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THE ACUTE EFFECTS OF DIFFERENT FOAM ROLLING TIMING DURATIONS ON HAMSTRING FLEXIBILITY

By

Chloe Marie Kipnis

Bachelor of Science in Athletic Training
The University of Michigan – Ann Arbor
2014

A thesis submitted in partial fulfillment
of the requirements for the

Master of Science – Kinesiology

Department of Kinesiology and Nutrition Sciences
School of Allied Health Sciences
Division of Health Sciences
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University of Nevada, Las Vegas
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ABSTRACT

The Acute Effects of Different Foam Rolling Timing Durations on Hamstring Flexibility

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The use of a foam roller is growing in popularity as a part of a warm-up in order to prepare for activity. The current research, however, lacks an accepted timing duration for how long an athlete should foam roll prior to activity in order to increase range of motion (ROM). In order to guide clinical practice, it is necessary to establish a standard for how long an athlete should foam roll a muscle group with the goal to increase ROM. Therefore, the purpose of this study was to compare hamstring flexibility changes following a single foam rolling bout, performed for durations of 30 seconds or 2-minutes, to controls. In order to execute this, 42 physically active males and females between the ages of 18-33 years were randomly assigned to either a 30 second, 2-minute, or control group. These participants reported to the Sports Injury Research Center (SIRC) for two testing sessions separated by one week. On day one, participants provided informed consent followed by filling out an eligibility questionnaire. After this, anthropometric measures were taken along with baseline flexibility measured via passive hip flexion ROM. This day also served as the familiarization day for the participants, where they were introduced to the foam rolling intervention, watched an instructional video and practiced the proposed method of foam rolling. Once all participants reported for day one, they were evenly distributed into one of three groups (30 seconds, 2-minutes, or control) by gender. In order to establish that there were no statistical differences for baseline flexibility between groups, a one-way analysis of variance (ANOVA) revealed no statistical differences ($p=0.79$). On day

two, data collection consisted of: 1) pre-warm-up flexibility, 2) 5-minute warm-up at a self selected walking pace, 3) post-warm-up flexibility, 4) assigned intervention, 5) reported perceived pressure on the foam roller, 6) immediately post-intervention flexibility, 7) 10 minutes post-intervention flexibility. During flexibility measurements, participants were taken into passive hip flexion ROM by an investigator until the participant verbalized that they had reached "perceived maximum stretch." A separate investigator who is a Certified Athletic Trainer took all goniometric measurements of all participants. Both of the previously mentioned investigators were blinded to the intervention that the participant will take part in. During the assigned intervention, a third investigator monitored the participant to ensure proper foam rolling technique at a cadence of 40 beats per minute and provide feedback as necessary. Those in the control group long sat for 2-minutes during their intervention. A 3x5 mixed model factorial ANOVA showed no significant differences within subjects for time and intervention ($p=0.788$). For all groups combined, there was a significant increase in hamstring ROM from baseline to post warm-up ($p=0.002$), immediately post warm-up ($p<0.001$), and ten minutes post-intervention ($p=0.005$). No matter what the timing duration, a single bout of foam rolling is not an effective tool to increase hamstring flexibility when compared to a warm-up.

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CHAPTER 1: INTRODUCTION

Fascia is a connective tissue sheath that encompasses soft tissue structures and links together all muscles, bones, nerves, blood vessels, and organs to provide stability and increase mechanical advantage.[1] Within the musculoskeletal system, fascia also plays a role in evenly distributing force across a muscle and protecting the soft tissue by adapting to stress.[1–3] Injury, inflammation, inactivity, muscular imbalances, or microtrauma can alter the orientation of fascia and produce changes in the histologic, physiologic, and biomechanical properties of the tissue.[2,4] These changes are often termed fascial restrictions or adhesions[3–5] and as a result, the fascia becomes immobile, stiff, and dehydrated which can prevent normal muscle mechanics.[1–4,6] Fascial adhesions can decrease strength and flexibility, alter skeletal alignment, and lead to poor biomechanics, which can affect athletic performance.[1,3,4]

Myofascial release is a soft tissue mobilization technique that aids in creating a stretch in restricted fascia and soft tissue.[4] Therapist provided myofascial release is a historically well accepted soft tissue mobilization technique theorized to relieve muscle spasm, reduce pain and improve range of motion.[7] Self-myofascial release strives to achieve similar results, but without the use of a therapist. Foam rolling as a form of self-myofascial release has gained popularity over the last decade due to its ease of use and the convenience of not needing a therapist.[1] A foam roller is a cylindrical modality, usually made of foam or another dense material such as PVC (polyvinyl chloride). It is theorized to that self-myofascial release can relieve tension and tightness in the soft tissue by mobilizing the tissue through the use of friction and mechanical stress.[3,6] To achieve self-myofascial release with a foam roller, patients use their body weight on the foam roller to exert pressure onto the soft tissue. By varying the body positioning and amount of pressure applied, patients can use the foam roller to isolate specific areas of the body

to treat adhesions in the soft tissue.[1] The theoretical goal when using a foam roller on the soft tissue is to produce viscoelastic lengthening and plastic deformation of the fascia by the means of a temperature increase from the friction between the roller and the soft tissue to return the fascia to a mobile state.[6] This lengthening of the soft tissue can facilitate a stretch in the soft tissue with the hopes of increasing range of motion (ROM).[4] Increases in ROM (when deficient) not only allow for optimal muscle mechanics and function, but also contribute to overall musculoskeletal health.[3,8] It is commonplace for athletes to partake in a warm-up prior to activity to increase intramuscular temperature to subsequently increase ROM and prepare for sports activity. Static stretching has often been used to elicit increases in flexibility, especially as a part of a warm-up regimen before activity, but has been previously associated with reductions in force production.[5,9–13] Another common technique that has been used prior to activity to attain increases in ROM is myofascial release through massage. Unlike static stretching, massage may be a way to increase ROM without a decrease in force production and athletic performance.[7,14] The foam roller is believed to elicit similar benefits as a massage and it can be used prior to activity in combination with or as a replacement to static stretching.[3,8,9,11–13,15–17]

Foam rolling is an emerging practice, with the available research indicating that foam rolling has the ability to increase flexibility and range of motion,[3,6,7,9,11,12,16–23] while its effectiveness to increase strength, power, athletic performance,[3,8–10,13–16,21] and decrease recovery time remains inconclusive.[5,18,24] Although some previous findings support the use of foam rolling to increase flexibility, the timing durations for foam rolling intervention are varied throughout the literature, ranging from 10 seconds to 2 minutes.[3,5,6,9,11,12,15–17,20–22,24] Additionally, the evidence on whether or not the therapeutic effects of the foam rolling last remain inconclusive.[6,11,20] In order to guide clinical practice, research investigating appropriate

timing durations for foam rolling that are feasible, yet effective in eliciting fascial property changes resulting in increased ROM, are needed. Therefore, the purpose of this study was to compare hamstring flexibility changes following a single foam rolling bout, performed for timing durations of 30 seconds or 2-minutes, to controls. The hamstrings muscle group was chosen due to its importance in many athletic activities, especially running. Hamstring flexibility was measured indirectly via passive hip flexion ROM. We hypothesized that; compared to the control group, there would be a significant difference in hamstring flexibility in both the 30 second and 2-minute groups immediately following the foam rolling intervention. We did not expect a statistically significant difference in hamstring flexibility 10 minutes post-foam rolling for each group when compared to baseline measures. We also predicted that there would be no significant difference between groups in the amount of perceived pressure that was exerted on the foam roller and that there would also be no significant differences between the day 1 baseline measure and the day 2 baseline measure for all three groups.

CHAPTER 2: REVIEW OF RELATED LITERATURE

The purpose of the current study was to compare hamstring flexibility changes following a single foam rolling bout, performed for timing durations of 30 seconds or 2-minutes, to controls. Currently a majority of the information used in the athletic training profession in regards to foam rolling is anecdotal and not evidence based. This review of the literature will explore the various effects that foam rolling has on flexibility,[3,6,7,9,11,12,16–23] athletic performance,[3,8,13,15] and recovery.[5,18,24] Additionally, the effectiveness of roller massager (a hand-held myofasical roller) and massage will also be reviewed. Another section will also be presented in regards to methodology and supporting arguments.

Flexibility Interventions

Massage is the most widely accepted form of myofascial release and is commonly used in with the athletic population. Foam rolling is also commonly utilized as self-myofascial release prior to activity in order to increase ROM and flexibility, due to the modality not requiring therapist assistance. Previous research investigating foam rolling and flexibility often combines foam rolling with static stretching. The following articles examine the use of a foam roller by itself and in combination with static stretching to determine its effects on flexibility and/or ROM as a part of their experimental approach. In addition, the effects of the handheld roller massager on ROM and flexibility will also be reviewed.

Škarabot, Beardsley, & Štirn,[11] conducted a research study comparing the acute effects of static stretching, foam rolling, and static stretching combined with foam rolling on the plantarflexor muscle group on passive dorsiflexion range of motion in resistance trained, adolescent swimmers with at least six months of foam rolling experience. Eleven adolescent swimmers were recruited to take part in the study (5 females; 6 males; age: 15.3±1.0 years;

height: 172.3±8.6 cm; mass: 64.5±10.3 kg). They each participated in 16 hours of swimming training weekly, along with three hours of resistance training and at least 30 minutes of foam rolling per week for six months prior to study participation. The three different interventions were foam rolling, static stretching, and foam rolling and static stretching combined. The structure of each testing day was as follows: baseline measurement of passive dorsiflexion ROM, intervention, passive dorsiflexion measurement immediately after intervention, 10, 15 and 20 minutes after. The static stretching was done off of a step for three sets of 30 seconds with 15 seconds rest in between each set. Likewise, foam rolling was performed for three sets of 30 seconds with 15 seconds rest in between each set. Foam rolling was performed with The Grid foam roller and subjects used their palms to propel the body over the roller from the popliteal fossa to the Achilles tendon in a fluid motion. Passive ankle dorsiflexion measurements were taken using a weight-bearing lunge test where subjects maximally leaned into a wall just before the heel raised off of the ground. The primary statistical analysis ran was a one-way ANOVA with post-hoc Bonferonni tests. There was a significant increase in passive ankle dorsiflexion ROM between baseline and immediately post-intervention for static stretching (6.2%; $p < 0.05$) and static stretching and foam rolling combined (9.1%; $p < 0.05$), but not for foam rolling (2.7%; p-value not reported). There were no other significant increases in passive ankle dorsiflexion ROM at any other time points for any intervention. Foam rolling and static stretching combined revealed a significant condition effect immediately post-intervention superior to foam rolling ($p \leq 0.05$) for increasing passive ankle dorsiflexion but not to static stretching. The significant increase in passive dorsiflexion ROM post-intervention was superior for foam rolling and static stretching combined compared to foam rolling, but not to static stretching. The authors did address that although they found a statistical increase in passive dorsiflexion ROM for foam

rolling and static stretching combined, that this might be due to the standard error of measurement at 1.1 cm. Additionally, the results of this study show that the increases in passive dorsiflexion ROM for all interventions last only immediately after the intervention. At any time point after that in which measurements were taken, the increase was no longer statistically significant. Overall, this study showed that increases in passive dorsiflexion ROM occur immediately after performing the intervention, and the greatest increases occur with a combination of foam rolling and static stretching.

Mohr, Long, & Goad[12] conducted a research study to examine the long term effects of six consecutive days of static stretching and foam rolling on passive hip flexion ROM. Forty recreationally active subjects who had less than 90° of passive hip flexion were randomly split up into four different intervention groups: static stretching (n=10, age: 22.00±3.80 years, height: 171.32±5.44 cm, mass: 78.14±14.44 kg), foam rolling (foam rolling: n = 10, age: 21.00±2.21 years, height: 173.20±6.31 cm, mass: 74.60±15.64 kg), foam rolling and static stretching (foam rolling and static stretching: n = 10, age: 21.20±2.44 years, height: 167.64±8.55 cm, mass: 68.05±10.32 kg), or control (n = 10, age: 20.80±2.70 years, height: 169.42±8.80 cm, mass: 72.86±13.30 kg). Data collection took place on six separate days separated by 48 hours each in which the following measurements were taken with a bubble inclinometer: baseline passive hip flexion ROM and post intervention passive hip flexion ROM. This was measured by taking the hip into full passive flexion until the point of discomfort. Baseline measurements were taken first, and then subjects took part in the intervention they were assigned to. Static stretching of the hamstrings was performed as a "partner stretch" for three sets of one minute with a 30 second rest in between each set. Foam rolling was performed by rolling from ischial tuberosity to popliteal fossa at a cadence of one second each in the superior and inferior directions, monitored

by a metronome. The foam rolling protocol was performed for three sets of one minute with a 30 second rest in between each set. For the combined foam rolling and static stretching group, foam rolling was performed prior to static stretching. A two-way ANCOVA with the GLIMMIX procedure was used to measure change in ROM between the initial measurement and the last measurement on day six. Independent t-tests were used to isolate any general differences and 95% confidence intervals were used. Regardless of treatment, there was a significant increase in passive hip flexion range of motion across time ($p=0.001$), with the greatest increase coming from the group that did foam rolling and static stretching combined ($p=0.04$) when compared to foam rolling ($p=0.006$), static stretching ($p=0.04$), and control ($p=0.001$). There were no significant differences between any of the other treatments ($p>0.09$). These results indicate that foam rolling, static stretching, and a combination of foam rolling and static stretching consistently for six days for patients with limited hip flexion mobility can create significant increases in passive hip flexion range of motion, with the combination treatment showing the most significant gains in ROM. This greater increase can likely be attributed to the increase in tissue temperature from foam rolling which then carries over to viscoelastic changes in the tissue when static stretching.

