. Perhaps the most recent method (gaining popularity within the past decade) is foam rolling, which has a certain appeal due to its ease of use, as an athletic trainer or physical therapist is not needed to help operate it. Since Michael Clark introduced it as a method of self-myofascial release, foam rolling has gained a lot of traction in the athletic community (Boyle, 2015). Compared to the cost of buying a shortwave diathermy machine, ultrasound machine, hot packs and hydrocollator, or getting a professional massage, foam rolling is a very affordable, as low as 20 dollars according to TP Therapy's website (TP Therapy, 2017).

While there is not a plethora of research involving foam rolling, many of the studies to date look at its ability to improve range of motion. One such study compared static stretching to foam rolling as a method to increase passive hip flexion range of motion (Mohr, Long, & Goad, 2014). Forty participants who all had less than 90 degrees of passive hip flexion volunteered (Mohr et al., 2014). The participants were split into four different intervention groups: foam rolling, static stretching, both foam rolling and static stretching, and a control group who received no intervention (Mohr et al., 2014). The participants each came in for six sessions on six consecutive days with range of motion measurements of hip flexion taken at the beginning and immediately following each of the interventions (Mohr et al., 2014). While all interventions yielded significant increases in hip flexion range of motion when compared to the control, the most effective was the combination of foam rolling along with static stretching (Mohr et al., 2014). This study supports the idea that foam rolling each day may have a cumulative effect in increasing range of motion (Mohr et al., 2014).

Kelley and Beardsley (2016) investigated foam rolling to find its effect on range of motion. They had 26 participants split into two equal groups: the control group sat quietly for two minutes, and another group foam rolled for 3 sets of 30 seconds with 10 seconds rest between sets (Kelly & Beardsley, 2016). A baseline measurement of ankle dorsiflexion range of motion was taken for all participants, as well 0, 5, 10, and 20 minutes following either foam rolling or the control (Kelly & Beardsley, 2016). The foam rolling group saw significant increases in range of motion compared to their baseline measurements at all time periods (Kelly & Beardsley, 2016). Range of motion was measured on both ankles, and the results showed an increase in range of motion on the contralateral limb for up to 10 minutes following the intervention (Kelly & Beardsley, 2016). The researchers did not, however, know the mechanism behind this 'cross-over' effect (Kelly & Beardsley, 2016). This 'cross-over' effect was only seen in the test group and not the control group (Kelly & Beardsley, 2016).

One long term study looked at the clinical relevance of foam rolling on the participants' hip extension angle during a dynamic lunge (Bushell, Dawson, & Webster, 2015). Thirty-one participants were chosen, with 16 of them serving as the intervention group, and the remaining 15 serving as the control (Bushell et al., 2015). The testing was split into three sessions in which each participant would perform two lunges, with measurements taken of the hip extension angle (Bushell et al., 2015). The foam rolling group would foam roll the anterior, proximal portion of the thigh in between the lunges in the session, as well as five times in the seven days between session one and session two (Bushell et al., 2015). No foam rolling was performed between sessions two and three, nor during session three; the control group had no interventions between the lung tests or the different testing sessions (Bushell et al., 2015). Overall, the researchers found that foam rolling regularly over one week had more of an effect on the range of motion of the hip than one single session or no foam rolling at all (Bushell et al., 2015).

Similar results were found when using foam rolling in conjunction with static stretching (Roylance et al., 2013). All 27 participants (14 male, 13 female) had a limited sit and reach score of 13.5 inches or less (Roylance et al., 2013). All participants performed foam rolling for 10 minutes on various muscle groups which could affect sit and reach score (including hamstrings, calves, erector spinae, gluteus maximus), along with either postural alignment exercises or static stretching of the hamstrings (Roylance et al., 2013). On the first day of testing, foam rolling was performed before the randomly assigned intervention (postural alignment exercises or static stretching), while on the second day foam rolling was performed after the intervention (Roylance et al., 2013). Sit and reach testing was performed at the beginning of each testing day, after the first intervention (foam rolling, postural alignment exercises, or static stretching), and after the final intervention (Roylance et al., 2013). Results showed that while all interventions increased range of motion, a combination of static stretching and foam rolling (in that order) was most effective in increasing the participants' sit and reach scores (Roylance et al., 2013).

While foam rolling can be effective with stretching, not everyone who foam rolls does so with the same pressure, due to differences in pain tolerance or body weight, which could possibly limit the efficacy (Sullivan et al., 2013). In an attempt to correct for this possible source of error, a study used a custom made machine to provide consistent rolling out pressure (Sullivan et al., 2013). In this study, seven males and 10 females each went through four trials of hamstrings roller massage (Sullivan et al., 2013). The trials varied in the number of sets and seconds that the rolling took place (Sullivan et al., 2013). Another group of three males and six females had no rolling intervention and served as the control group (Sullivan et al., 2013). A sit and reach test was performed before and after the interventions (Sullivan et al., 2013). The researchers found that there was an average of 4.3% increase in range of motion when compared to the baseline measurement across interventions, that rolling for 10 seconds was found to be more effective than five seconds, and that two sets was more effective than one (Sullivan et al., 2013). However, there was no significant change in maximal voluntary contraction force or EMG activity in the muscles from pre-intervention to post-intervention (Sullivan et al., 2013).

Another study investigated the pain that foam roller massage causes at the time, as well as the effect that foam rolling has on knee flexion range of motion during a dynamic lunge (Bradbury-Squires et al., 2015). The study found that there was 20.6% more pain when rolling out for 60 seconds rather than 20 seconds; however 60 seconds of foam rolling yielded greater results in knee range of motion, as well as increased neuromuscular efficiency (Bradbury-Squires et al., 2015). Both groups of foam rolling had greater results compared to the control group that sat quietly (Bradbury-Squires et al., 2015).

Another area of foam rolling that is researched is its ability to improve performance. Decreasing a muscle's tightness and improving range of motion is thought to be one way that it could accomplish this; another way is by force production in sport movements themselves (Boyle, 2016). One study looked at the effect that foam rolling combined with a dynamic warm-up had on a workout consisting of multiple sport movements, such as strength, agility, power, endurance, etc. (Peacock, Krein, Silver, Sanders, & Von Carlowitz, 2014). A participant group of 11 physically active males, all with a history of professional or collegiate athletics, was used (Peacock et al., 2014). All eleven participants received the intervention, and performed two workouts separated by a seven day rest period: before both workouts, they would perform a dynamic warm-up including arm circles, body weight squats, a five-minute jog, sprinting butt kicks, and other exercises (Peacock et al., 2014). Following the dynamic warm-up, all participants were given a battery of performance tests including sit and reach, vertical jump, standing broad jump, 1RM bench press test, and a 37m sprint test (Peacock et al., 2014). Those performance tests counted as one workout (Peacock et al., 2014). Following the seven day rest period, all participants performed the same dynamic warm-up, but this time preceded by self-myofascial release using a foam roller (Peacock et al., 2014). All of the major muscle groups were bilaterally rolled out, at the pace of five strokes per 30 seconds, covering the entirety of the muscle length (Peacock et al., 2014). The researchers found that the self-myofascial release using a foam roller, combined with the dynamic warm-up resulted in greater gains in power, agility, strength and speed when compared to the warm-up alone (Peacock et al., 2014). The researchers theorized that this is due to the foam rolling helps recruit more muscle fibers in subsequent exercise, and may cause some local arterial dilation, increasing the amount of blood flowing into the muscles (Peacock et al., 2014).

Some researchers suggest that foam rolling is a more effective alternative to static stretching, due to some research showing that static stretching can decrease force output (Halperin, Aboodarda, Button, Andersen, & Behm, 2014). Fourteen recreationally trained subjects had their passive dosrsiflexion range of motion in the talocrural joint, gastrocnemius maximum voluntary contraction velocity, and single leg balance with eyes closed tested for a baseline measurement (Halperin et al., 2014). After a 10-minute rest period, the participants were randomly put into an intervention group: three sets of 30 seconds of either static stretching or self-myofascial release using a foam roller (Halperin et al., 2014). Following the intervention, the same measurements as the baseline were taken in order to quantify the effects of static stretching and foam rolling (Halperin et al., 2014). Researchers showed that while both interventions were effective in increasing the dorsiflexion range of motion of the ankle, the static stretching decreased the maximum voluntary contraction velocity of the subjects, while the foam rolling caused a small increase in the maximum voluntary contraction velocity of the subjects (Halperin et al., 2014). No significant changes were found in the single leg balance scores of the participants (Halperin et al., 2014).

Oftentimes, delayed-onset muscle soreness (DOMS) and muscle tightness go hand in hand following intense exercise, a fact that foam rolling hopes to prevent (TP Therapy, 2017). Research has been conducted to look at foam rolling as both an effective treatment for delayed onset muscle soreness, as well as a tool to increase dynamic performance (Pearcey et al., 2015). Eight physically active males were split into two groups: one group foam rolled for 20 minutes following the exercise, while the second group had no intervention (Pearcey et al., 2015). All participants performed 10 sets of 10 repetitions of back squats at 60% of their 1RM (Pearcey et al., 2015). In order to more greatly elicit DOMS symptoms, participants would spend three seconds on the eccentric phase of the squat (lowering) and one second in the concentric phase (standing up) (Pearcey et al., 2015). Thirty meter sprint speed, power, change of direction speed, and dynamic-strength endurance, as well as a pressure-pain threshold measurement were collected pre- and post-intervention (Pearcey et al., 2015). Following the squats, the participants either foam rolled out immediately, 24 hours and 48 hours post exercises, or did nothing (Pearcey et al., 2015). Researchers found that foam rolling was effective in relieving the symptoms of DOMS, as well as improving some dynamic strength measures, such as sprint time, power, and dynamic strength-endurance (Pearcey et al., 2015). The researchers theorized that foam rolling's effect on muscular soreness could be connected to decreased edema, increased blood lactate removal, and enhanced muscular blood flow, which could lead to increased performance (Pearcey et al., 2015).

Pearcey et al. (2015) were not the only ones to look at foam rolling's efficacy as a recovery tool. Another group of researchers examined foam rolling's effect on the pressure-pain threshold of the iliotibial (IT) band (Vaughan & McLaughlin, 2014). All 18 participants participated in a three minute bout of foam rolling immediately following pain measurements (Vaughan & McLaughlin, 2014). Measurements were taken using a pressure algometer pre-intervention, immediately post-intervention, and five minutes post-intervention (Vaughan & McLaughlin, 2014). The researchers measured from three points on the participants' IT band: 10 cm below the greater trochanter, 10 cm above the lateral femoral epicondyle, and the midway point between these two points (Vaughan & McLaughlin, 2014). The researchers discovered that participants had less pain immediately following foam rolling, however the changes were gone at the five minutes post-intervention measurement (Vaughan & McLaughlin, 2014). Oftentimes, some of the limits to an athlete's range of motion can be associated with muscle soreness as well as tightness; attempting to ease some of the athlete's muscular pain can also help restore range of motion (Prentice, 2004; Vaughan & McLaughlin, 2014).

Foam rolling was also investigated to see its effects on a cellular and physiological level, as opposed to its macroscopic effects on myofascial adhesions generally studied (Hotfiel et al., 2017). In this study, 21 participants had their arterial tissue perfusion measured using Doppler ultrasound (Hotfiel et al., 2017). Arterial perfusion was represented by peak blood flow, time average velocity maximum, time average velocity mean, and resistive index (Hotfiel et al., 2017). Arterial perfusion was measured once at rest, and then immediately and 30 minutes after foam rolling (Hotfiel et al., 2017). All participants rolled out their lateral thigh for three sets of 45 seconds, with 20 seconds rest in between sets (Hotfiel et al., 2017). Results of the study showed a significant increase in arterial perfusion immediately and 30 minutes following the sets of foam rolling (Hotfiel et al., 2017). This increased arterial perfusion due to foam rolling is believed to play a role in recovery via the delivery of oxygen and nutrients to the muscles (Hotfiel et al., 2017).

Previously outlined studies have found that foam rolling has a positive effect on range of motion (Bradbury-Squires et al., 2015; Bushell et al., 2015; Halperin et al., 2014; Mohr et al., 2014; Roylance et al., 2013; Sullivan et al., 2013). However, Morton, Oikawa, Phillips, Devries, and Mitchell had found that foam rolling resulted in no significant improvement in range of motion measurements (Morton et al., 2016). The participants in this study were 19 males who all had limited hamstrings ROM (Morton et al., 2016). On the first day of testing, every participant came in for a baseline measurement of hamstrings flexibility (Morton et al., 2016). Each participant had both legs tested with a randomly assigned intervention: one leg would be given an intervention of 4x60 seconds foam rolling and 4x45 seconds static stretching, while the other would be only given 4x45 seconds static stretching (Morton et al., 2016). After four weeks of intervention (participants were told to perform their intervention daily), they reported for post-testing. Results showed that both interventions significantly increased ROM, but there was no significant difference with the addition of foam rolling to static stretching alone (Morton et al., 2016). However, because it was assumed that the participants would follow the protocol outside of the laboratory setting, some may have lied about how often they performed the interventions (Morton et al., 2016).

One of the more recent studies found regarding foam rolling was conducted by Behara and Jacobson (2017). Their crossover design study had all 14 participants perform the three treatments: no treatment (control), dynamic stretching, and deep tissue foam rolling (Behara & Jacobson, 2017). The dependent variables measured were vertical jump force and vertical jump velocity, isometric knee torque, and hip range of motion (Behara & Jacobson, 2017). Both the dynamic stretching and deep tissue foam rolling interventions targeted the same muscles (left and right hamstrings, left and right quadriceps, left and right gluteus maximus, and left and right gastrocnemius), and were performed for the same amount of time (one minute per muscle for a total of eight minutes) (Behara & Jacobson, 2017). Analysis of the results showed that there was no significant change in peak vertical jump force or velocity, nor were there any significant changes in isometric knee torque (Behara & Jacobson, 2017). However, both dynamic stretching and deep tissue foam rolling significantly increased hip range of motion when compared to the baseline measures (Behara & Jacobson, 2017). The dynamic stretching intervention increased range of motion to a greater extent than deep tissue foam rolling (19.9% vs 15.6% respectively), but was not better by a statistically significant margin.

Summary

As time has progressed, so too have the methods for increasing an athlete's limited range of motion due to muscle tightness. While massage has been used the longest, static stretching, dynamic stretching, PNF stretching, and heating (including moist heat, ultrasound and shortwave diathermy) have become commonplace. Joint mobilizations have also been shown to return normal range of motion when combined with other modalities, such as heating or stretching the surrounding tissues. The newest and one of the more popular methods is self-myofascial release via foam rolling. While there may be claims that foam rolling is the new "cure all" aid to increase range of motion, performance, strength or decrease muscular pain (Boyle, 2016; Clarke, 2016; TP Therapy, 2016), the research mainly backs up the claims of helping restore range of motion (Behara & Jacobson, 2017; Bradbury-Squires et al., 2015; Bushell et al., 2015; Halperin et al., 2014; Mohr et al., 2014; Roylance et al., 2013; Sullivan et al., 2013).

However it also has been shown to be an effective recovery tool to alleviate the symptoms of DOMs and increase blood flow to the muscles (Hotfiel et al., 2017; Pearcey et al., 2015; Vaughan & McLaughlin, 2014) While research has shown that there are other effective methods to increase normal range of motion, some of them, such as ultrasound, SWD, or professional massage therapy, are not as cost effective. Joint mobilizations can only safely be carried out by medical professionals such as athletic trainers or physical therapists, who would be mostly off limits for the average person, unless they have the means to access a physical therapist. The literature supports the claims that foam rolling can help range of motion when combined with static stretching (Mohr et al., 2014; Roylance et al., 2013); for an athletic trainer with multiple athletes and limited time, it would appear that heating and foam rolling would be the most logical, time-efficient method to relieve muscle tightness.

Thus, the purpose of this study was to investigate the effect that the combination of heating and foam rolling had on hamstrings tightness and active hip flexion range of motion, as measured via goniometry. It was hypothesized that both heat and foam rolling alone would increase range of motion in participants, and that the combination would be significantly more effective than either intervention alone.

Chapter III

Procedures

This study investigated the effect that moist hot packs, foam rolling, and a combination of the two have on active hip flexion and hamstrings tightness ROM in Division II female lacrosse athletes. It was hypothesized that both moist heat and foam rolling alone would be enough to increase range of motion compared to the baseline, and that the combination of heat and foam rolling would be significantly more effective than either treatment alone, and significantly increase range of motion from baseline.

Setting

The setting of this study was the university's athletic training room. The university was a small, rural, NCAA Division II institution.

Participants

The participants were all members of a NCAA Division II university women's lacrosse team. The entire team was asked to participate. In all, 13 athletes volunteered to participate. This number was later reduced to 11, as two of the original volunteers missed the first day of testing. Acknowledgement that the study was taking place was given by the head coach of the team, as well as assurances to the athletes that participation in no way affected their standing with the coach. All participants volunteered and had the procedures explained to them before they made their decision of whether or not to participate. All participants were given an informed consent form and were required to complete and sign it before participation. A copy of the informed consent sheet can be found in Appendix A. Institutional Review Board (IRB) approval was granted by the institution (Appendix A). There was also a questionnaire that participants were asked to complete, consisting of basic demographic information and their usage of a foam roller (see Appendix B). No athletes had a previous injury in the past 12 months that could have interfered with the results of the study and therefore no participants were excluded from the study.

Instrumentation

A model G300 goniometer was used to measure the angle of active hip flexion in all participants (See Figure 1 in Appendix II). The same goniometer was used with all participants to maintain consistency. Hip flexion was measured from the greater trochanter of the proximal femur and the lateral epicondyle of the distal femur (see Figures 2 and 4 in Appendix II). All measurements were taken while the participant was lying supine on a treatment table, and all data was recorded on a data sheet (Appendix C). Moist hot packs were taken from a hydrocollator, which was kept at 160°F (see Figure 5 in Appendix II). The same TP Therapy GRID Foam Roller (see Figure 6 in Appendix II) was used by all participants. This was to increase consistency, as there are multiple foam roller densities and sizes that can be used. The foam roller being used was new and unused; this was to ensure that the foam portion of the foam roller was not deteriorated from repeated use. Heights and weights of participants were taken using the same apparatus (Rice Lake RL-MPS Physician Scale-440lb/200kg with Height Rod). A questionnaire was given following the final intervention, using a Likert scale (Appendix D) to measure the participants' opinions on the efficacy of all interventions.

Research Design

All participants began by reading and signing the provided consent form and completing a demographic questionnaire before being tested. Before they began training for their spring lacrosse season, all athletes had their baseline active hip flexion range of motion tested to get a true baseline that is not affected by training. The measurement was taken on the participant's dominant leg, determined by asking them which leg they would kick a soccer ball with. To obtain the baseline measurement, athletes laid on a treatment table in the supine position. The goniometer was placed with the circular axis on the athlete's greater trochanter, with one arm of the goniometer parallel with the athlete's leg, pointed directly at the lateral epicondyle. The other arm was parallel with the participant's trunk, which remained in contact with the treatment table at all times (see Figure 4 in Appendix II). The subjects were instructed to lift their dominant leg as high as possible while keeping their knee in full extension (Mohr et al., 2014). Once the maximum hip flexion was reached, the center circle and stationary arm of the goniometer was kept in place at the hip joint, while the movement arm was brought up to remain parallel with the participant's leg, remaining pointed at the lateral epicondyle. The reading on the goniometer showed the degrees of active hip flexion range of motion. Range of motion was measured three times and then averaged.

Testing took place on three separate days, which came following an off day from their in-season training (see Appendix E). Testing days were separated by one week. Athletes came in at the same time of day for each testing day. None of the athletes came in after their practice to perform testing as to try and isolate any changes in range of motion to each individual testing day, rather than the day's training. Participants were all instructed to wear their team-issued athletic shorts and a t-shirt when reporting for testing. The shorts given to the team were thin and tight fitting enough to be able to accurately and consistently palpate the bony landmarks necessary for measuring range of motion.