Twenty-seven subjects (age: 22.7±2.4 years) with a sit-and-reach score of 34.3 cm or less were selected to participate in a two-day study comparing the effect of self-myofascial release, postural alignment exercises, and static stretching on joint range of motion. This study, conducted by Roylance et al. measured baseline joint ROM scores with the sit-and-reach test first, followed by the assigned intervention, and a post-intervention sit-and-reach test.[17] This process was repeated twice with one session consisting of the subjects performing foam rolling first and then postural exercises or static stretching, while the other had postural exercises or

static stretching first and then foam rolling second. Subjects foam rolled the low back, hamstrings, calves and piriformis/buttocks during the foam rolling intervention. The postural alignment exercises were static and dynamic mobility exercises that represented the following: cobra on elbows, upper spinal floor twist, static extension position, cobra, sitting floor twist, pelvic tilts and cats and dogs. A Bayesian paradigm was used to analyze the dependent and independent variables from the R (14) statistical program. Significant 95% posterior interval gains showed an improvement of 1.71 inches with postural alignment exercises first then foam rolling, 1.76 inches with foam rolling first then static stretching, 1.49 inches with static stretching then foam rolling, and 1.18 inches with foam rolling then postural alignment exercises. These results signify that for those individuals who have below average flexibility scores, including foam rolling with either static stretching or postural alignment exercises can demonstrate improvements in sit-and-reach scores. The authors recognized that repeating the sit-and-reach test multiple times might have influenced an improvement in scores as a limitation, as well as the fact that the treatments implemented were self-administered and therefore might not have always been done correctly or thoroughly.

Bushell, Dawson & Webster[6] investigated the lasting duration of foam rolling on dynamic hip angles in a functional lunge position. Thirty-one physically active subjects (males n=19, mass: 74.96±10.21 kg; height: 178.36±6.35 cm; females n=12; age: 21.35±2.44 years; mass: 62.79±7.72 kg; height: 165.93±7.18 cm) were divided into a control (n=15) or intervention group (n=16). Three separate testing days one week apart were implemented with two lunges in each session. Foam rolling of the quadriceps musculature was performed by the intervention group for three sets of one minute with 30 seconds rest in between each set between lunge sessions one and two and five additional times during a 7-day period after day two. The control

group performed the lunges, but did not have an intervention. The researchers' reasoning for the functional lunge positioning for hip extension measurements was to examine the superficial front line fascial chain. Hip extension angle in the functional lunge position was measured with Dartfish software for all lunges performed for all three sessions. The researchers also measured the clinical relevance of the functional lunge measured by using a Global Perceived Effect (GPE) scale, which subjects filled out after each session to determine if the subject felt worse, no change, or an improvement from the foam rolling. A mixed-effects ANOVA was used with post-hoc t-tests to measure the change in flexibility and differences in GPE scores. Statistical analysis indicated there were no significant increases in hip extension angle between the control and intervention groups immediately or across time for all 6 lunges measured over the three sessions ($p>0.05$). There were, however, significant increases in hip extension angle during pre- and post-measurements in test day two ($p\leq0.05$). The increase in flexibility isn't maintained over one weeks time, however, since the pre-lunge measurement of session two was not significantly greater than that of session one, despite foam rolling five times between test day one and two. This confirms that there were no significant differences in pre- and post-lunge hip extension measurements in session 3, therefore further supporting that the effect of foam rolling on the quadriceps musculature are not maintained long term after the intervention has ceased. After one week, the intervention group showed significantly greater positive feelings when performing a lunge compared to the control group ($p=0.00$); however, these feelings were significantly worsened after the intervention had ceased ($p=0.00$). The significance in scores was not shown after two and three weeks of foam rolling intervention. The researchers concluded that the implementation of foam rolling prior to physical activity can increase hip extension range of motion immediately and a consistent regimen of foam rolling can be

beneficial for increasing hip extension measurements in a functional lunge position, but the effects are not seen from the first exposure of foam roller usage.

Junker & Stöggl[22] aimed to determine the effects of a 4-week foam rolling intervention on the hamstring flexibility compared to a contract-relax proprioceptive neuromuscular facilitation (PNF) stretching group, and a control group. Forty-seven recreationally active male participants (age: 31.3±9.2 years; mass 78.0±9.9 kg; height 181.4±7.0 cm; BMI 24.3±2.4 kg/m^2) were randomly assigned to the foam rolling (n=13), contract-relax PNF (n=14), or control groups (n=13). Baseline hamstring and lower back flexibility measurements were taken with the stand-and-reach test that was measured after a 5-10 minute light-jogging warm-up. Those randomly assigned to the intervention groups took part in three training sessions per week for four weeks. The foam rolling group rolled their hamstrings unilaterally for 10 passes back and forth (about 30-40 seconds) and then repeated it on the other leg. Three sets were completed all together for both legs for each session. Foam rolling was performed three times a week for four weeks. The contract-relax PNF group performed 3 separate stretches at approximately 25% of their maximal voluntary isometric contraction with each leg. The isometric contractions were performed independently, using a towel to contract against with three total sets performed on each leg. Contract-relax PNF stretching was performed a total of 12 times a week for four weeks. The control group did not participate in any intervention. After four weeks, post-test hamstring and low back flexibility measures were taken again. A two-way repeated measures ANOVA was used to determine treatment, time, and interaction effects. Statistically significant increases in stand-and-reach scores for both the foam rolling group and contract-relax PNF group were found compared to the control group (p=0.004) and there were no differences found in scores between intervention groups (p=0.60). The authors concluded that both foam rolling and contract-relax

PNF stretching independently could increase hamstring flexibility with a 4-week training regimen. The prior research on contract-relax PNF stretching has already been convincing, however, research on foam rolling is very limited. This study showed that foam rolling could be just as effective as contract-relax PNF stretching in increasing hamstring flexibility.

Grieve et al.[19] conducted a pilot single-blind randomized control trial that examined the effects of self-myofascial release on the plantar surface of the foot on hamstring and lumbar spine flexibility. A baseline sit-and-reach test was used to measure hamstring and lumbar spine flexibility and then twenty-four subjects (males n=8; females n=16; age: 28±11.13 years) were randomly assigned to the intervention or control group. For the intervention group, participants rolled a tennis ball on the bottom of the foot from the metatarsal heads to the heel, with most of the intervention focused on the medial arch for two minutes. The intervention was repeated bilaterally and post intervention sit-and-reach measurements were taken immediately after. Those in the control group had the same protocol for sit-and-reach measurements as the intervention group, but instead of rolling their foot for four minutes, they sat in an identical chair in a stationary position. To determine the effect that the self-myofascial release intervention had on hamstring and lumbar spine flexibility, a one-way analysis of covariance (ANCOVA) was utilized. There was a statistically significant increase in post-intervention sit-and-reach scores compared to the control group (p=0.03). The results indicate that of two minutes of self-myofascial release on the plantar aspect of the foot can have immediate effects on increasing lumbar spine and hamstring flexibility as an outcome of pilot testing.

Another popular modality that has seen increasing recognition in athletic medicine is instrument assisted soft tissue mobilization (IASTM). IASTM uses tools commonly made of stainless steel, plastic, or fiberglass, with beveled edges to “scrape” the skin with the goal of

breaking up adhesions in the myofascia.[20] Markovic[20] compared the therapeutic effects of foam rolling and IASTM on knee and hip range of motion in male soccer players. Twenty male soccer players (age: 19±2 years; mass: 73.3±4.5 kg; height: 179±5.6 cm) participated in this study and were randomly divided into the foam rolling or IASTM group. The experiment consisted of two sessions separated by 24 hours. On day one, subjects performed a dynamic warm up and had baseline range of motion measurements taken. Both the passive straight leg raise and supine passive knee flexion were measured with a digital inclinometer. Those in the foam rolling intervention then foam rolled their quadriceps and hamstring muscle groups for two sets of one minute each. Those in the IASTM group received the Fascial Abrasion Technique (FAT) by a certified physical therapist for about two minutes for both the hamstrings and quadriceps muscle groups. Subjects' range of motion was then measured immediately after the treatment. Twenty-four hours later, subjects reported back to the laboratory to complete the dynamic warm-up and have their range of motion measures taken again. A two-factor ANOVA was used to determine differences between ROM measures between interventions with a Tukey's post-hoc analysis used to determine interaction. There was a significant main effect for both time and both range of motion measures (all $p<0.001$). There was also a significant group effect for the passive straight leg raise test ($p=0.039$) but not for the passive knee flexion test ($p=0.06$). Although both groups had increases in range of motion measures immediately after intervention, the effects from the IASTM treatment were greater, but not statistically significant. Additionally, the IASTM group maintained statistically significant changes in their range of motion measures 24 hours after intervention, while both range of motion measures for the foam rolling group went back to baseline values. The authors concluded from this study that a two-minute intervention of either foam rolling or IASTM of the hamstrings or quadriceps musculature could increase

passive range of motion immediately after treatment. The effects from the IASTM treatment show greater increases in range of motion and can last longer, however both interventions show encouraging findings acutely.

Sheffield & Cooper[23] investigated the effects of foam rolling on hamstring flexibility and performance. This study on fifteen amateur female football (soccer) players (age: 17±1.3 years), used the active knee extension (AKE) test as a measurement of flexibility, where the hip was measured to 90° of flexion and a goniometer was used to measure the amount of knee extension achieved in this position. This measure was done bilaterally. Data collection took place on the sideline of the football field, where AKE measurements were taken before and after the foam rolling protocol. The foam rolling protocol consisted of rolling on the hamstrings bilaterally three times proximally and three times distally and if at any point the subject felt discomfort, they were to sustain pressure on the roller for 30 seconds. Paired t-tests were used to analyze the differences in hamstring flexibility pre and post intervention. There was not a significant difference in flexibility pre and post foam rolling for the right leg ($p=0.08$), although, this number was approaching significance. In contrast, there is a significant increase in hamstring flexibility with the left leg post foam rolling ($p = 0.04$). The authors inferred from this study that there is promising evidence that foam rolling can improve hamstring flexibility. The study did recognize their sample size as a limitation and that they did not place restrictions on subject recruitment besides injury. They did not recognize their lack of a warm-up as a limitation.

Kuruma et al.[7] compared the effectiveness of myofascial release and static stretching on range of motion, muscle stiffness, and reaction time. Forty healthy individuals (males n=20; females n=20; age 21; mass: 58.1±9.9 kg; height: 167.4±9.2 cm) were evenly randomized to four groups: myofascial release for quadriceps (MFR-Q), myofascial release for hamstrings (MFR-

H), stretch for quadriceps (stretch group), and control. Prior to and after the intervention, active range of motion, passive range of motion, muscles stiffness, and reaction time were measured. The MFR groups received a myofascial release treatment from a therapist for eight minutes. Likewise, the stretch group received static stretching on the quadriceps musculature for eight minutes by a therapist. The control group lay in a supine position for eight minutes. Active and passive knee flexion range of motion was measured with a goniometer in the prone position. Muscle stiffness was measured three times with a durometer at 10, 15, and 20 cm above the joint line. Reaction time of knee extension was measured using EMG and a Biodex system where subjects were asked to contract the quadriceps as fast as they could after hearing an audible sound. Pre- and post-intervention measurement differences were analyzed using t-tests and a two-way repeated measures analysis of variance (ANOVA) analyzed the differences between interventions. Statistically significant increases in active and passive range of motion were found for all three interventions with the greatest increase found with the MFR-Q group ($p<0.05$). There were no significant differences identified for all groups in regards to muscle stiffness ($p>0.05$). Reaction time was significantly lower after both myofasical release interventions compared to controls ($p<0.05$). The researchers concluded from this study that contraction of the quadriceps musculature might be easier after myofacial release, therefore decreasing reaction time. They also concluded that both myofascial interventions increased active and passive range of motion possibly by the means of increasing tissue temperature and realigning the fascia.