At the beginning of each testing day, a measurement of the participant's active hip flexion range of motion was taken, using the procedures outlined above. Following the base-line measurement, participants performed one of three interventions, randomly assigned to them. The three interventions were the application of a moist hot pack, application of a foam roller, or heating immediately followed by foam rolling. Randomization took place by having participants draw a piece of paper out of a hat without looking. There were nine pieces of paper, three with an H (heat), three with an F (foam rolling), and three with a B (both interventions) written on it. If participants drew an intervention they had already performed, they continued to draw until they got a new intervention. The first testing day also included the participants' measurements of heights and weights. All participants performed each of the three conditions, separated by one week.

The moist hot packs used in this study were provided in the athletic training room. Moist hot packs were kept in a hydrocollator at a temperature of 71.1°C. or 160°F. Moist hot packs were removed from the hydrocollator using the tongs provided and placed in a cover (also provided) to prevent burns on the participants' skin. Participants placed the hot pack in the center of the hamstrings muscle group of the tested leg for the duration. Hot packs were applied directly to the skin instead of onto clothing. After the 10 minutes (Hanson & Day, 2012) had passed, participants removed the hot pack and had their range of motion tested once again using the same protocol as the baseline measures. Results were recorded on the participants' data sheet (see Appendix C).

In the foam rolling intervention, subjects foam rolled their hamstrings muscle group on the same leg for a total of three minutes, using the provided TP Therapy GRID foam roller. The researcher demonstrated correct foam rolling procedure, including instructions for how to apply the correct amount of pressure. Athletes were instructed to roll out from the popliteal fossa up to the ischial tuberosity in order to target the entire muscle group (Figure 7 in Appendix H). Subjects were also instructed to roll out with as much pressure as tolerated, in order to increase the effect of myofascial release. The non-tested leg was crossed over the tested leg in order to increase pressure on the tested hamstrings. Participants rolled out for three sets of 60 seconds, with 15 seconds break between sets (Bradbury-Squires et al., 2015; Kelley & Beardsley, 2016). The researcher supervised the participants to ensure that they were rolling out correctly, as well as ensure that the participants were rolling out for the correct time, using a stopwatch present in the athletic training room. Once the participant had rolled out for the allotted time, they had their hamstrings range of motion tested again using the same protocols outlined previously. Results were recorded on the participant's data sheet.

In the combination intervention, the same protocols outlined above were used. Athletes began by heating for 10 minutes with a moist hot pack, followed immediately by rolling out for three sets of 60 seconds, with 15 seconds break between sets. Immediately following the combination of treatments, the athlete's range of motion was once again tested, with the results recorded.

Participant bias was assessed via the Likert scale survey provided to participants at the conclusion of the study (Appendix D). The Likert scale survey asked participants how effective they felt each intervention was: one being not effective at all, four being somewhat effective, and seven being extremely effective.

Validity

The primary instrument of measurement, the goniometer, has a validity that ranges from $r = 0.88$ to $r = 0.94$ (Jones, Sealey, Crowe, & Gordon, 2014). The goniometer used was checked and calibrated before any measurements to ensure that the numbers were correctly labeled and that it was in good working condition. The researcher who took the participants' measurements had been trained in the use of a goniometer and knew how to correctly use it. The active straight leg raise as an indicator of hamstrings flexibility and hip flexion ROM has a validity of $r = 0.65$ (Davis, Quinn, Whiteman, Williams & Young, 2008). Other methods, such as flexed hip combined with knee extension have higher validity for isolated hamstrings flexibility, but may lead to more errors in goniometric measurements due to the higher number of joints involved (Davis et al., 2008). The researcher had been using a goniometer for five years on various joints, including measurements of active hip flexion, and its validity is high enough to have felt comfortable with its use in the study. The straight leg raise also allowed for a more accurate measurement than a sit and reach test (Bradbury Squires et al., 2015; Davis et al., 2008). While validity coefficients could not be found for foam rolling or heat packs, these modalities were used in the same manner as previously described studies, which were considered to be valid (Aytar et al., 2015; Bushell et al, 2015; Halperin et al., 2015; Hanson & Day, 2012; Khamwong et al., 2012, Mohr et al., 2014). The scale used was a medical grade scale and was zeroed and calibrated before each measurement.

Reliability

The active straight leg raise as an indicator of hamstrings flexibility has a reliability of .92 (Davis et al., 2008). A goniometer has a reliability that ranges from r = 0.82 to r = 0.9 (Jones et al., 2014). It should be noted that as previously mentioned, much of a goniometer's reliability and validity are dependent on the person using it. If the user had not been trained and practiced with it, or does not use consistent anatomical landmarks for measurement, then the reliability and validity would have been lower. The researcher in this study had been trained, with years of practice with a goniometer, and used consistent anatomical landmarks to maximize reliability and validity. The same goniometer was used throughout the study to further increase reliability. The participant's same leg was also used for all measurements in order to increase reliability and validity. While no reliability coefficients were found for moist hot packs or foam rolling, all participants placed the hot pack on the same portion of their hamstrings, and rolled out using the same procedures, as determined by the researcher who was supervising. This consistency with all participants increased reliability of these interventions. Because the medical grade scale was calibrated before each measurement, it was both valid and reliable. The same stopwatch was used to measure each intervention to maintain consistency and reliability.

Treatment of Data/ Statistical Analysis

No names were used in the documentation of this study. Instead, each participant was identified by an ID number. All of the participant's information and results were kept on a password protected personal laptop computer, in order to ensure privacy and confidentiality. All results were recorded on an individual data sheet (Appendix C) for each participant. Once the average hip flexion angles were calculated for each intervention, they were entered into a Microsoft Excel spreadsheet. All paperwork, including consent forms, demographic questionnaires, and data sheets were stored in a folder which was kept locked up in the researcher's office desk. The office remained locked whenever someone was not present in the room.

In this study, the dependent variable was the active hip flexion range of motion. The independent variables were the interventions: the application of a hot pack, foam rolling, or the combination of the two. The statistical analysis software SPSS (version 24.0, 2016) was used to analyze the data. A two-way repeated measures ANOVA was utilized to find any differences between groups or between the pre/post-test measurements. Following that, Mauchly's test of spericity, Bonferroni's correction, and pairwise comparisons were run to determine where the differences were, and their significance. Data was reported as the mean ± standard deviation; statistical significance was defined as a $p \leq 0.05$. While the results may or may not have been statistically significant, real world applicability was considered important. Cohen's effect size (d) was also calculated to find the magnitude of practical effect, with the following criteria used: 0.1 as trivial, 0.2 as small, 0.5 as medium, and 0.8 as large (Cohen, 1988). Means and standard deviations of the pre-season baseline, Likert survey responses for the effectiveness of the interventions, as well as the participants' age, height, weight, and years of experience playing lacrosse were calculated using Microsoft Excel. All effects of these interventions were considered when interpreting the data and applying it to real world practice in the sports medicine field.

Chapter IV

Results

A total of 13 lacrosse athletes volunteered for this study. All participants were female. Due to dropouts, a total of 11 athletes performed all three intervention measures. The two dropouts were due to the athletes oversleeping and missing their first appointment for data collection. Data was analyzed using SPSS (Version 24.0, 2016) statistical analysis software. Means and standard deviation for height, age, weight, years of experience, and Likert survey responses were calculated using Microsoft Excel. A two-way repeated measures analysis of variance (ANOVA) was performed on the data in order to find any significance between the three different interventions, from the pre- to post-test scores within each intervention. Mauchly's test of Sphericity and Bonferroni's correction were performed to find where these significant differences were, if any were found. Statistical differences were considered significant at $p \leq 0.05$. The independent variables in this study were the interventions of heating, foam rolling, and a combination of both. The dependent variable was the active hip flexion range of motion (reported in degrees).

Subject Characteristics

All statistical data reported is the mean ± standard deviation unless otherwise noted. Prior to any data collection, the participants ($n = 11$) had their mean height, weight, age, and years of experience playing lacrosse measured. Results showed a mean of 163.43 ± 8.5 cm, 62.15 ± 9.0 kg, 19.9 ± 1.51 years, and 6.55 ± 3.83 years of experience, respectively (see Table 1). The post-test survey provided to participants (Appendix D) asked the participants how effective they felt each intervention to be. The survey used a Likert Scale, with one being not effective at all, four being somewhat effective, and effective seven being extremely effective. The mean effectiveness of heating (H), foam rolling (FR), and the combination (HFR) was 5.27 ± 0.79, 4.64 ± 1.31, and 5.82 ± 1.08 respectively. Full responses to the post-test survey and measurements from each participant can be found in Table 1. The qualitative Likert survey responses match up with the quantitative data in how effective each intervention is.

Table 1. Demographic Information and Individual Responses to Post-Test Survey

Subject	H Survey	FR Survey	HFR Survey	Height (cm)	Weight (kg)	Age (years)	Exp. (years)
1	6	5	3	160.2	64	19	0
2	6	5	6	163.2	51.6	18	5
3	4	2	6	161	73.2	18	4
4	5	4	7	177.3	68.3	20	11
5	4	4	5	151.6	58.1	22	9
6	6	7	7	154.1	64.8	20	13
7	5	4	6	156.5	49.2	21	2
8	5	6	6	172.1	48.1	18	5
9	6	6	6	168.2	72.4	20	8
10	6	4	6	174.5	67.3	21	8
11	5	4	6	159	66.6	22	7
Mean	**5.27**	**4.64**	**5.82**	**163.43**	**62.15**	**19.91**	**6.55**
Std. Dev.	**0.79**	**1.36**	**1.08**	**8.51**	**9.03**	**1.51**	**3.83**

Statistical Analysis Results

Table 2 shows the mean pre- and post-treatment measurements, standard deviations, degrees increase from pre-post, the percent change from pre-post, and the effect size for each method. The combination treatment had the largest mean increase in hip flexion range of motion by 9.6 degrees, or 12.7%. Heating showed the second most improvement, with a mean increase of 8.2 degrees, 10.4%. Foam rolling was least effective with a mean increase of 5.9 degrees and a percentage change of 7.5%. Tables 3, 4 and 5 show the individual results for each participant compared to their pre-season baseline, as well as the degrees and percentage change for each intervention. The pre-season baseline had a mean of 79.6 ± 11.1 degrees (Tables 3, 4 and 5). The pre-intervention baselines of heating, foam rolling, and the combination was 78.1 ± 11.6, 78.9 ± 15.0, and 75.8 ± 12.1 degrees, respectively (Tables 3, 4 and 5 respectively).

The two-way repeated measures ANOVA showed a significant increase in range of motion in all treatments pre-post intervention with a p-value of ≤ 0.001 (Table 6 in Appendix II). However, the treatment group found no one intervention to be significantly different than any other group, with a p-value of .711 (Table 6 in Appendix II). All data passed Mauchly's Test of Sphericity (Table 7 in Appendix II). Therefore, no further post-hot testing of the data was necessary. When looking at the Tests of Within-Subjects Effects (Table 8 in Appendix II), the p-value of 0.204 for treatment * time indicates no significant interaction. There was no significance found in the tests of Within-Subjects Effects ($p = 0.800$) (Table 8 in Appendix II). This indicates that the treatment type did not have any significant effect on the changes from pre- to-post. There was a significant ($p \leq 0.001$) improvement from pre-post regardless of treatment type. The pairwise comparison table (Table 9 in Appendix II) shows a comparison of each treatment to every other treatment. There was no statistically significant ($p = 1.000$) differences between any of the three treatment types.

The calculation of Cohen's d gave the heating treatment a value of 0.54, foam rolling a value of 0.41, and the combination treatment a value of 0.85 (Table 2). These values are of medium, medium, and large effect, respectively. This indicates that while there was no statistically significant difference between any of the three intervention groups, there may be meaningful differences in practical effects. The combination of heat and foam rolling showed a much larger effect size than either condition alone, while the effect sizes of heat and foam rolling were both medium, and comparably close.

Table 2. Pre-Post Results, Standard Deviation, Degree and Percentage Change

Test	**Mean (°)**	**Std Deviation (°)**	**ΔROM (°)**	**% Change**	**Cohen's Effect Size (d)**
Pre-Heat	78.1	16.7	8.2	10.4	0.54
Post-Heat	86.3	15.1			
Pre-Foam Rolling	78.9	15.0	5.9	7.5	0.41
Post-Foam Rolling	84.8	13.4			
Pre-Combination	75.8	12.1	9.6	12.7	0.85
Post-Combination	85.4	10.5			

Table 3: Pre-Baseline, Changes Pre-Post, and Percent Change for Heat

Subject	Pre-Baseline (°)	Pre-Heat (°)	Post-Heat (°)	ΔROM (°)	% Change
1	88	76.7	84.3	7.6	9.9
2	76	51. 7	66	14.3	27.7
3	88	99	105	6	6
4	83.7	72.3	79.6	7.3	9.6
5	86.7	88.3	92	3.7	4.2
6	66.3	62.3	72.3	10	16
7	67	78	88	10	12.8
8	84.3	83.3	91	7.7	8.7
9	62.7	72.3	76	3.7	5.1
10	100.3	110.3	118.3	8	7.2
11	72	65.3	76.6	11.3	17.3
Mean	79.6	78.1	86.3	8.2	10.4
S.D.	11.1	11.6	16.7	3.2	6.9

Table 4: Pre-Baseline, Changes Pre-Post, and Percent Change for Foam Rolling (FR)

Subject	Pre-Baseline (°)	Pre-FR (°)	Post-FR (°)	ΔROM (°)	% Change
1	88	73.7	77	3.3	4.5
2	76	69.7	73	3.3	4.7
3	88	97.7	100	2.3	2.4
4	83.7	72.7	77.3	5	6.9
5	86.7	86.3	96	9.7	11.2
6	66.3	68.3	75.7	7.4	10.8
7	67	53.7	68	14.3	26.7
8	84.3	85.3	89.3	4	4.6
9	62.7	85	94.7	9.7	11.4
10	100.3	106.7	108.7	2	1.9
11	72	68.7	73.3	4.6	6.9
Mean	79.6	78.9	84.8	5.9	7.5
S.D.	11.1	15.0	13.4	3.9	7.0

Table 5: Pre-Baseline, Changes Pre-Post, and Percent Change for Combination

Subject	Pre-Baseline (°)	Pre-Both (°)	Post-Both (°)	ΔROM (°)	% Change
1	88	68.7	73.7	5	7.3
2	76	69.7	74.3	4.6	6.6
3	88	89.7	96.7	10	11.1
4	83.7	70	92.7	22.7	32
5	86.7	81	88	7	8.6
6	66.3	68.3	75.3	7	10.2
7	67	64.3	81.3	17	26.4
8	84.3	83.7	87	3.3	3.9
9	62.7	66	86	20	30.3
10	100.3	103	107	4	3.9
11	72	69.3	77.7	8.4	12.1
Mean	79.6	75.8	85.4	9.6	12.7
S.D.	11.1	12.1	10.5	6.8	10.5

Chapter V

Discussion

Introduction

The purpose of this study was to investigate the acute effects of moist heat, foam rolling, and a combination of the two treatments on active hip flexion range of motion in Division II university female lacrosse athletes. Testing took place on three separate days, each separated by a week. Participants were randomly assigned a treatment: a 10-minute application of a moist hot pack on their hamstrings muscle group, 3 sets of 60 seconds foam rolling of the hamstrings muscle group with 15 seconds rest between sets, or a combination of both, beginning with heat followed by foam rolling. Immediately before and after each intervention, athletes had their active hip flexion range of motion measured via goniometer. Following performance of all three interventions, participants were given a Likert scale survey to gauge how effective they found each intervention. The original hypothesis was that both heat and foam rolling alone would be enough to acutely decrease hamstrings tightness (measured by an increase in active hip flexion range of motion). It was also hypothesized that the combination of both heating and foam rolling would significantly increase range of motion and be the most effective intervention. There was a statistically significant increase in hip flexion range of motion in all three intervention groups ($p < 0.001$, $d \geq .041$), however the treatment group showed that no individual intervention was statistically more effective at increasing range of motion than any other intervention ($p > 0.05$).

When looking closer at the results given in Table 6 (in Appendix II), the p-value of 0.098 in the treatment * time section indicates a trend where the treatment across time is approaching significance. With more subjects and/or a longer study, this may have eventually reached significance. While there were no statistically significant differences between treatment groups, the combination of heat and foam rolling was shown to have the largest effect size (d = 0.85) of the treatments. Heating (d = 0.54) and foam rolling (d = 0.41) had medium effect sizes. This shows that while the differences between the groups was not statistically significant, the combination treatment appears to be the most effective at increasing range of motion. These results appear to support one of the hypotheses of the current study that the combination of heating and foam rolling would be more effective than either treatment alone, despite the fact that this was not by a statistically significant margin.

The Likert survey results also reflected the quantitative results of the study. Participants found the combination treatment to be most effective at increasing range of motion with a score of 5.82 ± 1.08 (Table 1), with seven being most effective and one being least effective. Heating was believed to be the second most effective, with a mean score of 5.27 ± 0.79 (Table 1), followed by foam rolling with a score of 4.64 ± 1.36 (Table 1). This indicates that participant bias is not believed to have played a role in the results of the study, as the opinions on the interventions match the quantitative results of the effectiveness of heat, foam rolling, and a combination of both.

When examining the pre-test baseline of all individuals, it appears that, on average, the majority of participants had slightly tighter hamstrings as the study continued for three weeks compared to the beginning of the study (Tables 3, 4 and 5).

The pre-season baseline mean of 79.6 ± 11.1 degrees was slightly greater than the means of all pre-intervention baselines of heat, foam rolling, and the combination (78.1 ± 11.6, 78.9 ± 15.0, and 75.8 ± 12.1 degrees, respectively) (Tables 3, 4 & 5). However, the results also show that the participants' range of motion was significantly improved (at least acutely) during the intervention period by the application of heat, foam rolling, or a combination. These discrepancies may be attributed, at least in part, to their five to six days a week of practice for the upcoming lacrosse season (Appendix E). This may indicate that as muscle tightness increases through regular, high intensity training, measures can be taken by athletes to regain lost range of motion. This is important for athletes to do, as it can make a difference in remaining healthy and maximizing performance as the season wears on (Kalli & Dimitrios, 2016; Prentice, 2004; TP Therapy, 2017).

Heating

The major finding of this study for the application of a moist hot pack for 10 minutes is in line with the hypothesis: that is, moist heat was enough to increase range of motion by a significant margin. Participants, on average, increased their hip flexion range of motion from 78.1 degrees to 86.3 degrees, a difference of 8.2 ± 16.7 degrees following moist heat application (Table 2). This equated to a 10.4% change, with a calculated effect size of 0.54. While the application of heat significantly increased range of motion from pre-post in this study, it was not significantly different from the other treatments ($p > 0.05$) (Table 6).

These results are in line with other research, however the current study found that heating was more effective than other studies have found. Hanson & Day (2012) investigated the effect that various forms of heat (warm whirlpool, moist hot pack, and exercise) had on hip flexion range of motion. They found that moist heat application for 10 minutes increased range of motion by an average of 1.8 degrees over three trials (Hanson & Day, 2012). This was not a significant margin, nor the most effective form of heat in their study (Hanson & Day, 2012). They found that heat in the form of exercise increased range of motion by an average 3.8 degrees (Hanson & Day, 2012). The differences in results between Hanson & Day's (2012) study and the current study could be explained by a different measurement tool (bubble inclinometer vs goniometer respectively) or the difference in passive (used by Hanson & Day, 2012) vs active hip flexion range of motion measurement (in the current study). Other discrepancies in data could be due to the larger sample size used in Hanson & Day's (2012) study (44 vs 11 in the current study), or using both male and female participants, as Hanson & Day (2012) did, as opposed to only females used in the current study.

Khamwong et al. (2014) also found similar results to the current study. They investigated the effect of moist heat on wrist flexor strength and range of motion (Khamwong et al., 2014). While their results indicated an increase in wrist flexion range of motion due to the application of moist heat (mean increase of 2.4 degrees), the increases were not statistically significant (Khamwong et al., 2014). Differences between the non-significant results of Khamwong et al.'s (2014) study and the current study could possibly be explained by the different joint measured. Khamwong et al.'s (2014) study also took place over eight consecutive days, which may indicate that there is no carryover effect of heating. This is further validated by Starkey (2004) noting that moist heat is primarily an acute modality.

Aytar et al. (2015) included the application of moist heat in their interventions of stretching and joint mobilizations. While heat was not used alone to investigate changes in range of motion, it was a part of all interventions, some of which were very effective (Aytar et al., 2015). However, heat alone was not responsible for these increases (Aytar et al., 2015). This indicates that moist heat combined with other treatments can help increase range of motion significantly, as confirmed in the current study.