The only published study whose main purpose was to compare different foam rolling durations on flexibility was administered by Couture, Karlik, Glass & Hatzel.[25] In a crossover design, 33 recreationally active subjects (19 female, 14 male: age=20±1.5 years, mass=72.2±10.8

kg) reported for three different testing sessions. The first day served as an orientation where the subjects completed informed consent and health history questionnaire. The subjects then completed a five-minute warm up on a stationary bicycle at 74 Watts and then had their baseline hamstring ROM measured, which also served as the control values. Days two and three, which were a minimum of 48 hours between each other, involved the same five minute warm-up, the assigned foam rolling duration, and post-rolling hamstring ROM measurement. The authors noted there was a 2-4 minute transition between completion of rolling and commencement of ROM measurements due to set up of instrumentation. The foam rolling technique involved using a solid black foam roller and the subject rolling the right leg from the ischial tuberosity to the back of the knee with the hands on the ground supporting the body. The two foam rolling conditions implemented in this study were the "long" condition which was four sets of 30 seconds and the "short" condition which was two sets of ten seconds. Each set of foam rolling was separated by 30 seconds. Subjects foam rolled at a cadence of 40 Hz while keeping maximum weight over their right leg. Hamstring ROM was measured using the passive knee extension test with the hip at 90° flexion. A mark was then made at 60.6% of the length from the fibular head to the lateral malleolus. This point was where the manual muscle tester (MMT) was placed and the MMT was used to measure the weight of the limb with the flexed to 90°. An inclinometer was secured to the middle of the right tibia while the knee was passively extended. The authors took into account passive lower leg weight and gravity and used trigonometry to take the average of three measurements in order to calculate the final ROM measurement. Seven subjects were used to investigate body weight applied to the roller by using a digital scale with the weight of the scale being recorded at knee, mid-thigh, and hip divided by the body weight of the subject. A one-way repeated measures ANOVA was used to analyze the ROM

measurements of the three groups. There were no significant differences found between the three groups ($p=0.986$) for knee extension ROM (baseline 67.6±9.9°, long duration 67.41±10.81° and short duration 67.3±10.6°). Percent body weight was also reported as knee (25.44±3.86%), mid-thigh (35.33±5.59%) and hip (46.44±4.7%). The authors noted that they might not have found significant increases due to the type of foam roller they used in their study. Even though they found a greater average percent body weight applied to the muscle compared to a previous study that used a roller massager, the authors pointed out that the increase diameter and decreased density of their foam roller compared to the roller massager might have prevented more body weight from being exerted on the roller. Although not addressed as a limitation, it's fitting to point out that the 2-4 minutes after foam rolling to set up the ROM instrumentation might have negated the therapeutic effects of foam rolling. The authors concluded that there are no significant differences between baseline knee extension and rolling for a short or long duration in healthy, active college aged individuals.

Overall, the majority of the research studies indicate that foam rolling, myofascial release, and the myofascial roller can be utilized to increase flexibility and range of motion, however there are a few exceptions. While it has previously been shown that static stretching alone can increase range of motion,[11–13,17] three studies examined the combination of both static stretching and foam rolling which produced the greatest increases in passive dorsiflexion,[11] passive hip flexion,[12] and sit-and-reach[17] flexibility when compared to each method independently. However, when examined as an independent modality, Škarabot, Beardsley, & Štirn found that foam rolling did not significantly increase flexibility when compared to static stretching and foam rolling and static stretching combined.[11] In addition, Kuruma et al.[7] made similar conclusions in regards to myofascial release and static stretching independently and

combined in which the two techniques increased active and passive range of motion in the lower extremity. However, the myofascial release performed by the therapist was an eight-minute long treatment, whereas the self-myofascial release treatments times in other studies ranged from 20 seconds to two minutes.[7] Even though the increases in flexibility were greater for static stretching in comparison to foam rolling,[11,12,17] the outcomes from foam rolling may reduce the likelihood for decrements in sport performance measures[5,9]; however, this was not directly tested in these studies. Bushell, Dawson & Webster[6] concluded that hip extension angles increased immediately during one session of foam rolling but this increase was not maintained over time during a three week period as hip extension angles returned to baseline after ceasing foam rolling for one week. Therefore, there were no long term effects seen after three weeks of a consistent foam rolling regimen.[6] Similarly, Markovic[20] showed that a two-minute foam rolling or IASTM treatment can increase hamstrings or quadriceps flexibility immediately after treatment, however only the IASTM treatment had positive effects on flexibility for greater than 24 hours; the foam rolling intervention groups flexibility returned to baseline. On the other hand, Junker & Stöggl[22] showed that a 4-week foam rolling training regimen can be just as effective as contract-relax PNF stretching to increase hamstring flexibility over the long term. Mohr, Long & Goad[12] found significant increases in hamstring flexibility for subjects' with less than 90° of passive hip flexion ROM after 6 days of foam rolling. These two studies show increased flexibility with long-term exposure to foam rolling. Independent of treatment time and treatment type, seven of the nine studies by all authors mentioned previously showed increases in range of motion and flexibility with the use a foam roller but the results need to be taken with a grain of salt as methods varied with pilot testing, timing duration, long-term exposure to foam rolling and the lack of a warm-up. [12,17,19,20,22,23] Previous research also supports that these increases are acute,

but the long term effects of foam rolling seem absent or inconclusive.[11,12,17,20,22] The research suggests that foam rolling may be effective for increasing flexibility, but more research needs to be done to examine difference parameters for rolling duration.

Athletic Performance Interventions

When devising a warm-up, sports performance professionals must take into account the most effective way to prepare an athlete for competition without subsequent negative effects on performance. Prior research findings have shown static stretching to decrease force production.[5,9] Sports performance professionals and coaches are now exploring other methods in which an athlete can adequately prepare for competition without having adverse effects on activity. Recently, it has become common for sports performance professionals to implement foam rolling in conjunction with a dynamic warm-up and is thought to improve performance. Therefore, the following studies looked to examine if foam rolling or the myofascial roller as a part of a warm-up effects force production and athletic performance.

Behara & Jacobson[9] examined the acute effects of a single bout of deep tissue self-myofascial release on muscular strength, power, and flexibility. Fourteen Division I male football linemen (age 20.04±1.41 years; mass: 136.28±6.67 kg; height: 194.92±3.63 cm; body fat %: 25.06±4.09) participated in the study. Baseline measures were taken for vertical jump (VJ), passive hip flexion range of motion (measured using a bubble inclinometer), peak and average power (collected with a Tendo Speed Analyzer), peak and average velocity (collected with a Tendo Speed Analyzer), peak and average isometric knee flexion and extension torque (measured with a Biodex System). Subjects were then randomly divided into three groups: deep tissue roller (DTR), dynamic stretching (DS), or no intervention. Those in the DTR group foam rolled unilaterally on the hamstrings, quadriceps, calves, and gluteus maximus for one minute

each. This process was then repeated on the other extremity. Those in the DS group performed self-stretching on the aforementioned muscles involved in the DTR group, also lasting 1 minute for each muscle group. The no-intervention group remained inactive for eight minutes. All subjects took part in each intervention group. Groups were switched one week apart for three weeks until all subjects participated in each group. All dependent variables were then measured again after the intervention. Multiple repeated-measured ANOVAs were conducted to determine statistical differences among the groups with Newman-Keuls post-hoc measures. For all groups, there were no significant differences pre- to post-test for VJ peak power (p=0.45), VJ average power (p=0.16), VJ peak velocity (p=0.25), VJ average velocity (p=0.23), peak knee extension torque (p=0.63), average knee extension torque (p=0.11), peak knee flexion torque (p=0.63) or average knee flexion torque (p=0.22). There were, however, significant increases in passive hip flexion range of motion for both the dynamic stretching and DTS groups, but not the no-intervention group (p=0.0001). The lack of significant changes in vertical jump, power, or strength show that both dynamic stretching and DTS can increase flexibility without a subsequent decrease in force and strength production or athletic performance. This study also concluded that the deep tissue roller could increase joint ROM similar to other rollers used in research, since this was the first known study to use the deep tissue roller.

Eleven healthy, physically active male subjects (height: 178.9±3.5 cm; mass: 86.3±7.4 kg; age 22.3±3.8 years) participated in an experiment by MacDonald et al. (2013)[3] examining if the effects of an increase in ROM from foam rolling can cause a decrease in force production in four different experimental conditions with 24-48 hours of rest in between each session. The control intervention was implemented in conditions 1 and 2, which measured range of motion (ROM) and force, respectively. The foam roller intervention was implemented in conditions 3

and 4, which measured ROM and force, respectively. Condition 1 served as a testing and familiarization day where subjects had baseline hip extension ROM measurements taken in a lunge position, as well as given time to practice the foam rolling technique. During condition 2, subjects executed a maximal voluntary knee extension contraction as a baseline measurement. For conditions 3 and 4, the subjects were tested on ROM and force after foam rolling the quadriceps for two sets of 1-minute bouts with 1-minute rest in between sets. Range of motion measurements were taken 2 and 10 minutes after the sets of foam rolling was completed. In order to determine differences between interventions and the dependent variables, a two-way ANOVA was performed. There were no significant differences between the control and foam rolling conditions for muscle force, rate of force development, and muscle activation ($p<0.001$). For the foam rolling intervention, hip extension ROM significantly increased 12.7 and 10.3% at 2 and 10 minutes post rolling, respectively ($p<0.001$). There was also a significant negative correlation between quadriceps force and range of motion ($p<0.001$) for both conditions. The increase in range of motion without detrimental effects of the neuromuscular variables of the quadriceps indicate that foam rolling for two sets of one minute bouts can serve as a part of a warm up without affecting performance measures.

As a result of the growth in popularity of implementing foam rolling as a part of a dynamic warm-up prior to activity, Peacock et al. (2014)[16] examined the effects of foam rolling in combination with a dynamic warm up on performance. Eleven physically active, healthy male subjects (mass: 77.64±9.70 kg; height: 176.76±7.25 cm; age 22.18±2.18 years; BMI 24.76±2.34; body fat % 10.36±2.30) participated in the study. They were advised to have a similar dietary intake during testing and refrain from caffeine, alcohol, and physical activity 24 hours prior to testing. Subjects reported for data collection on two separate days with a seven-day recovery

period in between each. Two experimental trails were counterbalanced and within-subjects: dynamic warm-up (DYN) and total body foam rolling (SMR). DYN began with a 5-minute general warm up jogging for 1000 meters. Subjects were then instructed through a 5-minute total body dynamic warm up that included arm circles, body weight squats, high knees, butt kickers, and split squats. All exercises were performed for two sets of ten repetitions within the 5-minute period. Following the dynamic warm up, the subjects were tested on the following dependent variables: sit-and-reach, vertical jump, standing long jump, pro-agility test, 1RM bench press, and a 37 m sprint. The experimental trial SMR began with the same 5-minute general warm-up as DYN. Subjects then underwent the foam rolling intervention at a rate of 5 strokes per 30 seconds for each muscle. The following muscles/regions were targets with foam rolling: thoracic/lumbar, gluteals, hamstrings, calves, quadriceps/hip flexors, and pectorals. Following the foam rolling intervention, subjects then went through the same dynamic warm-up and were tested on the same battery of tests as the DYN group. Multiple paired samples t-tests were used to measure differences between the performance (dependent) variables and the two conditions (DYN vs. SMR). There were significant increases in vertical jump ($p=0.012$), the standing long jump ($p=0.007$), pro-agility test ($p=0.001$) and 37 m sprint ($p=0.002$) after the SMR protocol compared to the DYN protocol. However, there were no significant differences in sit-and-reach scores between the two conditions, therefore the foam rolling had no effect on flexibility when being included with a dynamic warm-up. The authors concluded that an acute bout of foam rolling in addition to a dynamic warm up improved performance testing when compared to only a dynamic warm up but did not improve flexibility. The performance testing measures improved included lower extremity power, agility, and speed.