Results of these previous studies indicate that heat alone can be an effective treatment to acutely increase range of motion. As many athletes may find themselves short on time prior to practice or competition, heating alone for 10 minutes would appear to be enough to decrease muscle tightness, and thus increase range of motion. However, as heat is mainly an acute modality (Khamwong et al., 2014; Starkey, 2004), it is important that athletes heat as close to activity as possible in order to maximize these effects.

Foam Rolling

The major findings of the application of foam rolling to the hamstrings muscle group were that three sets of rolling for 60 seconds was enough to acutely increase active hip flexion range of motion. Participants, on average, increased their active hip flexion range of motion from 78.9 degrees to 84.8 degrees, a difference of 5.9 ± 3.9 degrees (Table 2). This equates to an average change of 7.5%, with an effect size of $d = 0.41$ (Table 2). While the application of foam rolling acutely increased range of motion by a statistically significant margin ($p < 0.05$), it was not significantly different at increasing range of motion from any other treatment ($p > 0.05$) (Table 6). These results are similar to those found in the current literature, and appear to support one hypothesis of the current study, that foam rolling alone is enough to increase hip flexion range of motion.

Mohr et al. (2014) investigated changes in range of motion following an application of stretching, foam rolling, and a combination of both treatments. Their study took place on six consecutive days, and found that foam rolling alone was enough to significantly increase passive hip flexion range of motion by 3.4 degrees ($p = 0.04$). The combination of both foam rolling and static stretching increased range of motion by an average of 8.1 degrees, a p value = 0.01. (Mohr et al., 2014). Mohr et al.'s (2014) study had findings very similar to the current study; however the key difference was the study design. While the current study included a seven day washout period between testing sessions, Mohr et al. (2014) had participants perform the interventions for six consecutive days. As foam rolling is a treatment that generally should be done daily to maximize effects (Prentice, 2004; TP Therapy 2017), including a washout period may have limited the effectiveness of foam rolling in the current study. While the current study was designed specifically to prevent any carry-over effects of foam rolling, they should be considered when foam rolling is applied to athletes in the sports medicine environment.

Bushell et al. (2015) also found similar results to Mohr et al. (2014) and the current study. Much like Mohr et al. (2014), Bushell et al.'s (2015) study took place long-term, with multiple sessions of foam rolling per week (Bushell et al., 2015). Similar to Mohr et al. (2014), it was found that the consecutive days of foam rolling yielded greater increases in hip extension range of motion compared to the control group which did nothing (3.5 degrees compared to 0.6 degrees) (Bushell et al., 2015). These increases were by a significant margin ($p > 0.05$). However, as the current study discovered, even one session of foam rolling is enough to acutely see range of motion gains.

The results of the current study support the findings by Behara and Jacobson (2017), Kelley and Beardsley (2016), Sullivan et al. (2013), and Bradbury-Squires et al. (2015) regarding the efficacy of roam rolling to increase range of motion. Kelley and Beardsley (2016) found that foam rolling for 30 seconds was enough to significantly increase ankle dorsiflexion range of motion, while Bradbury-Squires et al. (2015) found that both 20 seconds and 60 seconds of foam rolling were effective at acutely increasing range of motion. Sullivan et al. (2013) found that foam rolling increased hip flexion range of motion up to 4.3% with multiple sets of longer durations. This compares closely with the 7.5% increase found in the current study following three sets of 60 seconds foam rolling. Fewer sets/shorter durations also found range of motion increases, but were not as effective as the highest sets/durations studied (2 sets of 10 seconds) (Sullivan et al., 2013).

Behara and Jocobson investigated the changes in vertical jump force and velocity, isometric knee torque, and hip range of motion due to either dynamic stretching or deep tissue foam rolling (Behara & Jacobson, 2017). Results showed no significant changes in any measures other than range of motion, which both interventions increased by a statistically significant margin (Behara & Jacobson, 2017). However, neither dynamic stretching nor deep tissue foam rolling was significantly better than the other at increasing range of motion (19.9% increase vs 15.6%, respectively) (Behara & Jacobson, 2017). The 15.6% increase is more than double the percentage increase by foam rolling in the current study (7.5%). These differences could be attributed to the difference in participants used (Division I football offensive linemen vs Division II female lacrosse athletes). While the percentage increase was greater, overall the results found by Behara and Jacobson (2017) are similar the results of the current study, and indicate that foam rolling can be an effective tool for increasing range of motion; but it may not be significantly better than any other treatment option alone, at least acutely in one sitting.

When looking at the results of all of these studies, it appears that foam rolling can be a very useful tool in increasing range of motion, even if used sparingly. However, it seems that multiple sessions of foam rolling per day or rolling out on consecutive days can magnify these improvements. This is crucial for athletes who are chronically tight or who are in season and working out five to six times a week. Adding in foam rolling to their pre/post practice treatments may increase their range of motion and put them at a lower risk of injury (Lempainen et al., 2015; Prentice, 2004). As the results of the current study show, just three and a half minutes of acute foam rolling out can significantly improve hip flexion range of motion in athletes.

Combination of Heating and Foam Rolling

The major findings of the current study are that the combination of heating and foam rolling acutely increased active hip flexion range of motion in participants. The combination of both treatments increased participants' range of motion on average from 75.8 degrees to 85.4 degrees, a difference of 9.6 ± 6.8 degrees (Table 2). This equated to a 12.7% improvement in range of motion on average, as well as a calculated effect size of $d = 0.85$, the largest of the three treatments. Like the other treatments, the combination increased participants' range of motion by a statistically significant margin ($p < 0.001$), but was not significantly more effective than either of the other treatments ($p > 0.05$).

These results support the hypotheses of the current study; while all interventions were hypothesized to be effective in increasing hip flexion range of motion, the combination treatment would be the most effective. It should also be noted that when looking at the effect size, the combination treatment had the largest effect size of the three interventions, and therefore may have a greater practical effect compared to other treatments at increasing range of motion.

While no research reviewed in this study combined heat and foam rolling, foam rolling was used in conjunction with other treatments to increase range of motion. Mohr et al. (2014) combined foam rolling with static stretching. While static stretching and foam rolling alone were able to increase range of motion (foam rolling by a statistically significant margin), the combination of both treatments was found to increase passive hip flexion the most (Mohr et al., 2014). Like Mohr et al. (2014), the current study also found that foam rolling combined with another treatment (heating in this case) makes it more effective than either treatment alone.

The combination of multiple treatments was also utilized in the study by Roylance et al. (2013). These researchers found that, while postural alignment exercises and static stretching were enough to increase sit and reach scores of their participants, the greatest increases were when these were combined with foam rolling (Roylance et al., 2013). Those results are in agreement with those found in the current study, and indicate that a combination of treatments is more effective than either treatment alone when trying to increase range of motion.

One possible reason why a combination of two different treatments (heating and foam rolling, stretching and foam rolling, etc.) appear to be most effective could be the different mechanisms that each treatment uses to increase range of motion (Prentice, 2004). Heating is primarily an acute modality, but has been shown to, among other things, reduce muscle spasm and elongate tissue (Starkey, 2004). Foam rolling itself has more of a mechanical rather than chemical mechanism, physically massaging the muscle fibers in order to get rid of the myofascial adhesions (believed to be the most common cause of muscle tightness) and return the muscle fibers to their optimum length (Morton et al., 2016; Prentice, 2004; Sullivan et al., 2013; TP Therapy, 2017). Some textbooks in the sports medicine community recommend heating before adding other methods such as stretching or foam rolling, as elongating the tissues via heat can help increase the mechanical changes more than if they (stretching or foam rolling) were applied prior to heating (Prentice, 2004; Starkey, 2004).

Conclusions

When examining the results of the current study more closely, two main conclusions of the efficacy of heat, foam rolling, and a combination of both can be drawn as it pertains to active hip flexion range of motion. Firstly, as demonstrated by the results, regardless of which treatment is applied, all three will have a statistically significant effect on the flexibility of the hamstrings ($p < 0.05$), and thus hip flexion range of motion. These findings are backed up by those noted in earlier studies (Aytar et al., 2015; Behara & Jacobson, 2017; Bradbury-Squires et al., 2015; Bushell et al., 2015; Hanson & Day, 2012; Kelly & Beardsley, 2016; Khamwong et al., 2012; Mohr, Long, & Goad, 2014; Roylance et al., 2013; Sullivan et al., 2013).

Secondly, while all three treatments significantly increased hip flexion range of motion, none of the treatments were significantly more effective than any other at increasing range of motion. While not statistically significant, the p value of .098 (Table 6 in Appendix II) approaches significance, and may indicate that more treatments, a longer term study, and/or a larger sample size could make a difference and possibly result in statistical significance. When comparing effect sizes, the combination of both heating and foam rolling shows a large effect size of d = 0.85, compared to the medium effect sizes of d = 0.54 and d = 0.41 for heating and foam rolling, respectively (Table 2). This indicates that while any of the treatments alone will be effective, it may be most effective to use the combination of heating and foam rolling if time allows.

Moving forward, it appears that regardless of treatment to increase range of motion (stretching, heating, foam rolling), either of them alone would be enough to adequately decrease muscle tightness and increase range of motion (Behara & Jacobson, 2017; Bradbury-Squires et al., 2015; Hanson & Day, 2012; Mohr et al., 2014; Roylance et al., 2013; Sullivan et al., 2013). However, the effects can be increased by using stretching or heating in conjunction with foam rolling to increase range of motion (Mohr et al., 2014; Roylance et al., 2013). The current study supports this claim as well, given the significant increase to hip flexion range of motion provided by the combination of heat and foam rolling, as well as the large effect size (Table 2). It should also be noted that foam rolling appears to be most effective when used multiple times a day, and/or multiple days in a row (Mohr et al., 2014; Roylance et al., 2013; TP Therapy, 2017).