In a similar follow up study, Peacock et al. (2015)[21] compared the effects of a frontal plane foam rolling progression to a sagittal plane foam rolling progression on athletic performance, flexibility, and rate of perceived exertion (RPE). Sixteen athletically trained adult males (age: 21.9±2.0 years; height: 177.7±6.7 cm; weight: 78.0±9.3 kg; body fat: 10.8±2.2%) participated in two different counterbalanced foam rolling conditions separated by seven days. For the medial-lateral condition (FRml), subjects foam rolled the following muscles at a rate of 5 rolls per 30 seconds: erector spinae, glutes, hamstrings, calves, pectorals, and quadriceps. For the anterior-posterior condition (FRap), subjects foam rolled the following muscles at the same rate as FRml: latissimus dorsi, external obliques, piriformis, IT band, peroneals, and adductors. After foam rolling, subjects went through an extensive dynamic warm up in preparation for the performance testing measurements. The tests implemented were similar to those seen in the NFL combine and included: vertical jump, broad jump, shuttle run, bench press, sit-and-reach test. After each condition was completed, subjects also indicated their rate of perceived exertion using the Borg scale as well as preferred method of rolling (FRml or FRap). Differences in performance measures against condition were evaluated using a one-way ANOVA with post-hoc t-tests. A t-test was also used to evaluate differences in RPE between conditions. For the sit-and-reach test, a significant difference was found for the FRap condition ($p=0.003$). There were no significant differences found for any of the performance measures between conditions: vertical jump ($p=0.129$), bench press ($p=0.244$), shuttle run ($p=0.149$), broad jump ($p=0.814$). Results show that foam rolling in the anterior-posterior axis can improve sit-and-reach scores, as this makes sense since the foam rolling involves the hamstrings and lumbar spine. The authors also concluded that there were no differences in foam rolling technique on athletic performance measures of strength, power, and agility.

A study by Sullivan, Silvey, Button & Behm[8] assessed the effect of roller massager application on performance measures as well as determining the set and duration of roller massager application required to increase range of motion (ROM). Seventeen recreationally active subjects from a university population (7 males, mass: 70.2±10.4 kg; height: 173.4±8.8 cm; age: 22±1 years and 10 females, mass: 63.7±9.8 kg; height: 167.2±5.5 cm; age: 23±5 years) participated in this study with nine of the participants (3 males, 6 females) in the control group. Baseline testing on all subjects' hamstrings muscles included sit-and-reach, EMG, maximum voluntary contraction (MVC) force, evoked twitch force, and electromechanical delay (EMD). A total of four different interventions were examined: 5 seconds, 10 seconds, 1 set, and 2 sets. Subjects in the intervention groups reported for two separate visits, separated by 24 hours, in which two interventions were performed per visit. Within a session, each intervention was separated by 30 minutes and performed on the opposing leg. In lieu of the intervention, control subjects sat quietly for 5 minutes. A constant pressure roller apparatus was used in conjunction with the roller massager to apply myofascial release on the hamstrings for each intervention. The constant pressure device evoked 13 kg of constant pressure on the muscle at a rolling cadence of 130 beats per minute. Three minutes after each intervention, all variables measured in baseline testing were reevaluated. A three-way ANOVA was used to measured differences between time, rolling duration, and sets of rolling. There was a significant main effect for time with a 4.3% increase in sit-and-reach scores from pre to post rolling ($p=0.0001$). There was also a trend toward significance with 10 seconds of rolling versus 5 seconds of rolling in regards to range of motion ($p=0.069$). No significant differences between conditions were found for MVC force ($p=0.64$), muscle activation ($p=0.71$), or electromechanical delay ($p=0.47$). Twitch force was significantly decreased by 7.1% with one set of rolling versus two sets ($p=0.016$).

Additionally, main effects for pre- to post-rolling show a significant 10.5% decrease in evoked twitch forces (p=0.001). The main findings from this study are that roller massager application for at least 5 seconds increase hamstring flexibility without a subsequent decrease in force production.

In the only study to measure the effect of self-myofascial release on balance, Halperin, Aboodarda, Button, Andersen & Behm[13] compared the effects of static stretching and myofascial release with a roller massager on the calf muscles on ankle range of motion, MVC force, EMG, and a single limb balance test. Fourteen active individuals (12 males, mass: 70.2±10.4 kg; height: 175.1±8.8 cm; age 23±4 years and 2 females, mass: 56.7±3.8 kg; height: 167.2±2.5 cm; age: 22±3 years) with no lower extremity injuries participated in this study. All subjects reported for data collection on two different days, separated by 3-6 days. One of the test days served for the roller massager intervention, while the other day served as the static stretching intervention. Prior to all testing sessions, subjects performed a warm-up of ten unilateral heel raises while standing on a step. Two sets of pre-test measures for the dependent variables were then measured, ten minutes apart. The first set of pre-test measures served as intervention measures, and the second set was used as the control baseline. The dependent variables measured were ankle ROM (in-line lunge test), plantarflexors MVC & EMG, and single-limb balance (Stork stance test). For both the roller massager and static stretching interventions, subjects performed three sets of thirty seconds of the treatment with ten seconds rest in between each set. Subjects used the roller massager to travel the length of the calf muscle from origin to insertion while applying pressure on the foam roller equivalent to a pain level of 7 out of 10. For the static stretching intervention, subjects stood with one leg on a step while leaning against a wall with the knee straight. At one-minute and ten-minute post treatment, subjects then performed post-

intervention testing with a third and fourth set of dependent variable tests. A one-way ANOVA was measured for the effects of each intervention on the dependent variables across the four time intervals (two pre-tests and two post-tests). A two-way repeated measures ANOVA was measured to compare the effects of the two interventions (SS and roller massager) between conditions. For both static stretching and roller massager treatments immediately after the intervention, ROM was significantly greater with compared with pre-test one (SS: p=0.001; RM: p=0.004). Additionally, range of motion was significantly greater for the roller massager intervention ten minutes after when compared to pre-test one (p=0.006). For both static stretching and roller massager, there were no significant main effects found for MVC force, EMG, or balance testing. There was a significant interaction found between conditions for force, where subjects produced significantly greater forces ten minutes post roller massager intervention compared to static stretching (p=0.005). The main findings of this study are that both static stretching and roller massager increased range of motion after the treatment without effecting balance, MVC force, or EMG values. The roller massager treatment did however improve force production ten minutes after the self-myofascial release protocol when compared to static stretching. The authors concluded that both a roller massager and static stretching on the calf muscles can improve range of motion prior to activity, but using the roller massager might be more advantageous due to the increase in force post-treatment when compared to static stretching.

A similar myofascial roller to the roller massager, The Stick, was implemented to assess the acute effects of its implementation on strength, power, and flexibility in a group of collegiate athletes. Mikesky, Bahamonde, Stanton, Alvey & Fitton[14] utilized thirty NCAA Division II collegiate athletes (soccer, volleyball, basketball) (mass: 70.6±7.0 kg; height: 176.5±5.6 cm; age:

19.1±1.1 years) for a double-blind testing protocol with one familiarization session and three testing sessions over four weeks (each session was one week apart). The three interventions that were implemented for each test day were control (visualization), placebo (mock insensible electrical stimulation), and experimental (The Stick). On each test day, subjects performed a warm-up on an Airdyne ergometer. Assessments of hamstring flexibility, muscular power, and muscular strength were then measured. Hamstring flexibility was measured using a Leighton flexometer; vertical muscular power was measured with a vertical jump test and horizontal muscular power was measured with a flying start 20-year dash; muscular strength was measured on a KINCOM III isokinetic dynamometer. The subjects then participated in the intervention randomly assigned for that testing day. During the control intervention, subjects were supine on a table and asked to visualize the test they were about to perform for a duration of two minutes. During the placebo intervention, subjects were connected to an artificial electrical stimulation unit with electrodes on both ankles for two minutes. During the experimental intervention, subjects administered self-massage with The Stick for two minutes. Subjects then underwent post-testing for the same performance measures. In order to analyze the effects of the intervention on performance measures, a one-way repeated measures ANOVA was performed. There were no significant differences between pre-test and post-test measures for the dependent variables (hamstring flexibility, vertical jump, flying start 20-yard dash, and knee extension strength) between each condition (control, placebo, and The Stick) ($p>0.05$). It's important to note that this is one of the first studies published about self-myofascial release, and it was published around the time when the modality gained popularity. Although there were no significant effects from this study, some of it can be due to the limitations and complexity of a study that was researching such a new modality. For example, only hamstring flexibility was

measured, but the authors did not specify which muscles the subjects used The Stick for self-myofascial release on. Regardless, this study set the bar and provided a great base for future research on self-myofascial release.

Twenty-six recreationally active healthy college-aged individuals (13 men and 13 women) (age: 21.56±2.04 years; 23.97±3.98 body mass index, 20.57±12.21 body fat %) participated in a study by Healey, Hatfield, Blanpied, Dorfman & Rieve[15] comparing foam rolling to planking and its effects on athletic performance prior to testing. Subjects reported for data collection on three separate days with five days in between. One day served as a familiarization day while the two other served as experimental days. One experimental condition was foam rolling followed by athletic performance tests, while the other condition (control) was planking exercises followed by athletic performance tests. The athletic performance tests measured were vertical jump height and power, lower extremity isometric force (squat), and agility (pro-agility test). Prior to both conditions, subjects performed a dynamic warm-up. Immediately after, the foam rolling condition, subjects foam rolled for 30 seconds on the quadriceps, hamstrings, calves, latissimus dorsi, and rhomboids. After both conditions, subjects then completed the athletic tests previously mentioned. For the planking (control) condition, foam rolling was replaced by five sets of 30 seconds of planking. A 2x2 (trial x gender) repeated measures ANOVA was used to analyze the data. Multiple paired samples t-tests were used to determine significant differences between pre- and post-condition measures. There were no significant differences between foam rolling and planking for all four athletic performance tests measured ($p \leq 0.001$), however males performed significantly better on all athletic performance tests for both conditions compared to females. These results indicate that 30 seconds of full body foam rolling compared to planking had no effect on athletic performance.

Aside from performance testing measures, athletic performance can also be measured via anaerobic power testing. Janot et al.[10] authored the only study to directly measure the effects self-myofasical release on anaerobic power. Twenty-three healthy individuals (mass: 70.98±12.40 kg; height: 172.47±9.38 cm; age: 20.3±1.4 years) participated in this study. Subjects participated in three different trials, each separated by one week during the duration of the study. The trials included control, static stretching, and foam rolling conditions, in which subjects performed a Wingate anaerobic power test following each condition. Subjects first performed their control baseline trial for anaerobic power output, which had no intervention and then were randomized to complete either static stretching or foam rolling for trial 2, and then the other for trial 3. Wingate testing began with a properly fitting the bike to the subjects and then a warm-up at 2% body weight. Subjects then performed a sprint at 8% of body weight pedaling at their voluntary maximal revolutions per minute. Wingate testing software provided calculations for peak power output (PPO), average power output (APO), and minimum power output (MPO). Static stretching and foam rolling interventions were both performed for three sets of thirty seconds with a five second rest in between for each of the following muscles: gastrocnemius, gluteus maximus/piriformis, hip flexors, IT band, quadriceps, adductors, and hamstrings. After each exercise intervention, subjects again had their anaerobic power tested on the Wingate. A one-way repeated measured ANOVA was measured to compare the differences between the trials (control, static stretching, or foam rolling) and each variable measured during anaerobic power testing. For female subjects, peak power output was significantly decreased following static stretching compared to the control ($p<0.05$). In contrast, PPO was significantly increased following static stretching for males when compared to control ($p<0.05$). For both static stretching and foam rolling conditions, percent power drop was significantly decreased in

females ($p<0.05$) while it increased after foam rolling for males ($p<0.05$). For all other variables measured, there were no significant differences. Therefore, the authors suggested that the effects of foam rolling on anaerobic power output remain inconclusive. As this is the only study known to have measured the effects of foam rolling anaerobic power output, more research is necessary.

The studies reviewed showed significance that foam rolling or the use of a roller massager can increase flexibility without decreasing performance measures. When performed as part of a dynamic warm up, the use of a foam roller or roller massager was shown to improve or have no effect on measures of performance (vertical jump, agility, speed, force, power, reaction time, and balance).[3,7–10,13–16,21] In contrast, Janot et al.[10] was the first study to examine at a direct measure of anaerobic power and the results were inconclusive in regards to gender. There were different effects of foam rolling on anaerobic power for males and females. The effect of self-myofascial release on athletic performance has produced positive results. Peacock et al. (2014)[16] found that when comparing the effects of a dynamic warm-up by itself to foam rolling in addition to a dynamic warm-up, there were no differences in flexibility, however they did address a limitation of the study being a lack of a control condition.[16] Multiple authors have concluded that an increase in lower extremity flexibility, as a result of self-myofascial release, had no subsequent effect on performance testing measures.[3,8,9,13,21] The previous studies show promising use for self-myofasical release, especially in regards to its implementation prior to activity with an increase in range of motion without decreasing performance measures.

Recovery Interventions

Ever since self-myofascial release has gained popularity, its use has been synonymous with stretching and increasing flexibility. Similarly, sports performance professionals have used the foam roller after activity to benefit recovery from activity, without research to support the

claim. It has been accepted that foam rolling can serve as a means for recovery to decrease the effect of delayed-onset muscle soreness (DOMS) and performance outcome measures. The following studies look to justify the claim made by sports performance professionals by examining the effects of self-myofascial release on recovery.

By utilizing recovery measures of pain-pressure threshold, sprint time, change of direction speed, power, and dynamic strength-endurance Pearcey et al.[24] were able to examine the effects of foam rolling after an intense bout of exercise. Eight physically active males (mass: 88.4±11.4 kg; height: 117.0±7.5 cm; age: 22.1±2.5 years) participated in two conditions separated by four weeks. Pain-pressure threshold was measured at the beginning of each testing sessions followed by a warm-up on a cycle ergometer. Subjects then underwent the DOMS protocol with 10 sets of 10 repetitions to 60% of 1RM back squat. Testing sessions 2, 3, and 4 were conducted 24, 48, and 72 hours, respectively, after testing session 1. During all testing sessions, sprint speed (30 m sprint), agility (T test), and power (standing broad jump) were measured. In the fourth testing session, dynamic strength endurance was measured as as many repetitions as possible of 70% 1RM back squat. For the foam rolling condition, self-myofascial release was implemented after testing sessions 1, 2, and 3 were completed. Each muscle of the lower extremity was rolled for one set of 45 seconds with a 15 second rest in between at a cadence of 50 BPM for a total of 20 minutes total for foam rolling. Magnitude-based inferences and precision of estimation with confidence limits were measured to find differences between conditions and recovery measures. Pain-pressure threshold was substantially decreased by a large amount 24 hours post DOMS protocol and slightly decreased 72 hours post (Cohen d range, 0.59 to 0.84). Foam rolling had a moderate effect on sprint time 24 hours after exercise, (Cohen d range, 0.68 to 0.77), power (Cohen d range, 0.48 to 0.87), and dynamic strength-

endurance (Cohen d range 0.54). The authors concluded that 20 minutes of foam rolling of the lower extremity after an intense bout of exercise might reduce the likelihood of quadriceps tenderness and decrements in athletic performance.

In a similar study, MacDonald, Button, Drinkwater & Behm (2014)[5] assessed the effects of foam rolling as a recovery tool after exercise induced muscle damage. Thigh girth, muscle soreness, range of motion, muscle contractile properties, vertical jump, perceived pain while rolling, and force placed on the foam roller measured served as dependent variables. Twenty physically active subjects were randomly assigned to either the foam rolling condition (mass: 82.4±9.4 kg; height: 180.9±5.5 cm; age: 25.1±3.6 years; 1RM squat: 130.0±20.6 kg) or the control condition (mass: 89.6±98.6 kg; height: 179.4±4.9 cm; age: 24.0±2.8 years; 1RM squat: 128.4±32.9 kg). All subjects were required to attend five testing sessions: 1) orientation and 1RM testing, 2) pre-test measurements, 10x10 squat protocol, post-test 0, 3) post-test 24, 4) post-test 48 and 5) post-test 72. The dependent variables measured pre- and post-test were thigh girth, perceived pain, vertical jump, MVC force, and quadriceps and hamstrings ROM. Those in the foam rolling condition also performed a foam rolling intervention after all testing measurements. The foam rolling condition consisted of two sets of 60 seconds of foam rolling on both lower extremities targeting the anterior, lateral, posterior, and medial aspects of the thigh along with the gluteal muscles. Magnitude-based inferences on the interaction effects in the mean changes between the control and foam rolling groups were calculated to estimate the effect of foam rolling at each time point compared to the control. Results were expressed as a percent change from baseline measures, percent likelihood that the observed between-group difference was greater than a small effect size, and the effect size. Foam rolling substantially reduced muscle soreness at all time points while simultaneously improving ROM. Voluntary contractile

properties showed no between-group differences for all measurements besides voluntary muscle activation and vertical jump, with foam rolling improving muscle activation at all time points and vertical jump at 48 hours post. The authors concluded that foam rolling was beneficial in improving range of motion after exercise induced muscle soreness while reducing the amount of perceived muscle soreness.

By measuring similar variables to the previous article, Bradbury-Squires et al.[18] compared the effects of multiple sets of short duration (20 seconds) and prolonged duration (60 seconds) of a roller massager on the quadriceps on range of motion, pain, electromyography (EMG) while rolling and EMG while performing a dynamic movement (lunge) in a healthy muscle compared to a muscle damaged by exercise. Ten recreationally active males (age: 26.6±5.2 years; height: 175.3±4.3 cm; mass: 84.4±8.8 kg) participated. All participants performed three randomized conditions separated by 24 to 48 hours. Prior to all conditions, subjects performed a three-minute warm up on a cycle ergometer, knee flexion and extension MVIC measurements, and baseline knee flexion ROM in a lunge, and dynamic lunge EMG. In condition 1, participants applied the roller massager to the quadriceps for five sets of 20 seconds, whereas condition 2 consisted of five sets of 60 seconds, also to the quadriceps. Additionally, a Visual Analog Scale (VAS) was implemented to measure pain at the end of condition 2 and at 20-second intervals in condition 2. Condition 3 was a control condition in which subjects sat quietly for the average time it took to complete the other conditions. A constant-pressure rolling apparatus ensured consistent pressure and frequency of the intervention. Pressure remained consistent between subjects by adding weight plates that added to 25% of the subjects' body weight to the side of the apparatus. To determine the effects of the roller massager on pain, muscle activation, multiple one and two-way repeated measures ANOVAs were performed.

There were no significant differences in pain for the five sets of either condition (condition 1: $p=0.80$; condition 2: $p=0.90$), however, there was interaction with increased pain at 40 seconds ($p<0.05$) and 60 seconds ($p<0.05$) compared to 20 seconds. During the roller massager intervention, vastus lateralis and biceps femoris root mean square (RMS) EMG was 8% and 7%, respectively, of RMS EMG recorded during the baseline maximal voluntary isometric contraction. This can be indicative of a co-contraction during the initial adaptation stages of the pressure from the roller massager, in addition, these low intensity contractions can elicit benefits similar to contract-relax PNF stretching. Knee-joint ROM was 10% and 16% greater in condition 1 and condition 2, respectively, compared to the control condition ($p<0.05$). This difference between the two conditions, however, was not statistically different. There was a trend that condition 2 had greater increases in knee flexion ROM compared to the condition 1 ($p=0.80$). Finally, average lunge vastus lateralis RMS EMG decreased as roller-massage time increased ($p<0.05$), which means there was increased neuromuscular efficiency of the lunge. One of the biggest findings from these results is that the use of a roller massager for a longer duration (five sets of 60 seconds) involved higher perceptions of pain compared to five sets of 20 seconds of roller massaging. Additionally, this rolling resulted in a significant increase in range of motion, but there was no difference between the two durations of rolling. This was also achieved without the impairment of neuromuscular properties, which consequently increased neuromuscular efficiency of a lunge. The authors therefore recommended the use of a roller massager as a part of a dynamic warm up prior to activity.

All three of the articles reviewed regarding recovery used similar methods in determining the effects of foam rolling on recovery. The articles by Pearcey et al.[24] MacDonald et al. (2014)[5] are the only two articles available that used an exercise induced soreness protocol and both

articles found that foam rolling can reduce the perceived pain of muscle soreness while also helping to restore range of motion and performance measures. All three studies classified different outcome measures for recovery. Pain, as a variable to measure soreness, has been previously found to decrease 24 hours after a DOMS protocol and continued to decrease at all time points measured.[5,24] Foam rolling for 20-minutes was found to have a moderate effect on sprint time, power, and dynamic-strength endurance 24 hours after DOMS[24] and foam rolling helped improve vertical jump and voluntary muscle activation back to baseline measures 48 hours after DOMS[5]. Bradbury-Squires et al.[18] investigated the extent of discomfort or pain with a roller massager on a healthy muscle, because the extent of pain or discomfort might be associated with different durations of self-myofascial release. They found that subjects were able to tolerate pain at a higher percentage as the duration of self-myofascial release increased, which is similar to the findings of MacDonald et al. (2014)[5]. This increase in pain tolerance was also accompanied by an increase in range of motion and a decrease in vastus lateralis EMG[18]. This study determined that neuromuscular efficiency of a lunge improved as a result of an increase in range of motion and decrease in vastus lateralis EMG after the use of a roller massager for both 20 and 60 seconds. In addition, this was one of two studies to directly measure variables against two different roller massager timing durations. Although not significant, the 60 second foam rolling condition had greater increases in flexibility compared to the 20 second condition[18]. In regards to recovery, the results are encouraging. However, there is such little research dedicated to the effect that foam rolling has on recovery that more research is needed in the future.

Methodology & Supporting Arguments

The following articles will describe the supporting literature for the methodology and introduction of this study.

Curran, Fiore & Crisco[1] compared the pressure exerted by two different foam rollers on the IT band. Ten healthy college-age individuals (mass 80.7±22.1 kg; height: 177.3±10.3 cm; age: 20.8±1.1 years; 5 men, 5 women) volunteered for this study where two different foam rollers were used on a force plate. This study helped determine which foam roller was used in the present research, because the authors found that the foam roller with the PVC pipe core had significantly higher pressure per square inch ($p<0.001$) and isolated contact area ($p<0.005$) on the lateral thigh compared to the standard black foam roller. This is convincing evidence due the fact that the foam roller needs to be able to target the deep layers of the myofascia in order to release adhesions which can be achieved with a greater pressure exerted on the soft tissue. Therefore, roller design does make a difference when trying to achieve these effects.

Barnes (1996) explained the basic science of myofascial release. Not only did he describe the physiology of the technique, but the definition of myofascial release for this study comes from Barnes as well[4]. Starkey & Brown (2015)[26] published a textbook for the evaluation of athletic injuries. The textbook is used in all CAATE Accredited Athletic Training Programs to prepare students for the Board of Certification examination to become certified athletic trainers. This textbook was used to establish normal values for hip flexion range of motion (120°) for inclusion criteria when recruiting subjects. In addition, the goniometry used in this study to measure hip flexion range of motion was the same method described in the textbook[26].

The majority of the available research evaluating the different forms of self-myofasical release focuses mainly on flexibility and range of motion. These studies concluded that any form

of self-myofascial release is able to increase flexibility with timing durations ranging from 10 seconds to 2 minuites.[3,5–9,11–14,16–23] While this increase in flexibility has been shown in multiple studies in previous research, it was done so with self-myofascial release timing durations that are very inconsistent and with unreliable methods including pilot testing and the lack of a warm-up.[12,17,19,20,22,23] Furthermore, increases in flexibility due to self-myofascial release has no effect on athletic performance when implemented prior to activity.[3,8–10,13–16,21] Bradbury-Squires et al.[18] is one of two known studies to measure the difference in two timing durations in respect to flexibility. Although the 60 second roller massager condition produced greater flexibility compared to the 20 second condition, these results were not significant.[18] The other study by Couture, Karlik, Glass & Hatzel found no differences in hamstring flexibility between groups that use a foam roller for two sets of 10 seconds and four sets of 30 seconds.[25] The previous research also supports that these increases in flexibility are acute, but the long term effects of self-myofascial release seem absent or inconclusive.[11,12,17,20,22] In regards to self-myofascial release for recovery measures, the results are encouraging but only three published studies exist which showed that foam rolling can reduce the perceived pain of muscle soreness while also helping to restore range of motion and performance measures after delayed-onset muscle soreness.[5,18,24] What the current literature lacks is a standardized timing duration that can be clinically relevant with the goal of increasing flexibility via foam rolling prior to activity. Most of the studies chose their timing durations based off of anecdotal references since there is an absence of concrete evidence in the research for how long self-myofascial release should be performed for. Therefore, the purpose of this study was to compare hamstring flexibility changes following a single foam rolling bout, performed for timing durations of 30 seconds or 2-minutes, to controls.

CHAPTER 3: METHODOLOGY

Healthy, physically active individuals between the ages of 18 and 40 were recruited to participate in the current study. Both males and females were recruited in and around the University of Nevada, Las Vegas (UNLV) community through signage and word of mouth, including presentations of the proposed research within various classes offered by the department of Kinesiology & Nutrition Sciences at UNLV. Physically active was defined as partaking in exercise at least three times a week for at least thirty minutes each session.[15,18] Participants were required to be familiar with foam rolling, as defined by having used a foam roller at least once in the past six months for the purpose of self-myofascial release. Individuals who exceeded normal ranges of hamstring flexibility, defined as passive hip flexion ROM greater than 130° or had sustained a lower extremity injury within the past six months that resulted in a stoppage of activity for more than three consecutive workouts, were excluded from participation.[23,26]

A repeated measures design was used to evaluate the effect of foam rolling timing duration, as compared to controls, on hamstring flexibility. The dependent variables tested were hamstring flexibility, as measured via passive hip flexion ROM, and perceived pressure applied during the foam roller intervention. The independent variables were participant group assignment and the time points of when ROM was measured. Participants were scheduled for two thirty-minute testing sessions and advised to have a similar dietary intake and hydration status prior to each testing session.[16] Each testing session was within the same 1 hour time window of each other. Session one served as the familiarization and baseline testing session at the Sports Injury Research Center (SIRC). Participants were informed on the details of the study and given time to review and sign the university's Institutional Review Board (IRB) approved informed consent form. Consented subjects completed a pre-research questionnaire to provide

information on lower extremity injury history, physical activity, dietary and hydration status, and foam rolling history (Appendix A).[12] Subjects' anthropometric measures were collected (age, height, and weight)[1,3,5–10,12–24] and limb dominance was determined by asking subjects: "What leg would you use to kick a ball for distance?"[11,12] The dominant limb was the leg of interest in the current study and used to obtain baseline hamstring flexibility measures during session one. Hamstring flexibility was measured indirectly through passive hip flexion ROM with a goniometer (Baseline, Fabrication Enterprises, Inc., White Plains, NY).[23] The surface anatomy of the greater trochanter of the femur and lateral femoral condyle were identified on the skin with a marker to site the landmarks during goniometry measurements. Participants were positioned supine on the treatment table with their non-dominant leg secured to the table with straps.[12] Examiner one, who was a Certified Athletic Trainer, then positioned a goniometer on the lateral side of the thigh with the axis on the greater trochanter, with the stationary arm in the line with the torso, and the movement arm sighting the lateral femoral condyle.[26] Examiner two then passively moved the subject into hip flexion until the subject verbalized that they had reached a perceived maximum stretch and ROM was recorded in degrees by examiner one (Appendix C, Figure 8).

Following baseline ROM, subjects were familiarized with the foam rolling protocol by watching an instructional video while simultaneously mimicking the technique on the foam roller. Four identical myofascial foam rollers (TriggerPoint Performance Therapy, Austin, TX) were used during the course of data collection, with each foam roller being replaced every five days of data collection, in attempts to control foam roller deformation. The foam rollers used for the study were 15 inches in length and 5 inches in diameter with a non-uniform design made out of a polychloride (PVC) pipe core with a high density foam (ethylene-vinyl acetate) surrounding

(Appendix C, Figure 5). The foam roller was placed at the ischial tuberosity of the experimental leg while subjects held themselves up with their hands on the ground behind them and the foot of the non-rolling leg was flat on the ground with the knee bent (Appendix C, Figure 6)[23]. Participants were instructed to roll the experimental leg with as much of their body weight on the foam roller as tolerable without causing pain for the assigned time period using their non-rolling leg to assist in propelling the body along the foam roller.[12,22,25] The foot of the experimental leg was in a relaxed position during rolling. Subjects rolled the length of the hamstrings muscle group in the sagittal plane from ischial tuberosity to the popliteal fossa.[12,20,23,24] A metronome (Owik Time QT-3, Sweetwater, Form Wayne, IN) was used to maintain the foam rolling cadence at 40 Hz, established by pilot testing.[8,12,13,18] Once the video ended, subjects were then given an unlimited amount of time to practice the foam rolling task with the metronome and had the opportunity to watch the video as many times as desired until they felt comfortable with the technique. While participants were practicing the foam rolling technique, emphasis was placed upon the participants understanding how much of their body weight they placed on the foam roller without causing pain.

Following session one, participants were randomly distributed into three groups by gender: 30 second foam rolling, 2-minute foam rolling, or control (long sitting). A one-way ANOVA was then used to determine statistical differences for flexibility between groupings for gender.

The second session was conducted after all subjects completed their familiarization session in order to allow time for grouping and randomization. For session two, participants again reported to the SIRC for data collection within one hour of their testing time and followed a similar dietary intake as session one. Hamstring flexibility ROM measures during session two

were performed using identical methods as the baseline measures in session one and took place at the following times: prior to a 5-minute self-selected walking pace treadmill warm up, immediately following the warm-up, immediately following the group assigned intervention, and at 10 minutes following the group assigned intervention. Participants assigned to one of the two foam rolling intervention groups performed the hamstring foam rolling technique as instructed for the assigned duration, either 30 seconds or 2-minutes, as timed using a hand-held stopwatch (Adanac 3000, Marathon, Richmond Hill, Ontario, Canada). Those in the control (long sitting) group were instructed to remain stationary in a long seated position for 2-minutes to emulate the same body positioning as foam rolling, but they did not participate in any foam rolling. Both examiner one and examiner two were blinded to the intervention portion of testing. These two examiners stepped out of the lab with the door closed while a third examiner monitored the participants' intervention. Examiner three was the only member of the data collection team that had any knowledge of participants' grouping. In order to eliminate any indication of examiners one and two finding out which intervention was occurring while being blinded, the sound of the metronome was on during all three interventions. Additionally, to allow for similar timing for each intervention, the 30 second foam rolling group long sat on the ground for 90 seconds before beginning their 30 seconds of foam rolling. Immediately following the completion of the foam rolling groups, perceived pressure on the foam roller was measured using a Numeric Pressure Scale (NPS). The scale was numbered 0-100 and subjects were asked to write down the number on the scale correlating to the perceived percentage of their body weight that they exerted on the roller[5] (Appendix B). For example, if the subject felt that they exerted 80% of their body weight on the roller, they would write the number 80 on the NPS sheet. Those in the control groups did not report perceived pressure. After Numeric Pressure Scores were taken, post-intervention

ROM was measured. All participants then remained stationary on the treatment table with a bolster behind their back and under their knees for 10 minutes. The bolster was placed under the participants' knees to allow for comfort while long sitting, and to limit a stretching effect by putting the hips and knees into flexion (Appendix C, Figure 7). The 10 minutes of sitting was followed by a delayed post-intervention ROM measurement. The research procedures are visually represented in Figure 1.

A 3 x 5 mixed model factorial analysis of variance was performed using IBM SPSS (SPSS, IBM Inc., Version 24) for each group (30 seconds, 2-minutes, and control) against time (day 1 baseline, day 2 baseline, post-warm up, immediately post intervention, 10-minutes post intervention). The independent variables was a within subjects design were intervention group (30 seconds, 2-minutes, and control) and time (day 2 baseline, post-warm up, immediately post intervention, 10-minutes post intervention) had a between subjects design. Range of motion measurements was the dependent variable and had a within subjects design. An independent t-test was utilized to compare perceived pressure between the two foam rolling groups.

Figure 1: Data collection procedure

Session One

- Informed Consent
- Pre-Research Questionnaire
- Anthropometric Measurements
- Baseline Flexibility
- Watch Instructional Video
- Foam Rolling Practice

Stratified Sampling Method Used To Place Participants Into Groups By Gender

Session Two

30 Seconds

- Diet & Hydration Check
- Pre-Warm-Up Flexibility
- 5-Minute Warm-Up
- Post-Warm-Up Flexibility
- 30 Seconds Foam Rolling Intervention
- Perceived Pressure
- Post-Intervention Flexibility (within 1-minute)
- Post-Intervention Flexibility (after 10-minutes)

2-Minutes

- Diet & Hydration Check
- Pre-Warm-Up Flexibility
- 5-Minute Warm-Up
- Post-Warm-Up Flexibility
- 2-Minutes Foam Rolling Intervention
- Perceived Pressure
- Post-Intervention Flexibility (within 1-minute)
- Post-Intervention Flexibility (after 10-minutes)

Control

- Diet & Hydration Check
- Pre-Warm-Up Flexibility
- 5-Minute Warm-Up
- Post-Warm-Up Flexibility
- 2-Minutes Long Sitting Intervention
- Post-Intervention Flexibility (within 1-minute)
- Post-Intervention Flexibility (after 10-minutes)

CHAPTER 4: RESULTS

Forty-nine healthy, physically active participants (males=14; females=35) were recruited. Seven participants were unable to complete both data collections due to injury, illness, or not meeting the inclusion criteria. Forty-two participants completed both data collection sessions and were subsequently divided into three groups, each containing four males and ten females (30 seconds: age 22.2±2.9 years, height 164.8±9.6 cm, mass 69.0±15.0 kg; 2-minutes: age 22.9±3.5 years, height 164.9±6.7 cm, mass 66.3±19.3 kg; control: age 21.4±2.7 years, height 167.6±6.2 cm, mass 71.4±11.3 kg). Of those participants that completed the entire study, all were right leg dominant and reported to the lab on two separate occasions at least a week apart (7 days ± 1 hour).

Baseline Hamstring Range of Motion

Baseline hamstring ROM measurements were taken for all participants on Day 1 prior to randomized grouping. There was no significant difference between groups' day one baseline measures (F=0.28; p=0.79). Average baseline hamstring ROM measurements for all three intervention groups are presented in Table 4. For all groups combined, there was no significant difference between day 1 baseline and day 2 baseline hamstring ROM (p=1.00). This data is presented in Table 2.

Table 1: Day 1 Baseline Hamstring Range of Motion (°)

Intervention	Mean ± SD
30 seconds	88.79 ± 16.74
2 minutes	92.57 ± 14.28
Control	91.29 ± 13.1

Table 2: All Groups Combined Day 1 & 2 Baseline Hamstring Range of Motion (°)

All Groups Combined	Mean ± SD
Day 1 Baseline	90.88 ± 14.51
Day 2 Baseline	91.31 ± 13.06

Perceived Pressure

Perceived pressure exerted on the foam roller was self-reported post-foam rolling by a Numeric Pressure Scale (Appendix B) and analyzed via independent samples t-tests. Levene's Test for equality of variances was not significant (p=0.284), and therefore, equal variances were assumed. Differences in perceived pressure exerted on the foam roller between the two foam rolling groups were non-significant (p=0.558). Perceived pressure means are presented in Table 3.

Table 3: Perceived Pressure For Both Foam Rolling Groups

Intervention	Mean ± SD
30 Seconds	61.79 ± 21.18
2 Minutes	57.86 ± 12.82

Hamstring Range of Motion

Hamstring ROM measurements were taken for all groups at five different time points. Average hamstring ROM for each group across time is presented in Table 1 and graphically in Figures 2 & 3. A 3 x 5 mixed model factorial ANOVA was completed with a significance set to $\alpha=0.05$. Mauchley's test was significant ($p<0.001$) and therefore the Huynh-Feldt modification was used to analyze within-subjects effects. There was a significant within-subjects effect for

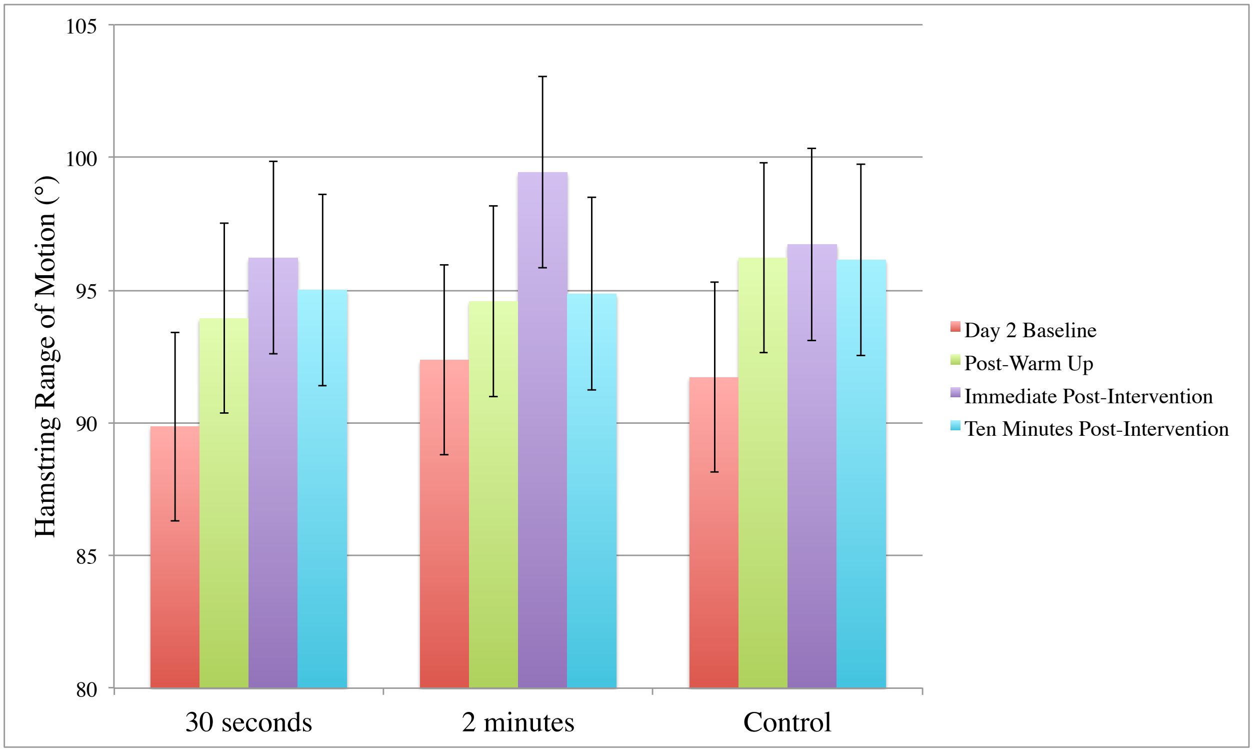
time (p<0.001). Differences in values for all groups were compared for each of the five time points. Sidak adjustments for multiple comparisons were made for pairwise comparisons for all groups combined. The results for average hamstring ROM for all groups across time are presented in Table 3 and can be seen graphically in Figure 4. For all groups combined, there was a significant increase in hamstring ROM from day 2 baseline to post warm-up (p=0.002), immediately post warm-up (p<0.001), and ten minutes post-intervention (p=0.005). All groups showed an increase in hamstring ROM that was approaching significance from post-warm up to immediately post-intervention (p=0.06). There was no significant difference between post warm-up and ten minutes post-intervention hamstring ROM (p=1.00). The analysis revealed no statistically significant interaction effect within subjects for time and intervention (p=0.788). Further analysis supported there were no significant differences between each of the three groups at all five time points (p>0.05).

Table 4: Hamstring ROM (°) At All Time Points (Mean ± SD)

Time	30 Seconds	2 Minutes	Control	All Groups Combined
Day 2 Baseline	89.86 ± 16.838	92.36 ± 12.17	91.71 ± 10.14	91.31 ± 13.06*^❖
Post-Warm Up	93.93 ± 17.757	94.57 ± 9.21	96.21 ± 11.81	94.91 ± 13.11*
Immediate Post-Intervention	96.21 ± 17.876	99.43 ± 11.39	96.71 ± 9.97	97.45 ± 13.27^
Ten Minutes Post-Intervention	95.00 ± 16.875	94.86 ± 11.01	96.14 ± 11.99	95.33 ± 13.21❖

Values presented are mean ± SD
* p=0.002 significant difference between Day 2 Baseline and Post-Warm Up
^ p<0.001 significant difference between Day 2 Baseline and Immediate Post-Intervention
❖ p=0.005 significant difference between Day 2 Baseline and Ten Minutes Post-Intervention

Figures 2 & 3: Hamstring ROM (°) for Each Intervention Across Time



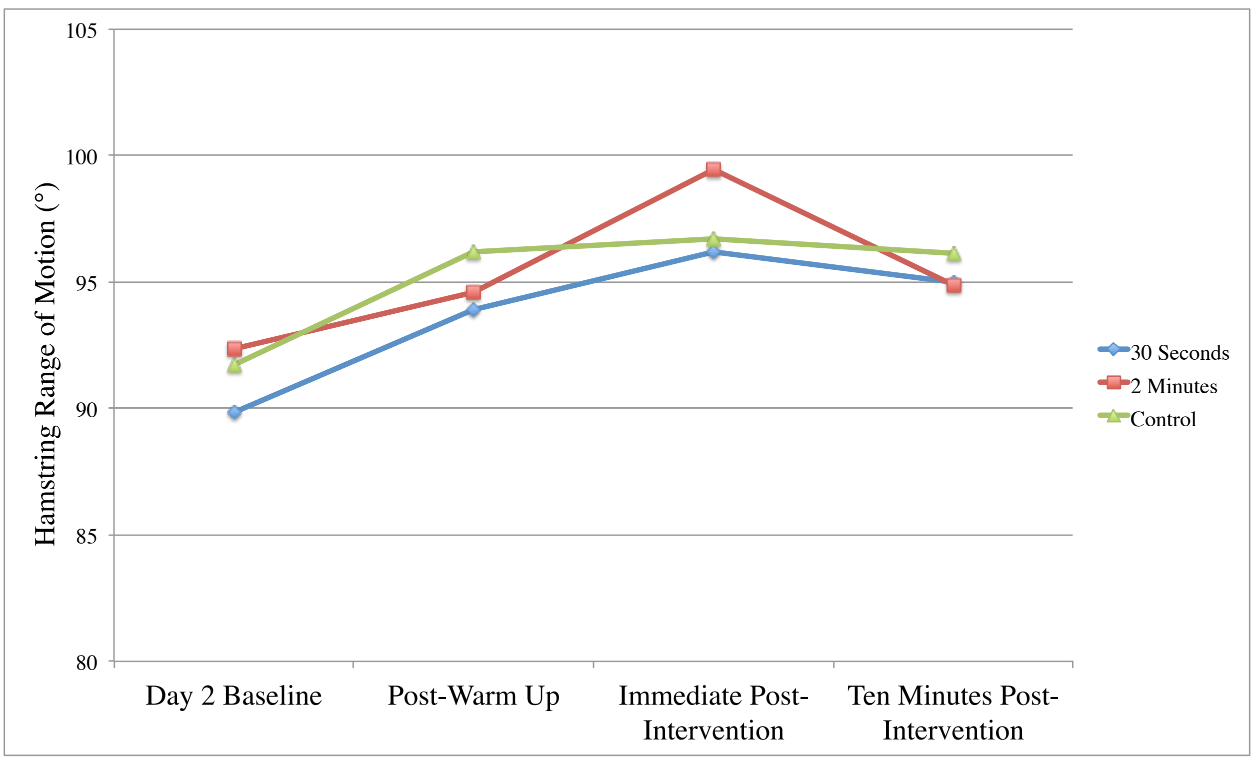
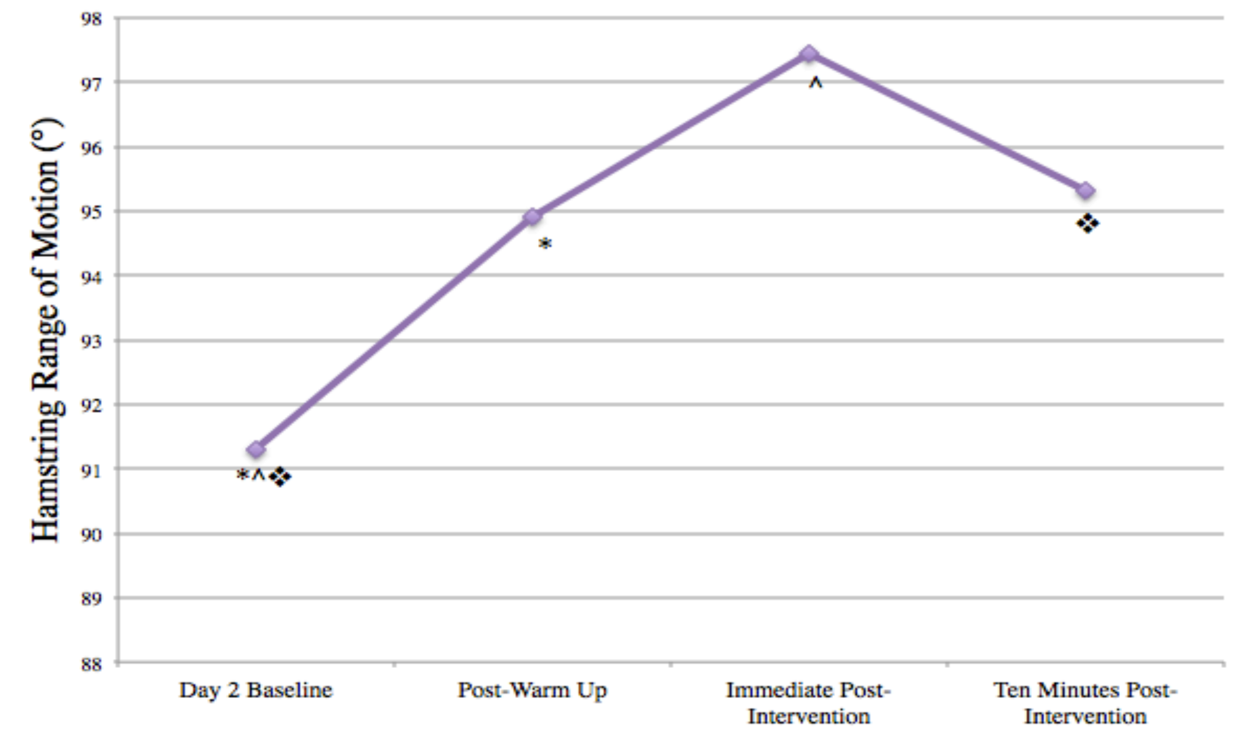


Figure 4: Mean Hamstring ROM (°) for All Interventions Combined Across Time



* p=0.002 significant difference between Day 2 Baseline and Post-Warm Up
^ p<0.001 significant difference between Day 2 Baseline and Immediate Post-Intervention
❖p=0.005 significant difference between Day 2 Baseline and Ten Minutes Post-Intervention

CHAPTER 5: DISCUSSION

The purpose of this study was to compare hamstring flexibility changes following a single foam rolling bout, performed for timing durations of 30 seconds or 2-minutes, to controls. In regards to baseline hamstring ROM, there were no significant differences found between day 1 baseline ROM for the three groups, confirming uniformity of participants' flexibility for grouping purposes. Additionally, there were no changes from day 1 to day 2 baseline flexibility measurements, which were about a week apart, for all groups. There was no difference between perceived pressure exerted on the roller between the two intervention groups (30 second 61.79±21.178; 2-minute 57.86±12.817). This finding confirmed our hypothesis that there would be no differences in perceived pressure between the two groups and we inferred that all participants who foam rolled were exerting the same amount of perceived pressure on the foam roller. For all groups combined, the significant increase in hamstring ROM from day 2 baseline to post warm-up, immediately post warm-up, and ten minutes post intervention indicates that the therapeutic effects of the warm-up are seen all the way up to ten-minutes after the intervention. As a result of the insignificant interaction effect between time and intervention, the most important finding of the current study was that foam rolling did not influence hamstring ROM. In disagreement with our hypothesis, the amount of time spent foam rolling had no effect on hamstring flexibility and therefore, the rate that hamstring flexibility increased between the 30 second, 2 minute, and control groups was the same across all five of the time points.

Regardless of intervention, there was a significant main effect for time where hamstring flexibility was increased for all groups combined after the warm-up compared to baseline values. This confirms findings from previous research that shows that a 5 minute warm-up will increase flexibility.[21] Additionally, hamstring ROM remained elevated immediately following the

intervention and following the 10-minute seated position compared to baseline measures for all groups combined. Compared to immediately post intervention measurements, hamstring flexibility decreased insignificantly after participants sat in a long seated position for ten minutes (95.333±13.214°), but remained significantly increased from baseline values (91.310±13.062°) for all groups combined. Due to non-significant interaction effect and no difference between groups at each individual time point, the elevated ROM measures ten minutes post intervention compared to baseline was attributed to the warm-up.

From our main analysis, the lack of interaction indicated that rate of change for each group over time was the same and therefore, there were no differences between the groups at any of the time points where hamstring ROM was measured. For all groups combined, the difference between post warm-up and immediately post intervention was approaching significance, indicating that ROM may have continued to increase following the intervention (p=0.06). However, since the control group was included in this analysis, these increases cannot be attributed to a foam rolling intervention. In agreement with our second hypothesis, there were no differences between groups for hamstring flexibility from immediately post-intervention to 10 minute post-intervention, indicating that the effects of foam rolling do not last after 10 minutes of sitting. Previous research by Škarabot, Beardsley, & Štirn[11] found significant increases in passive ankle dorsiflexion immediately after foam rolling but no lasting effects 10, 15, or 20 minutes after the intervention. Bushell, Dawson & Webster[6] examined the long-term effects of foam rolling and found one week post-intervention that there was no difference between baseline measures. Twenty-four hours after foam rolling, Markovic[20] also found that flexibility measurements reverted back to baseline. The previous research is consistent to the findings of

the current study in that foam rolling has no lasting effects ranging from immediately post to one-week post intervention.

Our finding of similar hamstring flexibility measurements between the three intervention groups supports the findings of Peacock et al. (2014)[16] who reported no difference between the sit-and-reach scores of a foam rolling & dynamic warm-up group compared to just a dynamic warm-up group. Additionally, Bushell, Dawson & Webster,[6] found no differences between the control groups and a group that used a foam roller for 3 sets of one minute on hip extension ROM. While there were increases of 4.858±2.188° (2-minute), 2.285±0.119° (30 seconds), and 0.500±1.846° (control) when comparing the groups to one another from post warm-up to immediately post intervention, in the current study, these increases were not significant. This comparison directly examines the effect of the foam rolling intervention on hamstring flexibility. The lack of significance could be attributed to the amount of variability present within each of the groups with an average standard deviation of 13.16°.

Although the current study found no significant differences with foam rolling duration on hamstring ROM, the effects of foam rolling remain inconclusive as other previous research does refute our findings. Significant increases in flexibility have been found after foam rolling intervention durations of 3 sets of one minute,[12] 2 sets of one minute,[3] 10 passes back and forth,[22] 2 minutes[19,20] and 1 minute.[9] Of these studies, only Junker & Stöggl[22] and Markovic[20] included a warm-up in their methods, while only Junker & Stöggl[22] included a non-foam rolling control group. Since only one of the six articles that found an increase in flexibility after foam rolling directly compared their findings to controls,[22] and along with the current study, it cannot be concluded that foam rolling increases flexibility.

Methodology of Bradbury-Squires et al.[24] was most similar to the current study in that it compared five sets of 20 seconds to five sets of 60 seconds of a roller massager technique on flexibility and found no differences between the two groups. Their findings were different to ours in that both timing durations had a significant increase in knee flexion ROM when compared to a control group. The authors attributed the significant increase in knee flexion ROM to the ability to control for the amount of pressure by using a constant pressure rolling apparatus that exerted 25% of the participants' body mass (mean: 21.1 kg) whereas we allowed the participants to foam roll independently and self-report how much perceived pressure was exerted on the roller.[18] While the constant pressure rolling apparatus may be useful for research purposes, it is not applicable in a clinical setting as a roller massager is used as a hand held device and the individual exerts their own pressure onto the muscle. In a second study directly comparing foam rolling timing durations, Couture, Karlik, Glass & Hatzel[25] found no significant differences in hamstring flexibility between the short and long duration groups. Couture, Karlik, Glass & Hatzel[25] had a higher percent of body weight applied to the roller compared to the Bradbury-Squires et al. article, but Couture, Karlik, Glass & Hatzel[25] concluded that the higher body weight was negated due to the greater surface area applied to the foam roller versus a roller massager which has a smaller diameter and surface area.[18] The current study found no significant difference between both foam rolling groups in the amount of perceived pressure exerted on the foam roller. We found that the participants in both foam rolling groups exerted an average of 59.825±16.998 perceived percentage of their body weight on the foam rollers. The use of the non-rolling leg and participants' hands to support some of the body weight could have affected the amount of body weight that was exerted on the foam roller. Further research needs to be explored with the use of force plates while foam rolling in order to investigate if there is a

relationship between the amounts of force exerted on the foam roller and potential flexibility gains. Curran, Fiore & Crisco[1] is the only study that has used force plates to measure pressure, however they examined the pressure exerted with two different foam rollers. They found that the foam roller with a PVC pipe core had greater pressure per square inch ($p<0.005$) on the lateral thigh compared to the standard black foam roller. This is important to the current study as we used this information when selecting to use The Grid foam roller, which has a PVC pipe core, for our interventions. The goal behind using a foam roller with a PVC pipe core was to have as much pressure on the muscle as possible in order to the elicit therapeutic effects of self-myofascial release by viscoelastic lengthening and plastic deformation of the soft tissue.

Additionally, cadence at which the self-myofascial modality is applied has varied throughout the literature. From previous research, cadences of 40 Hz,[25] 50 Hz[24] and 130 Hz[8] were implemented during the intervention. A majority of the studies, however, did not use a cadence to a metronome.[1,3,5,6,9–13,15–19,21–23] The frequency at which foam rolling is applied to the soft tissue is important to elicit changes in the tissue. If enough stress (or tension) is exerted onto the soft tissue at an optimal rate, strain (or deformation) will occur within the tissue, therefore possibly increasing flexibility.[2] Ultimately, more research is needed to study the effects of different foam rolling cadences on flexibility.

One limitation of the current study was that perception was used to measure pressure on the foam roller. The use of the Numeric Pressure Scale allowed subjects to gauge the amount of pressure they felt they were exerting on the foam roller, but this value was subjective. In order to decrease the possibility of any differences, all participants were instructed "to exert as much body weight on the foam roller as tolerable without causing pain." Another limitation existed with measuring passive hip flexion ROM. During this process, participants were instructed to

report when they “felt a maximum stretch without pain.” This subjective measurement is a limitation as some participants might have different perceptions of their “maximum stretch”.

Examining the current and past research, it cannot be concluded that foam rolling is effective in increasing flexibility. We found that there were no significant differences when comparing two different foam rolling timing durations to controls from baseline, post warm-up, immediately post intervention, and ten minutes post intervention. Therefore, we concluded there are no differences in the ability of a single bout of foam rolling to increase hamstring flexibility when compared to a warm-up. The literature on foam rolling and self-myofascial release is still novel, despite being a common treatment modality. Additional research needs to be done to explore if a foam rolling timing duration longer than 2 minutes can increase flexibility.

APPENDIX A: PRE-RESEARCH QUESTIONNAIRE

Age: ________________________

Gender: ________________________

Currently, how often are you working out? (days/week) ________________________

How long do you spend working out per session? (minutes) ________________________

What kind of exercise do you part take in? ________________________
(i.e. running, swimming, resistance training, CrossFit)

Have you ever had a lower extremity injury? Yes No

If so, when? ________________________
(please be as specific as possible)

If so, how many consecutive lower extremity workouts did you miss as a result of this injury? 1 2 3 More than 3

Have you ever used a foam roller before? Yes No

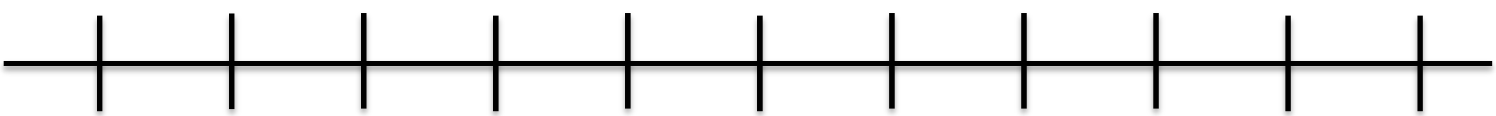
If so, when was the last time you used a foam roller? ________________________
(please be as specific as possible)

Which leg would you use to kick a ball for distance? Right Left

What did you have to eat today? ____

Approximately how much water did you drink today? (oz.)____

Please use the following scale as a guide to report the percent of your body weight that you exerted on the foam roller



0 10 20 30 40 50 60 70 80 90 100

I exerted ________ % of my body weight on the foam roller

APPENDIX C: DATA COLLECTION FIGURES

Figure 5: Image of the foam roller used for data collection

Figure 6: Demonstration of the positioning for foam rolling of the hamstrings

Figure 7: Participant positioning while sitting for 10 minutes post-intervention

Figure 8: Passive hip flexion ROM goniometric measurement

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CURRICULUM VITAE

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Education

University of Nevada, Las Vegas, NV — **August 2014 – Present**
Master of Science in Kinesiology
Sports Medicine Specialization
Thesis: The Acute Effects of Different Foam Rolling Timing Durations on Hamstring Flexibility
Advisor: Dr. Kara Radzak

University of Michigan, Ann Arbor, MI — **September 2010 – May 2014**
Bachelor of Science in Kinesiology
Athletic Training Major

Licensed Athletic Training Experiences

University of Nevada, Las Vegas, NV — **August 2014 – Present**
Academic Graduate Assistant Athletic Trainer

- Served as a graduate student instructor for undergraduate athletic training laboratory courses with hands-on learning.
    - Sports Injury Management 386: Clinical Evaluation of the Lower Extremity
    - Sports Injury Management 480: Therapeutic Exercise
    - Sports Injury Management 150: Management of Sports Trauma & Illness
- Assisted with day-to-day operations of the UNLV Athletic Training Program.
- Provided administrative support to the Director and Clinical Coordinator of the Athletic Training Program.
- Served as preceptor and proctor for AT clinical classes to approve students' proficiencies and aid in teaching instruction

Clark County, NV — **August 2014 – Present**
Licensed Athletic Trainer

- Provided coverage to various youth, collegiate, adult, and master's tournaments.
    - Hours worked: Soccer (125); Lacrosse (46); Tennis (13); Golf (24); Basketball (28); Football (8).

Select Physical Therapy, Las Vegas, NV — **October 2014 – Present**
Licensed Athletic Trainer – Per Diem

- Provided athletic training services for various tournaments throughout the Las Vegas area.
- Worked as a substitute athletic trainer providing health care services for high schools in the Clark County School District.
    - Hours worked: Soccer (15); Lacrosse (6); Volleyball (115); Softball (27); Wrestling (19); CCSD High Schools (75).

Sports Performance Experiences

EXOS Formerly Athletes' Performance, Carlsbad, CA — **May 2015 – August 2015**
Performance Specialist Intern

- Assisted in designing, implementing, and executing performance testing, coaching, and programming for NFL, MLB, collegiate, military, and general population athletes.
- Prepared pre- and post-workout beverages for optimal nutrition and recovery.
- Maintained a state-of-the-art performance facility with day-to-day operations across all fronts.
- Participated in weekly in-house education regarding EXOS methodology and professional development.

Licenses & Certifications

- Athletic Training Board of Certification #200017377 — **June 2014 – Present**
- State of Nevada Licensed Athletic Trainer #0506353 — **July 2014 – Present**
- National Strength and Conditioning Association Certified Strength and Conditioning Specialist — **January 2016 – Present**
- American Heart Association Basic Life Support Certification — **May 2016 – Present**
- American Red Cross CPR/AED for the Professional Rescuer — **September 2010 – May 2016**

Professional Memberships

- National Athletic Trainers' Association Member #51994 **January 2012 – Present**
- Far West Athletic Trainers' Association **July 2014 – Present**
- Nevada Athletic Trainers' Association **July 2014 – Present**
- Great Lakes Athletic Trainers' Association **October 2011 – July 2014**
- Michigan Athletic Trainers' Society **October 2012 – July 2014**
- National Strength and Conditioning Association Member #000758773 **February 2015 – Present**

Conference Attendance

- National Athletic Trainers' Association Clinical Symposia & AT Expo **June 2016**
- Far West Athletic Trainers' Association Annual Meeting & Clinical Symposium **April 2015**
- Great Lakes Athletic Trainers' Association Annual Meeting & Symposium **March 2012, 2013, & 2014**
- Michigan Athletic Trainers' Society Student Seminar **November 2011, 2012, 2013**

Related Experiences & Additional Activities

- Special Olympics Medical Volunteer **Summer 2013 & 2014**
- Gatorade Team Leader **Summer 2012, 2013, & 2014**
- University of Michigan Anatomy Lab Teaching Assistant **January – April 2014**
- University of Michigan Department of Recreational Sports Equipment Manager **October 2011 – July 2014**
- University of Michigan Kinesiology Mentorship **September 2010 – December 2013**
- USA Powerlifting- State Champion & Record Holder **November 2009 – Present**
    - California: 2010, 2012, 2013, 2015, 2016
- Cali-Camp Summer Day Camp Counselor **June 2009 - August 2011 & July – August 2013**

Professional Interests

- Integration of the athletic training domains with all components of strength & conditioning and sports performance.
- Incorporating injury prevention into a dynamic warm-up.
- Myofascial release via instruments, manual therapies, or other external modalities.

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