Chapter VI

Summary and Conclusions

Summary of Major Findings

As the sports medicine field has progressed over the past few decades, so too have the methods used to decrease muscle tightness and achieve normal, optimal joint range of motion. Current literature has found that the risk of some injuries, such as muscle strains, can be lowered by having looser muscles (thus more range of motion) (Lempainen et al., 2015). There is also some research that finds that increased range of motion can aid in both performance and recovery (Peacock et al., 2014; Pearcey et al., 2015). While heating and stretching modalities remain among the most commonplace, one of the newest and among the least researched has been self-myofascial release using a foam roller. While there are many purported uses of a foam roller, including increasing range of motion, decreasing DOMS, or increasing force output (Hotfiel et al., 2017; Pearcey et al., 2015; TP Therapy, 2017; Vaughn & McLaughlin, 2015), the current study focused on its use in decreasing muscle tightness and therefore increasing range of motion.

The results of this study demonstrate that the combination treatment had the largest mean increase in hip flexion range of motion: 9.6 degrees or 12.7%. Heating showed the second most improvement, with a mean increase of 8.2 degrees or 10.4%, while rolling was least effective with a mean increase of 5.9 degrees and percentage change of 7.5%. The pre-post results showed a p-value < 0.001, while the treatment * time results showed a p-value > 0.05 (Tables 6, 7 & 8). This indicates that while each treatment alone increased active hip flexion range of motion by a statistically significant margin, no intervention was significantly better than any other. Effect sizes indicated that the combination was most effective (large effect of $d = 0.85$), while heating and foam rolling were less but still moderately effective ($d = 0.54$, $d = 0.41$, respectively). The effect sizes of the current study, as well as the results of other pertinent research (Mohr et al., 2014l Roylance et al., 2013) indicate that a combination of treatments (heating and foam rolling, stretching and foam rolling, etc.) can be more effective at decreasing muscle tightness, thus increasing range of motion, than a single treatment alone.

Practical Applications

The first practical application of this study is applicable to the sports medicine community, more specifically athletic trainers. Athletic trainers often have many athletes who need treatment simultaneously, generally without the benefit of having any assistance. As a result, time management and athlete autonomy is key to getting the entire team ready in a timely manner. Application of moist heat and foam rolling is very simple, and an athlete would likely be able to do this with little to no supervision. As the combination of heating and foam rolling appears to be very effective in increasing range of motion, athletes would be free to get themselves ready for activity while the athletic trainer concentrates on taping or other treatments that require their expertise. It would also allow athletes to heat and roll out instead of needing an athletic trainer to stretch them.

Another important application of this study is the fact that heating ($p \leq 0.001$. $d = 0.54$) or foam rolling ($p \leq 0.001$. $d = .0.41$) alone can significantly increase range of motion. In some levels of athletics, especially high-school and college, athletes must sometimes come right from class to practice. As a result, they have minimal time to prepare. The knowledge that three and a half minutes of rolling is enough to get their muscles loose can help them maximize what little time they have before practice starts. While it would be more beneficial to both heat and roll out, being able to do even one may be enough to loosen their muscles before participating in practice or competitions (Lempainen et al., 2015, Prentice, 2004).

Another possible application of this research is for athletic departments or sports medicine programs on a tight budget. Seeing that moist hot packs and a foam roller may be enough to help decrease muscle tightness, athletic departments and/or sports medicine programs could invest in these relatively cheap modalities as opposed to more expensive treatment options with similar results.

Recommendations for Future Research

One suggestion for future research would to investigate the effects of heating and foam rolling on consecutive days. Other research has been done to investigate stretching and other techniques as well as foam rolling (Mohr et al., 2014; Roylance et al., 2013), but heating and foam rolling, to this point, has not been done investigated in a long-term study. Other studies have found increased benefits from foam rolling on consecutive days, possibly due to a carry-over effect to the next day (Kelley & Beardsley, 2016; Mohr et al., 2014; Sullivan et al., 2013). Combining an acute modality such as heating with a long-term modality with a carry-over effect, like foam rolling, could be the best way to maximize range of motion with lasting power, as opposed to just acutely. Three interventions to increase range of motion could also be combined. Because studies have demonstrated that static stretching or heating can be combined with foam rolling, combining both with foam rolling may increase range of motion even more.

Further studies could also look at a more diverse participant population, and/or a larger one to increase the sample size. The lacrosse team was chosen due to convenience and the rapport they have with the researcher in order to increase compliance. Getting a larger number of participants from diverse sports could help determine whether or not these interventions are beneficial to all types of athletes, or just female lacrosse athletes. A larger sample size could also make the statistics more powerful, and could add statistical significance between the treatments that were not there before. However, while there was no statistical significance between the different interventions in the current study, the medium/large effect sizes still indicate that the interventions were meaningful.

The hamstrings muscle group was chosen both for its convenience of measurement and rolling out, and also its important role in sport (Lempanien et al., 2015). As a large and powerful muscle group responsible for both knee flexion and hip extension, the hamstrings are vital in any activity involving running or lower extremity power (Prentice, 2004). Future studies could look at the effects on different muscles, such as the gastrocnemius or rotator cuff muscles in throwing sports. Another potential study would be to find the practical effects of increased hamstrings range of motion, either in women's lacrosse or other sports in general. Other research has found that hamstrings flexibility is important in preventing injury and succeeding in sport (Fujii et al., 2012; Ghandi et al., 2015; Nigg et al., 2000). Further studies could investigate the acute practical effects of increased hamstrings range of motion, either through muscular power, strength, endurance, or change of direction tests using the hamstrings.

Conclusions

As one of the newer methods used in the athletic community to increase range of motion, foam rolling has not had the chance to be as thoroughly researched as other, older methods, such as stretching, heating, or massage. While it has many purported uses (TP Therapy, 2017), one of the most commonly researched is the effect of foam rolling on range of motion. The current study researched the effect that moist heat, foam rolling, and a combination of both treatments had on the active hip flexion range of motion of NCAA Division II female lacrosse athletes. The results of the current study showed that, while no single intervention was more effective than any other at increasing range of motion by a statistically significant margin, all three interventions alone were enough to statistically significantly increase hamstrings flexibility and hip joint range of motion from the pre-intervention baseline of all individuals. However, the calculated effect size showed a large effect size for the combination intervention ($d = 0.85$), and only medium effect sizes for heating and foam rolling ($d = 0.54$ and $d = 0.41$, respectively), indicating a more meaningful and larger practical effect for the combination. Further studies could look at the range of motion effects of foam rolling on consecutive days when combined with heating, as foam rolling appears to be more effective when performed regularly (Mohr et al., 2014; Roylance et al., 2013; TP Therapy, 2017). Future studies could also look at a larger sample size or a combination of heating, foam rolling, and stretching. The results of the current study can be applied in the sports medicine community by allowing athletes a self-sufficient and simple way to increase range of motion in a relatively short amount of time.

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Appendix I

Documents

Appendix A

RESEARCH PARTICIPANT CONSENT FORM

Effect of Moist Heat and Foam Rolling on Hamstrings Range of Motion in Division II Female Lacrosse Athletes

Matthew R. Flattery

Adams State University

Department of Human Performance & Physical Education

Purpose of Research

The purpose of the research is to compare the effects of foam rolling and application of a moist heat pack on the participants' active hip flexion range of motion.

Procedures. The participants will be members of a Division II Women's Lacrosse team between the ages of 18 and 22 years. All participants will perform three interventions: application of a moist hot pack, foam rolling the hamstrings muscle group, or hot pack application followed immediately by foam rolling. Testing will take place on three separate days, separated by one week. The order of the interventions will be randomly assigned to each participant. Each testing session will begin with a baseline measurement of their active hip flexion ROM via goniometer and recorded. The heat pack group will apply a moist hot pack to their hamstrings muscle of their dominant leg (determined by asking participants which leg they use to kick a ball). The hot pack will remain on the hamstrings group for 10 minutes. The foam rolling group will roll out the hamstrings muscle group of their dominant leg for three sets of 60 seconds, with 15 seconds rest between sets. The group with both interventions will heat for 10 minutes, followed by rolling out their hamstrings muscle group for the same amount of time. Immediately following their intervention, a secondary measurement will be taken to determine the acute effect that the interventions had on their angle of active hip flexion.

Duration of Participation. The participation should take no longer than 20 minutes per testing session per participant, or one hour total. The testing will take place over 3 weeks on a Monday. This is due to the team's training schedule, which includes a day off on Sunday.

Benefits to the Individual. Potential benefits to participants include a possible decrease in muscular tightness due to either heating or foam rolling or both. Foam rolling and/or heat may also decrease soreness. These potential benefits could increase their performance during lacrosse practices or games.

Risks to the Individual. The application of heat packs may cause skin redness and may cause a heat rash in some participants; however nothing is foreseen to require medical attention or be life threatening, as it is a standard athletic training treatment modality and the hot packs are kept at a fairly constant temperature.

Rolling out may be painful or cause bruising in some participants. The study will take place in the Athletic Training room with medical care on hand if any risks to the participants' health should occur. Any foreseen risks to a participants' health are minimal.

Confidentiality/Use of Records. All participants will be assigned an ID number which will be used to identify them for the duration of the study on both the demographic questionnaire and data sheet. All data will be kept on individual data sheets for each participant, with the data sheets kept in the researcher's locked office when not in use. All data will be recorded onto a Microsoft Excel spreadsheet on a password protected computer. Once all data has been recorded and analyzed, all forms with participant's ID number will be kept for one year before being shredded. If research findings are to be presented in a public forum, they will be in aggregate form without use of any personal identifiers

Contact Information

Primary Investigator	Advisor	Advisor
Matthew R. Flattery	Dr. Tracey Robinson	Dr. Brian Zuleger
flatterymr@grizzlies.adams.edu	tlrobins@adams.edu	
brianzuleger@adams.edu		
515-681-0373	719-587-7663	719-587-7404

Voluntary Nature of Participation

"I understand that I can withdraw my participation at any time and will not suffer a penalty for doing so."

"I HAVE HAD THE OPPORTUNITY TO READ THIS CONSENT FORM. ASK QUESTIONS ABOUT THE RESEARCH PROJECT AND AM PREPARED TO PARTICIPATE IN THIS PROJECT."

Participant's Signature Date

Participant's Name (Printed)

Researcher's Signature Date

(f) **Protection Measures**: Risks to the participants are minimal. Minor risks include redness where the heat packs are applied. Other risks are possible pain and possible bruising due to foam rolling. Participation in this study is voluntary and participants can choose to cease participation at any point without penalty. If research findings are to be presented in a public forum, they will be in aggregate form without use of any personal identifiers. Participants will be identified by a given ID number when data is being recorded. All paperwork will be kept in the researcher's desk in his office, which will be locked when no one is in the room. Once data are recorded, they will be recorded in a Microsoft Excel file on the researcher's password-protected personal computer where it will be statistically analyzed. Once all data have been recorded and analyzed, the data sheets will be kept for one year before being shredded.

(g) **Consent:** All participants will be given an informed consent sheet with a detailed outline of the study's purpose and procedures. A copy of the informed consent sheet will be included.

(h) **Changes:** Any changes made to the testing objectives, testing methods, or protection measures will be brought to the attention of the IRB immediately so that the necessary paperwork can be filled out/updated.

1-25-17

Name and Signature of Department Chair or IRB Area Representative | Date

1-26-17

Name and Signature of IRB chair | Date

1-26-17

1-26-18

Adams State University

Request to obtain approval for the use of human participants

Date: 12-6-16

To: Beth Bonnstetter, ASU Institutional Review Board

From: Matthew Robert Flattery

Subject:

(a) Responsible Faculty Member: Brian Zuleger Tracey Robinson
brianzuleger@adams.edu tlrobins@adams.edu
719-587-7404 719-587-7663

(b) Others in Contact with Human Participants: None

(c) The title of the research: Acute Effect of Moist Heat and Foam Rolling on Hamstrings Range of Motion in Division II Female Lacrosse Athletes.

(d) Objectives of the research: The purpose of this research is to determine the effect that moist heat, foam rolling, and a combination of the two modalities have on hip flexion range of motion. A secondary purpose is to see if the effects of one day's treatment are carried over into the testing session 48 hours after.

(e) Methods of procedure: The participants will be members of a university women's lacrosse team between the ages of 18 and 22 years. Before the participants' spring season training begins, all will report to the testing site and have their baseline active hip flexion range of motion measured via goniometer. A demographic questionnaire will also be given to the participants at this time. There will be three measurements, which will be averaged. All participants will perform three interventions: application of a moist hot pack, foam rolling the hamstrings muscle group, or hot pack application followed immediately by foam rolling. Testing will take place on three separate days, separated by at least 48 hours. The order of the interventions will be randomly assigned to each participant. Each testing session will begin with a baseline measurement of their active hip flexion ROM via goniometer and recorded. The heat pack group will apply a moist hot pack to their hamstrings muscle of their dominant leg (determined by asking participants which leg they use to kick a ball). The hot pack will remain on the hamstrings group for 10 minutes. The foam rolling group will roll out the hamstrings muscle group of their dominant leg for three sets of 60 seconds, with 15 seconds rest between sets. The group with both interventions will heat for 10 minutes, followed by rolling out their hamstrings muscle group for the same amount of time. Immediately following their intervention, a second measurement will be taken to determine the acute effect that the interventions had on their angle of active hip flexion. Testing should take no more than 20 minutes per day per participant, or less than 1 hour total for the three days. Following the testing on the final day, all participants will be given a survey which will use a Likert scale to gauge their beliefs on how effective each intervention was. No deception will be used in this study.

(f) <u>Protection Measures</u>: Risks to the participants are minimal. Minor risks include redness where the heat packs are applied. Other risks are possible pain and possible bruising due to foam rolling. Participation in this study is voluntary and participants can choose to cease participation at any point without penalty. If research findings are to be presented in a public forum, they will be in aggregate form without use of any personal identifiers. Participants will be identified by a given ID number when data is being recorded. All paperwork will be kept in the researcher's desk in his office, which will be locked when no one is in the room. Once data are recorded, they will be recorded in a Microsoft Excel file on the researcher's password-protected personal computer where it will be statistically analyzed. Once all data have been recorded and analyzed, the data sheets will be kept for one year before being shredded.

(g) <u>Consent:</u> All participants will be given an informed consent sheet with a detailed outline of the study's purpose and procedures. A copy of the informed consent sheet will be included.

(h) <u>Changes:</u> Any changes made to the testing objectives, testing methods, or protection measures will be brought to the attention of the IRB immediately so that the necessary paperwork can be filled out/updated.

____ _______________

Name and Signature of Department Chair or IRB Area Representative Date

____ _______________

Name and Signature of IRB chair Date

also decrease soreness. These potential benefits could increase their performance during lacrosse practices or games.

Risks to the Individual. The application of heat packs may cause skin redness and may cause a heat rash in some participants; however nothing is foreseen to require medical attention or be life threatening, as it is a standard athletic training treatment modality and the hot packs kept at a fairly constant temperature.

Rolling out may be painful or cause bruising in some participants. The study will take place in the Athletic Training room with medical care on hand if any risks to the participants' health should occur.

Confidentiality/Use of Records. All participants will be assigned an ID number which will be used to identify them for the duration of the study on both the demographic questionnaire and data sheet. All data will be kept on individual data sheets for each participant, with the data sheets kept in the researcher's locked office when not in use. All data will be recorded onto a Microsoft Excel spreadsheet on a password protected computer. Once all data has been recorded and analyzed, all forms with participant's ID number will be kept for one year before being shredded. No publication is planned for this research.

Contact Information

Primary Investigator	Advisor	Advisor
Matthew R. Flattery	Dr. Tracey Robinson	Dr. Brian Zuleger
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______________________________ ______________

Participant's Signature Date

____

Participant's Name

______________________________ ______________

1-26-17
1-26-18

Appendix B

Demographic Questionnaire

ID: ______________________

1. What is your age?

2. How many years have you played lacrosse, and what position do you play?

3. How many times a week (on average), if any, do you roll out?

4. How many times a week (on average), if any, do you use any other methods to relieve muscle tightness (eg. ultrasound, moist hot packs, stretching, massage, etc)? Please note which method(s) you use, if any.

5. If used before, how effective, on a scale of 0 to 10, do you find foam rolling at decreasing muscle tightness (0 being not effective at all, 10 being extremely effective)?

Appendix C

Data Sheet

ID_______________________

Measured Height:

Measured Weight:

Pre-Experiment Baseline

Trial 1	Trial 2	Trial 3	Average

Day 1

Baseline Measurements

Trial 1	Trial 2	Trial 3	Average

Intervention: ___________________

Trial 1	Trial 2	Trial 3	Average

Day 2

Baseline Measurements

Trial 1	Trial 2	Trial 3	Average

Intervention: ___________________

Trial 1	Trial 2	Trial 3	Average

Day 3

Baseline Measurements

Trial 1	Trial 2	Trial 3	Average

Intervention: ____________________

Trial 1	Trial 2	Trial 3	Average

Other Notes:

Appendix D

Post-Study Survey

ID ________________

Please fill out the following short survey regarding your opinions about all interventions. Be completely honest. Circle the number which best describes your feelings.

1.) How effective did you find heating at increasing hamstrings range of motion?

1 2 3 4 5 6 7

Not effective at all — Very effective

2.) How effective did you find foam rolling at increasing hamstrings range of motion?

1 2 3 4 5 6 7

Not effective at all — Very effective

3.) How effective did you find the combination of heating and foam rolling at increasing hamstrings range of motion?

1 2 3 4 5 6 7

Not effective at all — Very effective

Appendix E

Daily Practice Log: 1/23 – 2/13/2017

M 1-23	T 1-24	W 1-25	Th 1-26	F 1-27	Sat 1-28	Sun 1-29
-1 mile run -BW circuits* -ladder drills -1 mile run	-1 mile run -stick skills**	-1 mile run -BW circuits* -ladder drills -1 mile run	-1 mile run -stick skills**	-1 mile run -BW circuits* -ladder drills -1 mile run	-1 mile run -stick skills**	No Practice

M 1-30	T 1-31	W 2-1	Th 2-2	F 2-3	Sat 2-4	Sun 2-5
Test Day I -1 mile run -BW circuits* -ladder drills -1 mile run	-1 mile run -stick skills**	1 mile run -BW circuits* -ladder drills -1 mile run	-1 mile run -stick skills**	1 mile run -BW circuits* -ladder drills -1 mile run	-2 mile run -stick skills**	No Practice

M 2-6	T 2-7	W 2-8	Th 2-9	F 2-10	Sat 2-11	Sun 2-12
Test Day II -2 mile run -BW circuits* -ladder drills -1 mile run	-2 mile run -stick skills**	-2 mile run -BW circuits* -ladder drills -1 mile run	-2 mile run -stick skills**	-2 mile run -BW circuits* -ladder drills -1 mile run	-2 mile run -stick skills**	No Practice

M 2-13
Test Day III

*- consisted of planks, push-ups, jumping jacks, burpees, crunches, squat

**- throwing/catching drills, including cone drills, running and catching

Appendix II

Figures and Tables

Figures

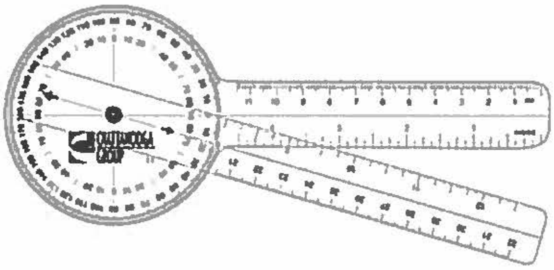

Figure 1: Goniometer (Model G300)

http://www.rainbow-printing.com/images/goniometers-spread
Retrieved September 10th, 2016

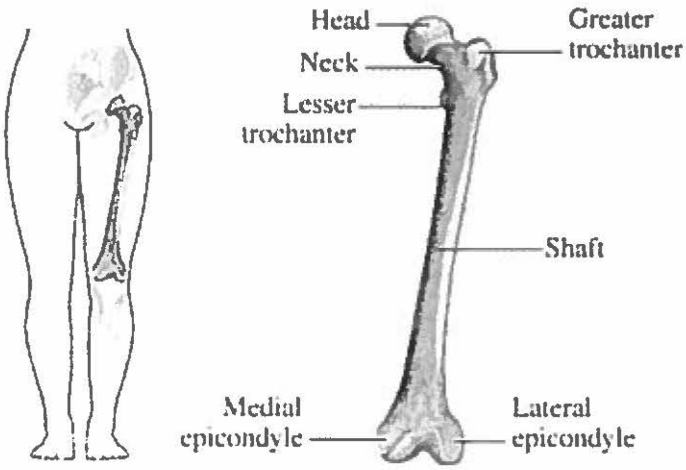

Figure 2: Location of Greater Trochanter and Lateral Epicondyle

http://www.johnthebodyman.com/wp-content/uploads/2014/06/Femur-detailed-with-Head-Greater-Trochanter-Medial-and-Lateral-Epicondyles.jpg
Retrieved September 10th, 2016

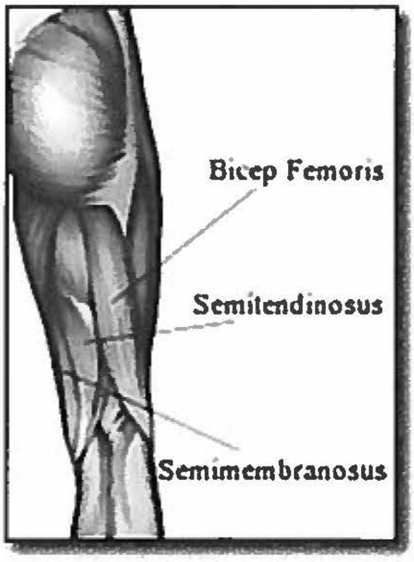

Figure 3: Hamstrings Muscle Group

http://www.algj.com/files/hamstrings-2.png
Retrieved September 10th, 2016

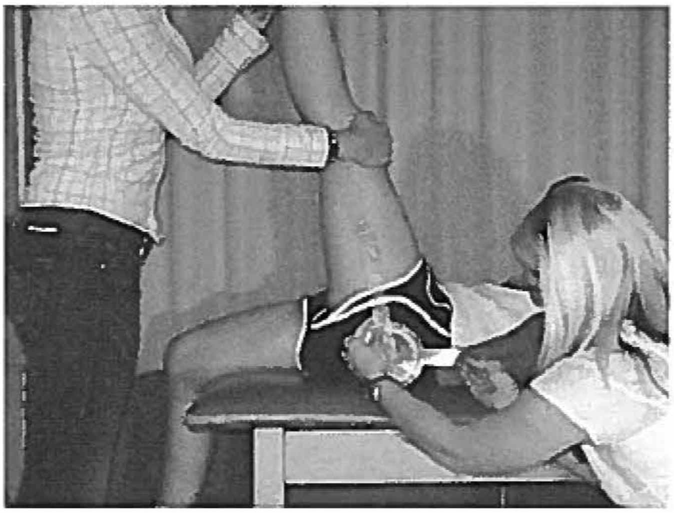

Figure 4: Goniometric Measurement of Hip Flexion (Left Hip)

https://www.researchgate.net/figure/26891917_fig2_Figure-2-Straight-leg-raise-technique-for-measuring-hip-range-of-motion
Retrieved September 10th, 2016

Figure 5: Hydrocollator with Moist Hot Pack

https://www.tartangroup.com/assets/1/15/DimRegular/Hydrocollator.jpg
Retrieved September 10th, 201

Figure 6: TP Therapy GRID Foam Roller

https://images-na.ssl-images-amazon.com/images/I/81Tt6yPc--L._SL1500_.jpg
Retrieved January 3rd, 2017

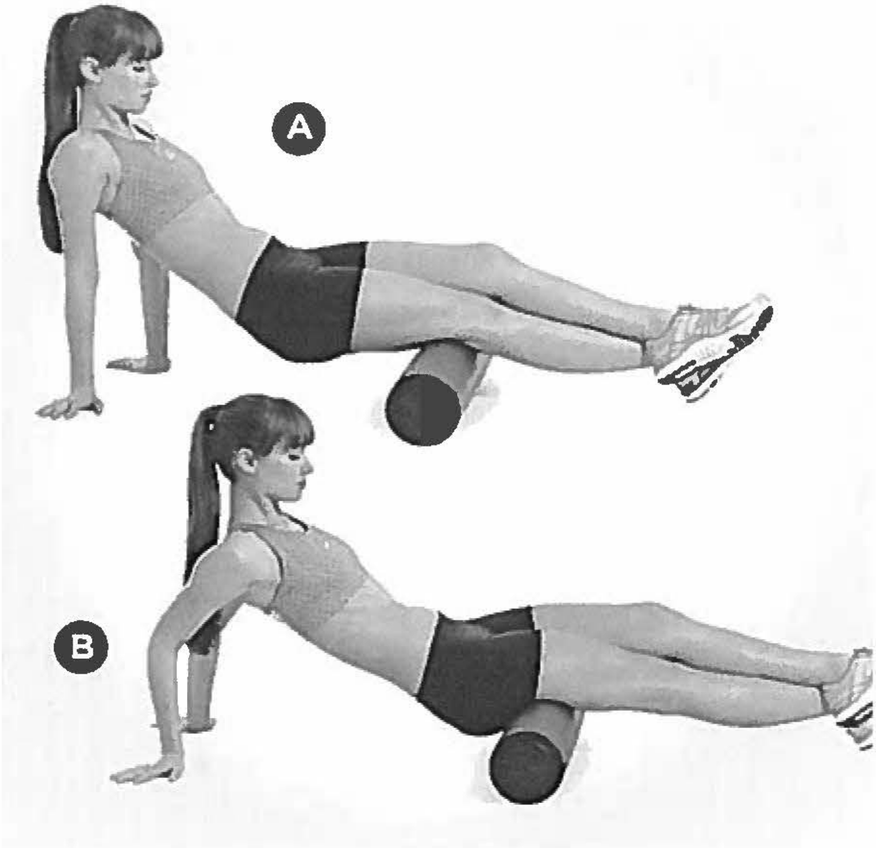

Figure 7: Application of Foam Roller to Hamstrings

https://jacquirowleyyoga.files.wordpress.com/2014/10/hamstrings_foam-roller.jpg
Retrieved September 10th, 2016

Tables

Table 6: Comparison of Treatment vs Time Significance

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[c]
Treatment	Pillai's Trace	.073	.354[b]	2.000	9.000	.711	.073	.709	.091
	Wilks' Lambda	.927	.354[b]	2.000	9.000	.711	.073	.709	.091
	Hotelling's Trace	.079	.354[b]	2.000	9.000	.711	.073	.709	.091
	Roy's Largest Root	.079	.354[b]	2.000	9.000	.711	.073	.709	.091
Time	Pillai's Trace	.881	73.827[b]	1.000	10.000	.000	.881	73.827	1.000
	Wilks' Lambda	.119	73.827[b]	1.000	10.000	.000	.881	73.827	1.000
	Hotelling's Trace	7.383	73.827[b]	1.000	10.000	.000	.881	73.827	1.000
	Roy's Largest Root	7.383	73.827[b]	1.000	10.000	.000	.881	73.827	1.000
Treatment * Time	Pillai's Trace	.403	3.032[b]	2.000	9.000	.098	.403	6.065	.445
	Wilks' Lambda	.597	3.032[b]	2.000	9.000	.098	.403	6.065	.445
	Hotelling's Trace	.674	3.032[b]	2.000	9.000	.098	.403	6.065	.445
	Roy's Largest Root	.674	3.032[b]	2.000	9.000	.098	.403	6.065	.445

a. Design: Intercept
Within Subjects Design: Treatment + Time + Treatment * Time

b. Exact statistic

c. Computed using alpha = .05

Table 7: Mauchly's Test of Sphericity to Determine Further Post-hoc Tests

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Treatment	.785	2.176	2	.337	.823	.964	.500
Time	1.000	.000	0		1.000	1.000	1.000
Treatment * Time	.685	3.409	2	.182	.760	.868	.500

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

a. Design: Intercept
Within Subjects Design: Treatment + Time + Treatment * Time

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

Table 8: Significance of Time and Treatment within Subjects

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Treatment	Sphericity Assumed	31.031	2	15.516	.226	.800	.022	.452	.081
	Greenhouse-Geisser	31.031	1.646	18.848	.226	.758	.022	.372	.078
	Huynh-Feldt	31.031	1.929	16.090	.226	.792	.022	.436	.080
	Lower-bound	31.031	1.000	31.031	.226	.645	.022	.226	.072
Error(Treatment)	Sphericity Assumed	1373.072	20	68.654					
	Greenhouse-Geisser	1373.072	16.464	83.398					
	Huynh-Feldt	1373.072	19.286	71.196					
	Lower-bound	1373.072	10.000	137.307					
Time	Sphericity Assumed	1030.792	1	1030.792	73.827	.000	.881	73.827	1.000
	Greenhouse-Geisser	1030.792	1.000	1030.792	73.827	.000	.881	73.827	1.000
	Huynh-Feldt	1030.792	1.000	1030.792	73.827	.000	.881	73.827	1.000
	Lower-bound	1030.792	1.000	1030.792	73.827	.000	.881	73.827	1.000
Error(Time)	Sphericity Assumed	139.623	10	13.962					
	Greenhouse-Geisser	139.623	10.000	13.962					
	Huynh-Feldt	139.623	10.000	13.962					
	Lower-bound	139.623	10.000	13.962					
Treatment * Time	Sphericity Assumed	38.325	2	19.162	1.722	.204	.147	3.445	.318
	Greenhouse-Geisser	38.325	1.521	25.205	1.722	.213	.147	2.619	.274
	Huynh-Feldt	38.325	1.737	22.068	1.722	.209	.147	2.991	.294
	Lower-bound	38.325	1.000	38.325	1.722	.219	.147	1.722	.221
Error(Treatment*Time)	Sphericity Assumed	222.499	20	11.125					
	Greenhouse-Geisser	222.499	15.206	14.633					
	Huynh-Feldt	222.499	17.367	12.812					
	Lower-bound	222.499	10.000	22.250					

a. Computed using alpha = .05

Table 9: Comparison of Significance between Different Treatment Types
treatment 1 = Heating
treatment 2 = Foam Rolling
treatment 3 = Combination

Pairwise Comparisons

Measure: MEASURE_1

(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.353	3.010	1.000	-8.285	8.991
	3	1.599	2.324	1.000	-5.072	8.269
2	1	-.353	3.010	1.000	-8.991	8.285
	3	1.245	2.065	1.000	-4.681	7.172
3	1	-1.599	2.324	1.000	-8.269	5.072
	2	-1.245	2.065	1.000	-7.172	4.681

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni