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The Effect of Foam Rolling Duration on Subsequent Power Performance

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THE EFFECT OF FOAM ROLLING DURATION ON SUBSEQUENT POWER PERFORMANCE

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CERTIFICATE OF APPROVAL

MASTER OF SCIENCE THESIS

This is to certify that the Thesis of
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submitted in partial fulfillment of the requirements for the degree of
Master of Science in the School of Health Sciences and Human Performance
at Ithaca College has been approved.

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ABSTRACT

The use of a foam roller has become increasingly popular among athletes and casual exercisers; however, few studies have investigated the effects of foam rolling on subsequent exercise performance. This study was conducted using 24 healthy participants between the ages of 18 and 35 years who exercised at least three times a week. They each completed a familiarization with baseline and post-condition measurements made in the vertical jump test (VJ), pro-agility test (PA), modified weight bearing lunge test (WBL) and modified kneeling lunge test (MKL). In a partially randomized but balanced order, each subject was asked to perform three conditions: supported planking on a heating pad (control), 1-min foam roll (FR), or 5-min FR. Four 3 x 2 repeated measures analysis of variance (ANOVA) were used to determine whether there were significant differences between the three conditions (control, 1-min FR, 5-min FR) at two times (pre-FR, post-FR) in VJ, PA, WBL, and MKL measurements. The 5-min FR and control condition negatively affected VJ performance while the 1-min FR had no such effect. Furthermore, the 5-min FR exhibited a significantly greater negative effect on VJ performance than the control. The control showed a significant decrease in PA while the 5-min FR did not negatively affect PA performance and the 1-min FR increased PA performance. In the WBL, the 1-min and 5-min FR significantly increased range of motion (ROM) compared to the control. In the MKL, the 1-min and 5-min FR both significantly increased range of motion with the 5-min FR showing significantly greater increase in ROM. These data show that increased 5-min of foam rolling may decrease VJ or power performance but increases ROM to a greater degree than 1 min of foam rolling.

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INTRODUCTION

In the last decade, the use of the foam roller has become increasingly popular within strength and conditioning programs and fitness facilities. However, despite the increased use of foam rolling by recreational and competitive athletes, there is little research on the effects of foam rolling on performance. Foam rolling is adopted by athletes as a way to perform self myofascial release (SMR). Due to an inflammatory response as a result of injury or microtrauma from regular exercise, collagen in the fascial tissue becomes fibrous and dense due to the formation of fascial cross-links and scar tissue, causing elastin to lose its pliability (Barnes, 1997; Curran, Fiore, & Crisco, 2008; Macdonald, Button, Drinkwater, & Behm, 2014). This can cause muscle pain, dysfunctions, restrict range of motion (ROM) and decrease strength (Barnes, 1997; Curran et al., 2008; MacDonald et al., 2013). The expectation is that through external pressure myofascial release and SMR break up fascial adhesions, return the tissue to a gel-like state, and promote proper length-tension relationships within the muscle to improve these dysfunctions (Barnes, 1997; Bushell, Dawson, & Webster, 2015; Healey, Hatfield, Blanpied, Dorfman, & Riebe, 2014; MacDonald et al., 2013).

Although traditionally myofascial release is performed manually by therapists, recently more attention is being given to SMR. Self myofascial release provides similar mechanical pressure and produces the benefits of myofascial release provided in a clinical setting without the cost or time required of seeing a clinician (Healey et al., 2014). This may allow people to perform SMR more frequently and is speculated to help chronically improve ROM, reduce pain due to spasms, and improve movement dysfunctions (Bushell et al., 2015; Healey et al., 2014). Massage and SMR are also thought to improve recovery after exercise by decreasing delayed onset muscle soreness (DOMS), which is thought to be caused by an acute inflammatory response due to damage to the muscle and fascial tissue (Macdonald et al., 2014; Waters-Banker, Dupont-Versteegden, Kitzman, & Butterfield, 2014). Myofascial release works through immunomodulation which decreases the immune response and the subsequent byproducts that are thought to cause the pain associated with DOMS (Butterfield, Zhao, Agarwal, Haq, & Best, 2008; Waters-Banker et al., 2014). Research has shown foam rolling to decrease DOMS and the negative effects fatigue has on performance up to 72 hours after intense exercise (Macdonald et al., 2014; Pearcey et al., 2015).

In addition to being used with the intention of decreasing DOMS, SMR and massage have been proposed to act as an additional form of warm-up to precede exercise (Arabaci, 2008; MacDonald et al., 2013). While myofascial release may increase ROM and restore proper length-tension relationships, another proposed benefit is increased blood flow to the muscles and an increase in muscle temperature (Arabaci, 2008; Weerapong, Hume, & Kolt, 2005). In massage studies, this increase in blood flow is thought to occur due to the kneading motion of the massage; the increase in muscle temperature is thought to occur as a result of increased blood flow, friction on the skin, and body heat from the masseur (Weerapong et al., 2005). Although massage has been shown to increase muscle temperature, it is unknown whether this benefit is present in foam rolling because the increase in temperature may be due to body heat transfer from the *masseur* (Weerapong et al., 2005).

Although massage and foam rolling have been both shown to increase ROM (Healey et al., 2014; Huang et al., 2010; MacDonald et al., 2013), some massage studies have shown a decrease in subsequent muscular isokinetic peak force, sprint performance, and vertical jump height (Arabaci, 2008; Arroyo-Morales et al., 2011; Wiktorsson-Moller, Oberg, Ekstrand, & Gillquist, 1983). Contradicting this massage literature, several studies using foam rollers and hand rollers have yielded increased ROM without a decrease in subsequent power performance (Halperin, Aboodarda, Button, Andersen, & Behm, 2014; Healey et al., 2014; MacDonald et al., 2013; Sullivan, Silvey, Button, & Behm, 2013). A clear difference between the massage and the foam roller studies is the duration that the muscle is subjected to myofascial release. The foam rolling and hand rolling studies have mostly used treatment durations of less than 30 s (Halperin et al., 2014; Healey et al., 2014; Sullivan et al., 2013). The longest duration used in a foam rolling study that investigated performance measures was two, 1-min FR intervals with 1-min rest in between (MacDonald et al., 2013). However, the massage studies finding a negative impact on power performance have used treatment durations of 6 min per muscle group (Arroyo-Morales et al., 2011) and 15 min total (Arabaci, 2008). It is possible that a treatment duration effect on muscle function exists with longer myofascial release times resulting in a greater loss of muscle activity, electromyography (EMG), and muscular performance (MacDonald et al., 2013). Previous literature has recommended applying pressure during SMR for 60-90 s to up to 5 min or until a release is felt (MacDonald et al., 2013; Paolini, 2009). Foam rolling appears to show no decrease in performance with short durations of less than 2 min but it is possible that longer durations could cause a decrease in subsequent power performance. However, the effects of longer duration foam rolling on performance has not been studied.

Statement of Purpose

The purpose of this study is to determine the effects of foam rolling duration on lower extremity power, agility, and ROM.

Hypotheses

The hypotheses for this study are:

1. As the time of foam rolling increases, there will be a decrease in vertical jump (VJ) and pro-agility (PA) performance scores.

2. A 5-min FR duration will not elicit ROM greater than that seen in a 1-min FR duration.

3. Foam rolling conditions will exhibit greater ROM improvements than a control condition.

Scope of the Problem

Foam rolling is commonly used in the warmup of athletes and active individuals. Anecdotally, some use the foam roller on a particularly sore area for a long duration. While this may be beneficial in terms of flexibility and reducing muscle tightness (Healey et al., 2014; MacDonald et al., 2013), it is possible that foam rolling for too long may decrease the ability to produce force in subsequent efforts. This concept is important for fitness professionals working with active individuals whose primary goal is to gain strength or increase power performance. Loss in power would also have consequences for athletes if they were to FR for a long duration before competition. It is important for athletes and coaches, as well as strength and conditioning coaches, to be aware of the effects that foam rolling before competition or exercise could have on power performance.

Assumptions of the Study

The assumptions of this study are:

1. Subjects apply equal pressure on the foam roller throughout each of the foam rolling conditions.

2. The planking control condition will not have a fatiguing effect that causes a detriment to performance.

Definition of Terms

1. Foam roller – a cylindrical piece of foam used for SMR.

2. Foam rolling – the act of rolling on a foam roller in which the person places themselves upon the foam roller and rolls across the belly of muscle.

3. Myofascial release – a manual therapy technique used to reduce adhesions or restrictions in fascial tissue.

4. Self myofascial release (SMR) – applying myofascial release to oneself sometimes using a device such as a foam roller.

Delimitations

The delimitations of this study are:

1. Only subjects who exercise at least three times per week and at least 150 minutes per week will be used for the study.

2. Only 1-min FR and 5-min FR conditions will be used to compare duration effects on performance.

3. A maximal VJ, PA, modified Weight Bearing Lunge Test (WBL) and modified kneeling lunge (MKL) test will be used to measure power and ROM.

4. Performance and flexibility variables will be tested before and after treatment on the same day.

Limitations

The limitations of this study are:

1. The results may not be generalizable to untrained or sedentary individuals.

2. The results may not be generalizable to foam rolling durations shorter than 1 min or greater than 5 min.

3. Only tests of lower body power, agility, and flexibility will be investigated and may not be generalized to other performance tests (e.g., strength or cardiovascular endurance).

PROPOSAL

REVIEW OF LITERATURE

Introduction

Because massage, hand rollers, and foam rollers apply similar mechanical pressure to the fascial tissue, a thorough examination of previous literature may indicate what effects, if any, myofascial release will have on subsequent power performance. This chapter examines the mechanisms of myofascial release, effects of massage, hand rolling, foam rolling on ROM, foam rolling on post-exercise recovery, and foam rolling on subsequent performance.

Mechanisms of Myofascial Release

The primary mechanism of massage and myofascial release techniques is believed to be external mechanical pressure which breaks up adhesions in the fascial tissue and returns the tissue to a gel-like state and promotes proper length-tension relationships within the muscle (Barnes, 1997; Bushell et al., 2015; Healey et al., 2014; MacDonald et al., 2013). In the presence of an inflammatory response as a result of injury or microtrauma from regular exercise, collagen in the fascial tissue becomes fibrous and dense due to the formation of fascial cross-links and scar tissue, causing elastin to lose its pliability (Barnes, 1997; Bushell et al., 2015; Macdonald et al., 2014). As a result, fascial components lose their pliability, become restricted and may cause tension at a particular joint or throughout the body (Barnes, 1997). This status can limit the functional length of the muscle, causing a reduction in strength, contractile potential and deceleration capacity (Barnes, 1997). By breaking up these adhesions and improving pliability of the fascia, it may be possible to return the muscle and fascial tissue to a healthier state, reducing these negative outcomes. Self myofascial release and other myofascial release techniques are speculated to help chronically improve ROM, reduce pain due to spasms, and improve movement dysfunctions (Bushell et al., 2015; Healey et al., 2014).

While acutely restoring length-tension relationships and increasing ROM may lead to a better warm-up, an additional benefit of massage before exercise may be increased blood flow to the muscles and an increase in muscle temperature (Arabaci, 2008; Weerapong et al., 2005). In massage studies, this increase in blood flow is thought to occur due to the kneading motion of the massage and the increase in muscle temperature is thought to occur as a result of increased blood flow, friction on the skin, and body heat from the masseur (Weerapong et al., 2005). There is evidence showing massage can increase the temperature of the muscle (Drust, Atkinson, Gregson, French, & Binningsley, 2003; Longworth, 1982), but there is no conclusive proof that increased blood flow is responsible for the increase in temperature (Weerapong et al., 2005). It is unknown whether foam rolling offers the benefits of increased blood flow or temperature because the increase in temperature may be directly related to transfer of body heat from the *masseur*.

Massage and SMR are also thought to improve recovery after exercise by decreasing DOMS, which is thought to be caused by an acute inflammatory response due to damage to the muscle and fascial tissue. As part of this inflammatory response, neutrophils respond and create a respiratory burst which releases free radicals and oxidants (Waters-Banker et al., 2014). The afferent nerve cells respond to endogenous chemicals and the hypoxic environment created by the inflammation and send a pain response to the brain. Massage is thought to work through immunomodulation and has been shown to decrease cellular infiltration and promote normal intracellular spacing (Butterfield et al., 2008). This process decreases subsequent inflammation and edema which aids in recovery of normal muscle function (Waters-Banker et al., 2014). By decreasing the immune response, myofascial release can reduce the subsequent muscle damage and thus decrease pain felt during DOMS. Massage and SMR may also help to immediately improve performance by increasing blood flow, nutrient supply, and removing waste products from muscle metabolism (Rinder & Sutherland, 1995). By employing myofascial techniques before and after exercise, one may be able to improve warm-up effects and reduce some negative effects after intense exercise.

Effects of Massage

Range-of-Motion

Several investigations have looked at the effects of massage on ROM. Wiktorssen-Moller et al. (1983) investigated the effects of warming up, massage, and stretching on ROM tests using six tests: hip flexion, hip extension, hip abduction, knee flexion, and ankle dorsiflexion with knee straight and flexed. They found massage increased ROM for ankle dorsi-flexion but not for any other lower body ROM measures. They also found that there was a decrease in strength in the hamstrings and quadriceps after the massage treatment. However, the strength tests were done immediately after the ROM tests; therefore, the decrease in strength could be due to the stretching and not the massage. There also was not a control for the length of time the massage was performed. The *masseur* used in the study was instructed to massage anywhere from 6 to 15 min depending how tight he felt the muscles were. It is possible that there was an effect of the time of massage on increased ROM and decreased strength found in this study.

Huang et al. (2010) investigated the effects of short duration (10 s and 30 s) friction massage on hip flexion ROM, hamstring EMG, and passive muscle tension. They found that for 10 women there was a significant increase in ROM after 30 s of massage and no significant differences in EMG. However, another study subjected 11 healthy males to either a 15-min massage (*petrissage* and *effleurage*) or a supine rest control (Barlow et al., 2004). They found that there was no significant increase in sit and reach performance following 15-min massage compared to the control (Barlow et al., 2004). This finding coincides with a similar study showing no increase in ROM after massage treatment in adolescent soccer players (Jourkesh, 2007). Based on the current literature, there appears to be contradictory evidence on whether massage increases ROM.

Relaxation and Mood

Massage has also been reported to increase parasympathetic activity and decrease related markers such as heart rate and blood pressure (Weerapong et al., 2005). However, a study by Longworth (1982) found that while there was a wide range of individual responses to massage, on average, there was an increase in heart rate and blood pressure, indicating a sympathetic response. In contrast, the same study found there was an average decrease in galvanic skin response indicating a conflicting parasympathetic response (Longworth, 1982). Other research found no changes in heart rate or blood pressure after Swedish massage in nine medical students one day before an examination (Zeitlin, Keller, Shiflett, & Bartlett, 2000). While these studies do not show a decrease in heart rate, one study found that 15-min moderate pressure massage resulted in increased heart rate variability, indicating an increased parasympathetic response (Diego & Field, 2009).

Another study reported massage may increase relaxation by evaluating changes in mood before and after different treatments (Weinberg, Jackson, & Kolodny, 1988). They compared the effects of massage to different forms of exercise such as jogging, swimming, racquetball and tennis. They found that the jogging and massage groups had a significant positive improvement of mood in college-aged students. Both groups had decreased tension, depression, anger, fatigue, anxiety and confusion, which may indicate relaxation. Other research has found massage to be effective at reducing anxiety, but there have been flaws in the study designs with regards to lack of control groups (Leivadi, Hernandez-Reif, & Field, 1999; Weerapong et al., 2005; Zeitlin et al., 2000). Thus, the literature seems to point to massage effectively relaxing the body, while improving mood and decreasing anxiety. However, the literature is limited and more research is needed to substantiate these claims.

Delayed-Onset Muscle Soreness

One of the benefits of massage is that it may prevent or reduce DOMS and allow an individual to recover faster between intense bouts of exercise. One study used eight active, but non-resistance trained males, and loaded them with 10% of their body weight on a downhill walk (Farr, Nottle, Nosaka, & Sacco, 2002). One leg was given a 30-min massage two hours after the exercise while one leg served as a control (no treatment). The results indicated that the massaged leg had less soreness 24 h post-treatment but displayed a greater decrease in strength from baseline levels. However, the massaged limb recovered to baseline strength faster (at 72 h post compared to control at 120 h post) and was significantly stronger at 120 h post treatment than the non-massaged limb. There were no significant differences in VJ height or creatine kinase levels at any time point. Another study used 18 healthy, untrained subjects and induced DOMS using 6 sets of 10 maximal eccentric contractions of the hamstrings (Hilbert, Sforzo, & Swensen, 2003). At 2 h post-exercise, the subjects were given a 20-min massage or rested for 20 min after a placebo lotion was applied as a control. The results of the study found that the control experienced greater soreness at 48 h post-exercise but there were no significant differences in peak torque, ROM, or neutrophil count at any time point. A similar study using 14 untrained subjects designed to produce DOMS on the biceps and triceps also used a 30-min massage at 2 h post-exercise (Smith et al., 1994). They found that DOMS was higher in the control group from 24 h to 96 h post-exercise and that DOMS in the control group peaked at 48 h while the massage group peaked at 24 h. In summary, it appears as though massage is effective at reducing DOMS, although whether this is due to reduced inflammation, reduced muscle damage, or other causes is still unknown.

Immediate Exercise Recovery

The effects of massage on immediate recovery following exercise may be beneficial to certain sports, such as track and field, where athletes compete in multiple events on the same day and massage between events could improve performance. In one study, 20 health club members were provided an exercise protocol that fatigued the quadriceps (Rinder & Sutherland, 1995). Immediately after exercise they were given a 6-min rest time (control) or a 6-min massage. They were then immediately subjected to a leg extension performance test where they performed as many repetitions as possible at 50% of one repetition maximum (1RM). The results showed that massage significantly aided in recovery from fatigue and improved performance 15.7% over the control group. In another study, 11 healthy, active females were involved in a high intensity cycling protocol (Ogai, Yamane, Matsumoto, & Kosaka, 2008). The protocol consisted of eight, 5-s sprints with 20-s rest over a total of 3 min. A 35 min rest period was given between this bout of exercise and a second set with an identical protocol. During the rest period, the subjects were either given a massage (petrissage) or a control (no massage) and measures of total power, perceived lower limb exertion (using 0-100 visual analog scale), muscle stiffness (using a durometer), and blood lactate concentrations were subsequently compiled. The authors reported that massage during the rest period significantly improved performance by increasing total power, decreasing muscle stiffness, and decreasing perceived lower limb exertion. There was no change in blood lactate between the groups. While these studies show that massage may improve recovery from exercise, Arroyo-Morales et al. (2008) found the opposite. Arroyo-Morales et al. (2008) found that massage after exercise decreased maximum voluntary contraction (MVC) force and EMG activity in the vastus medialis. The author proposed that this may be due to a parasympathetic response decreasing motor unit recruitment, action potential amplitude, and firing rate. However, the authors also acknowledged EMG data were not simultaneously collected with measures of strength and was a limitation of the study. It appears that massage may aid in recovery, though, this conclusion awaits further investigation.

Subsequent Exercise Performance

Massage before exercise has been proposed to act as an alternate form of a warm-up because of potential increases in flexibility, blood flow and muscle temperature (Arabaci, 2008; Fletcher, 2010). One study compared massage to a traditional warm-up (consisting of four laps in a standard sports hall at 30 s per lap, 10 s static stretching for each muscle group and four bouts of 20 m self-paced running) and a massage plus traditional warm-up (Fletcher, 2010). The study found that the traditional warm-up and massage plus traditional warm-up were significantly better than massage alone for improving 20-m sprint times. The authors also noted that all subjects performed their slowest sprints after massage only. Therefore, massage followed by a warm-up would not affect sprint performance but massage without a subsequent warm-up would be detrimental to performance. However, since there was no difference between the massage plus traditional warm-up and a traditional warm-up, it does not appear massage has any benefits to subsequent performance. In this study, ROM measurements were not made to investigate whether massage plus traditional warm-up could have a greater impact on flexibility than a traditional warm-up.

Another study using massage before exercise examined 23 recreational athletes with massage consisting of *effleurage*, *petrissage* and *tapotement* (Arroyo-Morales et al., 2011). Massage was performed for 6 min on each muscle group except craniofascial muscles which only received a 2-min massage resulting in 20 min of total massage. They found massage before exercise decreased isokinetic peak force of concentric knee extension at 180° s^{-1} and 240° s^{-1}. This finding supports Arabaci's (2008) work demonstrating massage of both the anterior lower limb (between knee and hip) and posterior lower limb (between ankle and hip) after a warm-up resulted in decreased performance in VJ and sprint times in active, college-aged males. The researcher subjected participants to massage, static stretching or a rest control in a randomized crossover design. The massage consisted of 10 min on the posterior limbs and 5 min on the anterior limbs using up to 18 different massage techniques. While the findings showed there was a decrease in performance for the VJ, 10-m acceleration, and 30-m sprint time, they also showed an improvement in joint ROM (i.e., sit and reach test).

In contrast to the above, other investigations have found that there is no effect on performance when massage is performed before exercise. Goodwin et al. (2007) studied 37 athletes from sports that required sprinting and put them through a massage treatment or an ultrasound control treatment. After the treatment, the subjects went through a dynamic warm-up and were then tested on a 30-m sprint trial. It was found that 15 min of lower limb massage did not affect sprint performance. Similar results were seen in moderately trained students who performed a control and two massage treatments, and completed ROM tests before and after each treatment (McKechnie, Young, & Behm, 2007). Following treatment, the subjects were also tested on a drop jump test and concentric calf raise. Massage had no effect on jump height and no effect on calf peak force or rate of force development. The limitations to this study were that the drop jump test uses several muscles other than the plantar flexors, and subjects were not tested on performance variables before treatment to evaluate pre- to post-treatment effects.

In conclusion, although some contradictory evidence exists, it appears as though massage after exercise could have a positive impact on recovery and subsequent ROM performance. With regards to massage before exercise, massage does not appear to improve power performance or recovery. Massage has been shown to increase flexibility but whether massage negatively affects force production is not clear. Further research might investigate whether including a traditional warm-up after massage may decrease the negative effects found in some of the literature. It is still unclear if massage used as a warm-up has any real benefit when compared to a traditional warm-up.

Hand Rolling

Hand rollers have become a popular form of SMR where a person uses a small roller with handles to push on the desired muscle. In one study, 17 subjects applied a roller treatment using a custom made rolling device that provided equal pressure to each subject (Sullivan et al., 2013). The treatment durations were either 5 s or 10 s of rolling applied over one or two sets. In total there were four interventions and a control (sitting for 5 min) with no rolling. The study was structured in a pre-post test design where each variable was tested before and after the rolling treatment. The measures tested were muscle activity, MVC isometric force, evoked contractile force, and ROM measured through a sit and reach test. Rolling with either duration increased ROM without decreasing force production or EMG. Therefore, it seems ROM can be changed with as little as 5-10 s of rolling. A limitation of this study is that it only used short durations and greater ROM effects or changes in force production may be seen with greater rolling times.

In another study, investigators studied the effects of hand rolling on plantar flexor performance in 14 subjects performing either a static stretching intervention or hand rolling (Halperin et al., 2014). They rolled across the plantar flexors for 30 s three times with 10 s between sets at a pain level of 7 out of 10. Variable pain levels may have caused variability in rolling pressures between subjects. The static stretching group stood with one foot on the edge of an aerobic stepper with their toe pointed up and their heel against the ground for an unreported length of time. The dependent variables measured in this study were plantar flexion MVC, EMG (soleus and tibialis anterior), ankle ROM and balance (using a stork stand single limb balance test). They found that hand rolling and static stretching each increased ROM without decreasing force production, although the hand rolling condition had significantly greater MVC force production at 10 min after the treatment. The main limitations of this study were that there was no control group and that the pressure produced using the hand roller was subjective to the person.

Foam Rolling

Foam Rolling and Range-of-Motion

Multiple studies have been conducted to investigate the effects of foam rolling on ROM without examining subsequent power or strength performance. Bushell et al. (2015) studied the effects of foam rolling the quadriceps on hip extension ROM. They recruited 31 active subjects and looked at acute and long-term effects of foam rolling on hip-extension ROM in a functional lunge. Subjects in the intervention group performed three sessions with pre-test and post-test measurements recorded in each session. The first session established a baseline measurement of ROM. They were then asked to FR for three 1-min bouts that were separated by 30 s (3 min FR total). After the first session, the intervention group performed the same 3 x 1-min FR session on five different days over the next week while the control did not FR. Both groups returned for session two where pre- and post- lunge ROM measurements were taken again. The subjects in the intervention group were then instructed to do no foam rolling for a week and then returned for session three where they were tested for pre- and post-test hip extension ROM measurements again. The study found that only during session two, after foam rolling for one week, was there an acute increase in ROM. Thus repeated foam rolling exposure over the course of a week may have contributed to the acute increase in ROM seen in session two (Bushell et al., 2015) They also found that there was not a significant difference between pre-test measures on session one and after foam rolling for a week on session two, suggesting that foam rolling each day for one week had no long-term ROM effects.

Mohr, Long, and Goad (2014) compared the effects of FR, static stretching (SS), and a combination of FR and SS before exercise. They divided 40 subjects into four groups: control, FR, SS, and FR plus SS. Subjects were tested for passive hip flexion ROM using a baseline bubble inclinometer. Researchers secured the non-tested leg flat to a table and moved the tested leg through hip flexion with a straight leg. Subjects in the SS group were stretched in the same manner as during the test but moved to a point of mild discomfort where the stretch was held for three 1-min intervals separated by 30 s. The FR group rolled the hamstrings for three 1-min intervals separated by 30 s. The SS plus FR group performed both of the previously mentioned protocols with foam rolling done first. The control group was tested at approximately the same time interval pre-test and post-test (5 min apart) as the other conditions with no treatment in between. There were significant increases in passive hip flexion ROM regardless of treatment. However, the FR plus SS group increased ROM more than the other groups. There were no significant differences among the FR, SS, and control groups. Therefore, it seems that FR before SS may increase ROM to a greater degree than either of these alone. However, the increase in ROM may be due to a greater total time spent foam rolling and SS, as the time spent receiving treatment was not equalized across groups.

Škarabot, Beardsley, & Štirn (2015) investigated the effects of FR, SS, and FR plus SS on ankle dorsiflexion ROM in 11 trained, adolescent swimmers. The subjects performed each condition at least 24 h apart, were measured using the WBL for baseline measurements, and were tested immediately, 5, 10, and 20 min after treatment. The FR condition used three sets of 30 s durations with 15 s rest between sets on the calves. The SS group stood with one foot on the edge of a bench with the heel toward the ground and leaned forward into dorsiflexion. They performed this stretch for three bouts of 30 s with 15 s rest between sets. The FR plus SS group performed the same protocols with the foam roller first followed by SS. Immediately post-condition, there were increases in ROM for SS (6.2%) and FR plus SS (9.1%) but no increase with FR alone. At the other times (5, 10, and 20 min) post-condition, they were not significantly different from baseline. Foam rolling plus SS elicited significantly greater changes in ROM, but no other significant differences were found between the other groups. Foam rolling plus SS may be better for increasing ROM than FR alone. The limitations of this study are that the FR plus SS condition received a greater total treatment time than the other groups, and that there was no control group and no warmup was performed before testing.

In another study, investigators addressed the effects of foam rolling duration on hamstring ROM with 33 healthy, active subjects (Couture, Karlik, Glass, & Hatzel, 2015). The subjects were tested using two conditions: FR for four sets of 30 s separated by 30 s rest (long duration) and FR for two sets of 10 s separated by 30 s rest (short duration) on the hamstrings. Passive hamstring ROM was measured using an inclinometer (knee extension test). The transition time between foam rolling and hamstring ROM measurements was approximately 4 min. There were no significant differences between either of the conditions compared to baseline measurements. This finding conflicts with other studies and may be attributed to the ROM measurement protocol or that the foam roller used was less dense than those used in previous studies. Applying pressure to the hamstrings also presents a greater challenge to FR than other muscle groups; it is possible that not being able to put optimal amount of pressure into the roller, compared to other muscle groups along with a less dense foam roller, did not present enough of a stimulus to elicit changes in ROM.

Post-Exercise Recovery

Macdonald and associates (2014) investigated foam rolling as a post-exercise recovery tool with 20 active, resistance trained males, assigned to either a FR or control group, who completed five testing sessions. In the first session, both groups were tested on one repetition maximum (1 RM) back squat performance and then given at least 96 h rest to allow full recovery. In the second session, subjects completed a 10 x 10 squat protocol at 60% 1RM in an attempt to elicit DOMS. For testing sessions 2-5, subjects first had their thigh girth and perceived pain assessed and then completed a cycling warmup. They were then tested for VJ, quadriceps MVC (knee extension), passive knee flexion ROM, and passive and active hip flexion ROM (kicking as high as possible with knee braced). Session two differed slightly because measurements were taken before and immediately after the 10 x 10 squat protocol. The FR group completed two sets of 60 s bouts of foam rolling on the lateral, medial, anterior and posterior parts of the thigh, as well as, the gluteals. Foam rolling was done at 0 h, 24 h, and 48 h post-exercise while the control did not receive any treatment. The FR group experienced greater improvements in percent muscle activation and passive and active ROM. At each time point, the control group scored higher on muscle soreness readings showing that foam rolling was successful at reducing muscle soreness. The peak muscle soreness for the FR group occurred 24 h post-exercise and the peak muscle soreness for the control was at 48 h post-exercise. The results also showed that there was greater muscle activation in the interpolated twitch technique 24 h to 72 h post-exercise in the FR group compared to the control. However, the findings did not show any differences in MVC force at any time point after the treatment. Of particular interest, one finding was that VJ height was greater in the FR group than the control at 24 and 48 h post intervention. This suggests that foam rolling may aid in recovery for dynamic movements requiring power.

In another study, investigators tested the effects of foam rolling on recovery using eight recreational resistance trained males in a within subjects design (Pearcey et al., 2015). Each subject performed a FR or control condition after a DOMS-inducing protocol (10 x 10 repetition back squat at 60% 1RM), and conditions were separated by four weeks. The FR group rolled the quadriceps, hip adductors, hamstrings, IT band, and gluteals for 45 s with 15 s rest on each muscle group. The rolling sequence was repeated twice. Measures of pressure-pain threshold on the quadriceps, sprint speed (30 m), broad jump distance, agility (T-test), and strength endurance (maximal repetition back squat at 70% 1RM) were tested at baseline, 24 h post, 48 h post, and 72 h post-intervention for both groups. Foam rolling was found to have a moderate effect on decreasing pain-pressure threshold on the quadriceps at 24 h post-intervention and a larger effect at 48 h post-intervention. The authors reported that sprint time and broad jump performance were negatively affected but not to the same extent as the control at 24 h and 72 h post intervention. Strength endurance was also negatively affected but not to the same as the control at 48 h post-exercise. Foam rolling had no effect on agility performance post-intervention compared to the control. They concluded that foam rolling may help alleviate muscle soreness and improve post-exercise performance up to 72 h after a DOMS-inducing protocol.

Foam Rolling and Performance

MacDonald and associates (2013) investigated the effects of foam rolling on muscle performance with 11 subjects and had them FR for 1 min on the quadriceps, rest 1 min, and then FR for another minute. They measured knee extensor MVC force production, rate of force development, EMG, and knee extensor ROM (using a modified kneeling lunge) at pre-condition, and 2 and 10 min post-condition. The FR treatment significantly increased knee joint ROM at 2 min and 10 min after foam rolling (11˚ and 9˚ ROM, respectively). Furthermore, they found that after foam rolling there was no change in muscle force, rate of force production, or activation. This study was the first to investigate foam rolling on strength and power performance; researchers hypothesized that foam rolling would increase ROM but decrease power and muscle activation. However, there was an increase in ROM with no decrease in power or strength performance after foam rolling for 2 min total.

Healey and collaborators (2014) examined the effects of foam rolling on VJ height, isometric force production, speed, and agility. They recruited 25 healthy college-aged individuals and compared foam rolling to a control group that did similar planking exercises to mimic the positions of foam rolling. The treatment group began with foam rolling their quadriceps, hamstrings, calves, latissimus dorsi, and rhomboids for 30 s each. The control group was asked to perform planking exercises that were similar to the positions of foam rolling for 30 s each. After the warm-up and after each test, subjects were asked to rate soreness and fatigue using the Soreness of Palpation Rating Scale, Overall Fatigue Scale, Overall Soreness Scale, and the Borg CR-10. The testing of isometric squat force involved standing on a force plate in quarter squat position. The participants were asked to push maximally against a Smith squat machine for 10 s at a knee angle at 135 degrees. Vertical jump was evaluated using a countermovement jump on a Vertec while vertical force was measured with a force plate. Agility was tested using the pro-agility (PA) test also known as a 5-10-5 shuttle run. Participants were given instruction and time to practice before being evaluated on each test. There were no significant differences in performance between the control group and the FR group. However, fatigue was perceived to be greater by the planking control group than the FR group. One limitation to this study, when compared to massage literature, is that the subjects only used the foam roller for 30 s on each muscle group. Greater foam rolling durations may result in different effects on muscle force and ROM.

Peacock et al. (2015) compared the medio-lateral axis FR and antero-posterior axis FR protocols in 16 athletically trained adults. Using a within subjects design, subjects completed five rolls in 30 s. The medio-lateral condition treated the lumbar spine, medial gluteal, hamstring, posterior calf, pectoral and quadriceps regions while the antero-posterior axis FR condition treated the latissimus dorsi, midaxial, lateral hip, iliotibial band, lateral calf and adductor regions. After completing the FR conditions, subjects went through a dynamic warm-up consisting of mobility and plyometric exercises. The subjects were then tested on performance measures similar to those used in the NFL Combine consisting of a VJ, standing broad jump, PA, bench press (maximum reps with 225 lbs), and sit-and-reach test. There were no significant differences between conditions in the VJ, broad jump, PA, or bench press. However, there was a significant increase in the sit-and-reach for the antero-posterior group, which may be due to the hamstrings foam rolled in this condition and not in the medio-lateral condition. The limitation to this study is that there was no control group to see if any foam rolling at all would be beneficial compared no foam rolling.

Summary

Through reviewing the literature, it appears that short duration foam rolling and massage can increase ROM without decreasing subsequent performance. There is a trend within the literature that as the time of massage increases there may be a decrease in subsequent force production performance. However, with this decrease in performance, there still tends to be an increase in ROM. The decrease in performance seen in massage may be due to relaxation or decrease in parasympathetic activity that is not present in foam rolling. However, foam rolling durations greater than 2 min have not been studied and it is possible that as the time of foam rolling increases, there may be a decrease in subsequent power performance.

PROPOSAL

METHODS

This chapter describes the methodology of the study detailing data collection and analysis procedures to examine the impact of foam rolling duration on power and flexibility performance. This methods section is subdivided as follows: (a) subjects, (b) procedure, (c) measurements, (d) foam rolling, and (e) data analysis.

Subjects

This study will test 24 participants who are healthy and participate in cardiovascular and/or resistance exercise at least three times a week for a total of at least 150 min. They will be between the ages of 18 and 35 years and have no recent or current injuries. Recent or current injuries will be defined as having no current orthopedic issue that has given them pain when exercising and no serious injuries within the last six months. Subjects will be evaluated for physical activity and injury status through a medical health and habits history with a 24-hour recall questionnaire (Appendix A). Subjects will be recruited through referrals and approaching potential subjects around campus. The participants will be asked to refrain from intense lower body exercise that may cause DOMS within 48 h of all testing days. They will also be asked to refrain from alcohol, nicotine, and caffeine within 4 h of each test. Before participation, subjects will sign an informed consent form (Appendix B) explaining the testing procedures. This study will be approved by the Ithaca College Institutional Review Board.

Procedures

The testing process will consist of four visits per subject. The first day will be a familiarization day for subjects to become accustomed to the procedures. They will be asked to wear athletic attire and be prepared for light amounts of physical activity. Upon arriving for the first visit, participants will sign an informed consent and fill out a medical health history and 24-hour questionnaire. The documents will be reviewed and participants will be informed of their eligibility for the study. Participants will then be educated on how to perform the FR and plank (control) technique and allowed to practice both. Next, they will be instructed on how to execute the VJ and PA and allowed to practice until they feel comfortable with each. Finally, they will be familiarized with the modified kneeling lunge test (MKL) and a modified weight bearing lunge test (WBL). Before the end of the first day any questions or concerns will be addressed and the subjects will be scheduled for the next visit.

The next three days will all be testing days. All three testing sessions will start with two repetitions of a dynamic warmup consisting of 10 bodyweight squats, 10 walking lunges, 10 side lunges, 10 walking knee-to-chest, 10 walking heel to butt, 10 yards high knees, and 10 yards butt kickers. Subjects will then be tested for baseline measurements (pretest) in the VJ, PA, WBL and MKL. Following baseline testing the subjects will perform one of the three treatment conditions: supported planking on a heating pad (control), a 1-min FR, or a 5-min FR. These conditions will be randomly assigned so that the six potential sequences of administering the three conditions are evenly distributed among the subjects. After completing their condition, subjects will be post-tested on the performance variables again. This will conclude the testing day and participants will be asked to return for the two remaining testing sessions on separate days. The testing days will be separated by at least 48 h to ensure subjects are not fatigued from a previous day of testing.

Measurements

The VJ test will be measured using a Vertec (Perform Better, Inc., West Warwick, RI, USA), which contains a vane stack with vanes spaced ½ inch apart, and will follow the guidelines of Nuzzo, Anning and Sharfenberg (2011). The reliability of the Vertec is very good with intraclass correlation coefficients (ICC) of .87 - .89 (Nuzzo, et al., 2011). The participants will stand directly underneath the vane stack and will be instructed to reach as high as they can with the closest arm to the stack. The vane stack will be lowered to the hand stretched overhead to establish the testing height. The subject will then be instructed to perform a countermovement jump. The jump must be performed from a standing position; no stepping into the jump will be allowed. The subject will reach as high as they can with the same arm used to measure the vane stack height and tap the highest vane possible. The highest vane achieved, as well as, the vanes below it will be moved to the side and leave only higher vanes remaining. The subject will be given 1 min rest before taking another attempt to reach a greater height. Each participant will be given three attempts. In the event that a participant reaches the top of all available vanes, the position will be marked and raised 6 to 12 inches. The raised height will be added to the height measured by the stack. Maximum height will be recorded (in inches).

The PA will be measured using a Smart Speed laser timing system (Fusion Sport, Coopers Plains, Australia) using the protocol of Healey and associates (2014). The PA has been shown to have an ICC of .90 (Stewart, Turner, & Miller, 2014). The test will be set up using three in-line cones separated 5 yards apart. The participant will start with either hand on the middle cone until an auditory signal is given. Then the subject will run 5 yards to the cone to their left and touch the cone with their hand. They will then sprint

10 yards to the cone furthest to their right, touch the cone and then sprint all the way past the middle cone. The time of each attempt will be recorded at the start and when the person passes back through the middle cone. The subject will have two trials with 1 min rest between and the best time of the two will be used in data analysis. Times will be recorded to the nearest thousandth of a second.

The WBL will be measured using a tape measure secured to the ground perpendicular to a wall. A similar protocol to that used by Hoch (2011) will be administered with the only difference being that measurements will be taken at the heel instead of the great toe. The reliability for the WBL has been shown to excellent with ICC at .98-.99 (O'Shea & Grafton, 2012). The subjects will remove their shoes and place their right heel at a starting point of 30 cm from the wall with their right toe and knee pointing straight towards the wall and in line with the tape measure. The left foot will be placed approximately one foot length behind the right foot and the hands will be placed on the wall in front of them for stability. The subjects will be instructed to keep their right heel flat on the floor and move their right knee forward to touch the wall with their anterior knee. For each successful attempt, the heel will be moved back 5 cm away from the wall until they are unable to keep their heel flat on the floor. Once the heel is lifted, the heel will be moved forward 3 cm. After this point, the heel will be moved forward towards the wall for all unsuccessful attempts and backwards for all successful attempts. This procedure will be continued until their maximum distance from the wall is narrowed to the nearest .5 cm and will be recorded at the heel.

The MKL will be performed with the subject positioned in a lunge position with the left foot forward and flat on the ground (MacDonald et al., 2013). Although no research on the reliability of the MKL exists, goniometry has been shown to have an intratester error of 1% up to 5% (Gajdosik & Bohannon, 1987). The right leg will be positioned behind the left leg with the right knee on a mat. The right foot will be raised in the air and ankle dorsi-flexed. The subject will push their right hip forward to create a stretch on the hip flexors and will keep the torso in an upright position. In this position, angles of the right knee and hip will be taken using a goniometer and recorded. The same hip angle will be used throughout all testing conditions. The subject's right heel will be pushed in towards the gluteals until a point of mild discomfort. This position will be held and the angle of the knee will be recorded with a goniometer to the nearest degree.

Foam Rolling

The FR treatment will be done using a dense foam roller (PB Elite Level Foam Roller; Perform Better, Inc., West Warwick, RI, USA) and the same roller will be used throughout the duration of the study. The subjects will roll the quadriceps and calves for 1 min or 5 min on each side of each muscle group. They will start with the left quadriceps, switch to the right quadriceps, and then to the left and right calves. The participants will start at the proximal end of each muscle group and roll to the distal end of the muscle group. For each muscle group, the participants will attempt to roll across the full body of the muscle group working laterally to medially. This is to ensure that all heads of the muscle are rolled. The participants will be instructed to place their body weight into the roller to create as much pressure on the muscles as they can tolerate. The speed of the foam rolling will be one roll every 6 s (10 rolls/min) and the participant will change positions from lateral to medial every two rolls.

To FR the quadriceps, the participant will lay face down with the foam roller positioned just below the hip joint supporting themselves with the hands or elbows. They will then roll slowly towards the knee and then return slowly to the hip once they have reached the knee. After each roll down and back up, the person will tilt their body in a way to work medially every two rolls, repeating the proximal to distal rolling. This pattern will continue until the allotted time has been reached. The participant will then switch to the opposite quadriceps and repeat the same protocol.

The calves will be rolled from a seated position with the calves supported on the foam roller with their hands directly underneath their shoulders. They will push down into the ground to lift the hips off the floor and then flex and extend at the shoulder to move themselves forward and backward. By moving their body forward and backward, they will roll proximal to distal on the calves and after every two rolls, they will switch their toe angle from pointing laterally to pointing medially to roll a different portion of the muscle. The calves will be rolled from just below the knee to just below the ankle. They will roll for the allotted time before switching the other limb.

During the control condition, the participants will hold the FR position with one limb supported on risers with a heating pad instead of on a foam roller. The heating pad will be set to the lowest setting to prevent deep heating of muscle tissue. The height of the risers will be the same as the foam roller and the person will position themselves so the riser is in the middle of the muscle group. A mat will be placed under the heating pad to prevent any potential myofascial release from pressing the muscles into a hard surface. The FR positions will be held for 5 min and the subjects will be instructed to rotate medial-laterally every 12 s. The purpose of the supported plank is to control for a warm-up effect of simply holding the positions necessary for foam rolling and to control for fatigue of holding the FR position for 5 min. Since one of the proposed benefits of foam rolling is that it increases blood flow to the muscle and helps someone to warm up, a counter-claim could be proposed that it is not the foam rolling itself but the act of holding themselves up that causes these changes to happen. When the person holds himself or herself with foam rolling, it may also activate certain muscle groups, especially in the core, that could aid in subsequent performance. The heating pad serves to create a deception leading the subjects to believe they are getting a treatment.

Data Analysis

Data will be analyzed using four 3 x 2 repeated measures analysis of variance (ANOVA) to determine whether there are statistically significant differences between the three conditions (1-min FR, 5-min FR, control) at two times (pre-treatment and post-treatment) for VJ height, PA run time, WBL length, or MKL angle. If statistical significance is found, the three conditions will be analyzed at pre-treatment and post-treatment times using a one-way ANOVA to determine significance between conditions. If statistically significant differences are found between conditions, paired samples t-tests will be used for further analysis. Paired samples t-tests will also be used to determine statistically significant differences over time for each condition (pre-treatment to post-treatment). All statistics will be tested at an alpha of .05 and run using IBM SPSS.

REFERENCES

Arabaci, R. (2008). Acute effects of pre-event lower limb massage on explosive and high speed motor capacities and flexibility. *Journal of Sport Science and Medicine*, *7*(4), 549–555.

Arroyo-Morales, M., Fernandez-Lao, C., Ariza-Garcia, A., Toro-Velasco, C., Winters, M., & Diaz-Rodriguez, L. (2011). Psychophysiological effects of preperformance massage before isokinetic exercise. *Journal of Strength & Conditioning Research*, *25*(2), 481–488.

Arroyo-Morales, M., Olea, N., Martínez, M. M., Hidalgo-Lozano, A., Ruiz-Rodríguez, C., & Díaz-Rodríguez, L. (2008). Psychophysiological effects of massage-myofascial release after exercise: A randomized sham-control study. *Journal of Alternative and Complementary Medicine*, *14*(10), 1223–1229.

Barlow, A., Clarke, R., Johnson, N., Seabourne, B., Thomas, D., & Gal, J. (2004). Effect of massage of the hamstring muscle group on performance of the sit and reach test. *British Journal of Sports Medicine*, *38*(3), 349–351.

Barnes, M. (1997). The basic science of myofascial release: Morphologic change in connective tissue. *Journal of Bodywork & Movement Therapies*, *1*(4), 231–238.

Bushell, J., Dawson, S., & Webster, M. (2015). Clinical relevance of foam rolling on hip extension angle in a functional lunge position. *Journal of Strength & Conditioning Research*, *29*(9), 2397–2403.

Butterfield, T. A., Zhao, Y., Agarwal, S., Haq, F., & Best, T. M. (2008). Cyclic compressive loading facilitates recovery after eccentric exercise. *Medicine and Science in Sports and Exercise*, *40*(7), 1289–1296.

Couture, G., Karlik, D., Glass, S. C., & Hatzel, B. M. (2015). The effect of foam rolling duration on hamstring range of motion. *The Open Orthopedics Journal, 9*, 450–455.

Curran, P., Fiore, R. D., & Crisco, J. J. (2008). A comparison of the pressure exerted on soft tissue by 2 myofascial rollers. *Journal of Sport Rehabilitation*, *17*(4), 432–442.

Diego, M. A., & Field, T. (2009). Moderate pressure massage elicits a parasympathetic nervous system response. *International Journal of Neuroscience, 119*(5), 630–638.

Drust, B., Atkinson, G., Gregson, W., French, D., & Binningsley, D. (2003). The effects of massage on intra muscular temperature in the vastus lateralis in humans. *International Journal of Sports Medicine*, *24*(6), 395–399.

Farr, T., Nottle, C., Nosaka, K., & Sacco, P. (2002). The effects of therapeutic massage on delayed onset muscle soreness and muscle function following downhill walking. *Journal of Science and Medicine in Sport, 5*(4), 297–306.

Fletcher, I. (2010). The effects of precompetition massage on the kinematic parameters of 20-m sprint performance. *Journal of Strength & Conditioning Research*, *24*(5), 1179–1183.

Gajdosik, R. L., & Bohannon, R. W. (1987). Clinical measurement of range of motion review of goniometry emphasizing reliability and validity. *Physical Therapy*, *67*(12), 1867–1872.

Goodwin, J. E., Glaister, M., Howatson, G., Lockey, R., & McInnes, G. (2007). Effect of pre-performance lower-limb massage on thirty-meter sprint running. *Journal of Strength & Conditioning Research*, *21*(4), 1028–1031.

Halperin, I., Aboodarda, S. J., Button, D. C., Andersen, L. L., & Behm, D. G. (2014). Roller massager improves range of motion of plantar flexor muscles without subsequent decreases in force parameters. *International Journal of Sports Physical Therapy*, *9*(1), 92–103.

Healey, K., Hatfield, D., Blanpied, P., Dorfman, L., & Riebe, D. (2014). The effects of myofascial release with foam rolling on performance. *Journal of Strength & Conditioning Research*, *28*(1), 61–68.

Hoch, M., Staton, G., & McKeon, P. (2011). Dorsiflexion range of motion significantly influences dynamic balance. *Journal of Science and Medicine in Sport*, *14*(1), 90–92.

Hilbert, J. E., Sforzo, G., & Swensen, T. (2003). The effects of massage on delayed onset muscle soreness. *British Journal of Sports Medicine*, *37*(1), 72–75.

Huang, S., Di Santo, M., Wadden, K., Cappa, D., Alkanani, T., & Behm, D. (2010). Short-duration massage at the hamstrings musculotendinous junction induces greater range of motion. *Journal of Strength & Conditioning Research*, *24*(7), 1917–1924.

Jourkesh, M. (2007). The effect of massage on performance of the sit and reach test in adolescent soccer players. *Medicina Dello Sport*, *60*(2), 151–155.

Leivadi, S., Hernandez-Reif, M., & Field, T. (1999). Massage therapy and relaxation effects on university dance students. *Journal of Dance Medicine & Science, 3*(3), 108–112.

Longworth, J. (1982). Psychophysiological effects of slow stroke back massage in normotensive females. *Advances in Nursing Science*, *4*(4), 44–61.

MacDonald, G., Penney, M., Mullaley, M., Cuconato, A., Drake, C., Behm, D., & Button, D. (2013). An acute bout of self-myofascial release increases range of motion without a subsequent dcrease in muscle activation or force. *Journal of Strength & Conditioning Research*, *27*(3), 812-821.

Macdonald, G. Z., Button, D. C., Drinkwater, E. J., & Behm, D. G. (2014). Foam rolling as a recovery tool after an intense bout of physical activity. *Medicine and Science in Sports and Exercise*, *46*(1), 131–142.

McKechnie, G., Young, J., & Behm, D. (2007). Acute effects of two massage techniques on ankle joint flexibility and power of the plantar flexors. *Journal of Sports Science & Medicine*, *6*(4), 498–504.

Mohr, A. R., Long, B. C., & Goad, C. L. (2014). Effect of foam rolling and static stretching on passive hip-flexion range of motion. *Journal of Sport Rehabilitation*, *23*(4), 296–299.

Nuzzo, J., Anning, J., & Scharfenberg, J. (2011). The reliability of three devices used for measuring vertical jump height. *Journal of Strength & Conditioning Research*, *25*(9), 2580-2590.

Ogai, R., Yamane, M., Matsumoto, T., & Kosaka, M. (2008). Effects of petrissage massage on fatigue and exercise performance following intensive cycle pedalling. *British Journal of Sports Medicine*, *42*(10), 834–838.

O'Shea, S., & Grafton, K. (2013). The intra and inter-rater reliability of a modified weight-bearing lunge measure of ankle dorsiflexion. *Manual Therapy*, *18*(3), 264-268.

Paolini, J. (2009). Review of myofascial release as an effective massage therapy technique. *Athletic Therapy Today*, *14*(5), 30–34.

Peacock, C., Krein, D., Antonio, J., Sanders, G., Silver, T., & Colas, M. (2015). Comparing acute bouts of sagittal plane progression foam rolling vs. frontal plane progression foam rolling. *Journal of Strength & Conditioning Research*, *29*(8), 2310–2315.

Pearcey, G., Bradbury-Squires, D. J., Kawamoto, J. E., Drinkwater, E. J., Behm, D. G., & Button, D. C. (2015). Foam rolling for delayed-onset muscle soreness and recovery of dynamic performance measures. *Journal of Athletic Training*, *50*(1), 5–13.

Rinder, A. N., & Sutherland, C. J. (1995). An investigation of the effects of massage on quadriceps performance after exercise fatigue. *Complementary Therapies in Nursing and Midwifery*, *1*(4), 99–102.

Škarabot, J., Beardsley, C., & Štirn, I. (2015). Comparing the effects of self-myofascial release with static stretching on ankle range-of-motion in adolescent adults. *The International Journal of Sports Physical Therapy*, *10*(2), 203–212.

Smith, L. L., Keating, M. N., Holbert, D., Spratt, D. J., McCammon, M. R., Smith, S. S., & Israel, R. G. (1994). The effects of athletic massage on delayed onset muscle soreness, creatine kinase, and neutrophil count: A preliminary report. *The Journal of Orthopaedic and Sports Physical Therapy*, *19*(2), 93–99.

Stewart, P. F., Turner, A. N., & Miller, S. C. (2014). Reliability, factorial validity, and interrelationships of five commonly used change of direction speed tests. *Scandinavian Journal of Medicine and Science in Sports*, *24*(3), 500–506.

Sullivan, K., Silvey, D., Button, D., & Behm, D. (2013). Roller-massager application to the hamstrings increases sit-and-reach range of motion within five to ten seconds without performance impairments. *International Journal of Sports Physical Therapy*, *8*(3), 228-236.

Waters-Banker, C., Dupont-Versteegden, E., Kitzman, P., & Butterfield, T. (2014). Investigating the mechanisms of massage efficacy: The role of mechanical immunomodulation. *Journal of Athletic Training*, *49*(2), 266–273.

Weerapong, P., Hume, P., & Kolt, G. S. (2005). The mechanisms of massage and effects on performance, muscle recovery and injury prevention. *Sports Medicine*, *35*(3), 235–256.

Weinberg, R., Jackson, A., & Kolodny, K. (1988). The relationship of massage and exercise to mood enhancement. *Sport Psychologist*, *2*(3), 202-211.

Wiktorsson-Moller, M., Oberg, B., Ekstrand, J., & Gillquist, J. (1983). Effects of warming up, massage, and stretching on range of motion and muscle strength in the lower extremity. *American Journal of Sports Medicine*, *11*(4), 249–252.

Zeitlin, D., Keller, S., Shiflett, S., & Bartlett, J. (2000). Immunological effects of massage therapy during academic stress. *Psychosomatic Medicine*, *62*(1), 83–84.

RESEARCH MANUSCRIPT

INTRODUCTION

In the last decade, the use of the foam roller has become increasingly popular in strength and conditioning and fitness facilities. However, despite the increased use of foam rolling by recreational and competitive athletes, there is little research on the effects of foam rolling on performance. Due to an inflammatory response as a result of injury or microtrauma from regular exercise, collagen in the fascial tissue becomes fibrous and dense due to the formation of fascial cross-links and scar tissue, causing elastin to lose its pliability (Barnes, 1997; Curran, Fiore, & Crisco, 2008; Macdonald, Button, Drinkwater, & Behm, 2014). This can cause muscle dysfunctions, restrict range of motion (ROM), decrease strength and cause pain (Barnes, 1997; Curran et al., 2008; MacDonald et al., 2013). Myofascial release and self myofascial release (SMR) use external mechanical pressure in an attempt to break up fascial adhesions and return the tissue to a gel-like state and promote proper length-tension relationships within the muscle to improve these dysfunctions (Barnes, 1997; Bushell, Dawson, & Webster, 2015; Healey, Hatfield, Blanpied, Dorfman, & Riebe, 2014; MacDonald et al., 2013). Foam rolling is adopted by athletes as a way to perform SMR and potentially combat adverse effects of exercise.

Although myofascial release is traditionally performed manually by therapists, recently more attention is being given to SMR. SMR provides similar mechanical pressure and may produce the benefits provided in a clinical setting without the cost or time required of seeing a clinician (Healey et al., 2014). This may allow people to perform SMR more frequently and is speculated to help chronically improve ROM, restore proper length-tension relationships, reduce pain due to spasms, and improve movement dysfunctions (Bushell et al., 2015; Healey et al., 2014; MacDonald et al., 2013). Massage and SMR are also thought to improve recovery after exercise by decreasing delayed onset muscle soreness (DOMS), which is thought to be caused by an acute inflammatory response due to damage to muscle and fascial tissue (Macdonald et al., 2014; Waters-Banker, Dupont-Versteegden, Kitzman, & Butterfield, 2014). Myofascial release works through immunomodulation which decreases the immune response and the subsequent byproducts that are thought to cause the pain associated with DOMS (Butterfield, Zhao, Agarwal, Haq, & Best, 2008; Waters-Banker et al., 2014). Research has also shown foam rolling to decrease DOMS and improve recovery after intense exercise (Macdonald et al., 2014; Pearcey et al., 2015).

In addition to being used with the intention of decreasing DOMS, SMR and massage have been proposed to act as an additional form of warm-up to precede exercise (Arabaci, 2008; MacDonald et al., 2013). While myofascial release may increase ROM and restore proper length-tension relationships, another proposed benefit is increased blood flow to the muscles and an increase in muscle temperature (Arabaci, 2008; Weerapong, Hume, & Kolt, 2005). In massage studies, this increase in blood flow is thought to occur due to the kneading motion of the massage and the increase in muscle temperature is thought to occur as a result of increased blood flow, friction on the skin, and body heat from the *masseur* (Weerapong et al., 2005). Although massage has been shown to increase muscle temperature (Weerapong et al., 2005), it is unknown whether this benefit is present with foam rolling.

Although massage and foam rolling have both been shown to increase ROM (Healey et al., 2014; Huang et al., 2010; MacDonald et al., 2013), some massage studies have shown a decrease in subsequent muscular isokinetic peak force, sprint performance and vertical jump height (Arabaci, 2008; Arroyo-Morales et al., 2011; Wiktorsson-Moller, Oberg, Ekstrand, & Gillquist, 1983). Contradicting the massage literature, several studies using foam rollers (and hand rollers) have shown increased ROM without a decrease in subsequent power performance (Halperin, Aboodarda, Button, Andersen, & Behm, 2014; Healey et al., 2014; MacDonald et al., 2013; Sullivan, Silvey, Button, & Behm, 2013). A clear difference between the massage and foam rolling studies is the duration of myofascial release to which the muscle is subjected. Previous literature recommends applying pressure during SMR for 60-90 s to up to 5 min (MacDonald et al., 2013; Paolini, 2009). Foam rolling and hand rolling studies have mostly used treatment durations of less than 30 s (Halperin et al., 2014; Healey et al., 2014; Sullivan et al., 2013). The longest duration used in a foam rolling study investigating performance measures was two 1-min foam roll (FR) intervals with 1-min rest in between (MacDonald et al., 2013). In contrast, the massage studies finding a negative impact on power performance have used treatment durations of 6 min per muscle group (Arroyo-Morales et al., 2011) and 15 min total (Arabaci, 2008). Foam rolling appears to show no decrease in performance with short durations of less than 2 min but it is possible that longer durations could cause a decrease in subsequent power performance. However, foam rolling for longer durations has not been studied. It is possible that a treatment duration effect on muscle function exists with longer myofascial release times resulting in a greater loss of muscle activity, electromyography (EMG), and muscular performance (MacDonald et al., 2013). The purpose of this study is to determine the effects of 1-min FR and 5-min FR durations on power, agility and ROM.

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METHODS

Experimental Approach to the Problem

A within subjects crossover design was used to determine the acute effects of foam rolling durations on power, agility, and flexibility. Each participant completed three different conditions: control, 1-min FR, and 5-min FR. The quadriceps and calves were continuously rolled for the allotted time on each side of each muscle group, starting with the quadriceps. After a familiarization session, each subject performed the three conditions in an order that was randomized and balanced over six possible order combinations. Sessions were separated by 48 h. Before and after each condition, subjects were tested on a vertical jump test (VJ), pro-agility test (PA), modified weight bearing lunge test (WBL) and modified kneeling lunge test (MKL).

Subjects

This study tested 24 healthy participants (8 male, 16 female; height: 168.3 ± 14.9 cm; mass: 69.3 kg; age: 23.7 ± 4.5 yr) between the ages of 18 and 35 y who exercised at least three times a week for a total of at least 150 min. Subjects were defined as healthy if they had no orthopedic condition that caused pain when exercising and no serious injuries within the last six months. Subjects were evaluated for physical activity and injury status using medical health and habit history and 24 hour recall questionnaires. Participants were asked to refrain from intense lower body exercise within 48 h of all testing days and to refrain from alcohol, nicotine and caffeine within 4 h of each test. This study was approved by the Ithaca College Institutional Review Board and each subject signed an informed consent form before participation in the study.

Procedures

The testing process consisted of four visits with the first visit being a familiarization session where instructions on the testing protocols were provided. After completing a warm-up, subjects practiced each performance test, and the FR and control treatment conditions. Subjects were given as much practice as needed (approximately 20 min) to become familiarized with the procedures. All three testing sessions started with two repetitions of a dynamic warmup consisting of 10 bodyweight squats, 10 walking lunges, 10 side lunges, 10 walking knee-to-chest, 10 walking heel to butt, 10 yards high knees, and 10 yards butt kickers. Subjects were baseline tested in all performance variables (VJ, PA, WBL, and MKL) and then asked to perform one of the three conditions: supported planking on a heating pad (control), 1-min FR, or 5-min FR. Immediately following the condition, they were again tested on each performance variable. The three conditions were randomly assigned so that six potential sequences of administering the three conditions were evenly distributed among the subjects. Each testing day was separated by at least 48 h to ensure subjects were not fatigued from the previous day of testing.

Measurements

The VJ was measured using a Vertec (Perform Better Inc., West Warwick, RI, USA) following the guidelines of Nuzzo, Anning, & Sharfenberg (2011). Vertical jump test reliability has been shown to have intraclass correlation coefficients (ICC) of .87 - .89 with coefficient of variations of 4.6% - 5.5% (Nuzzo et al., 2011). For the VJ test, the subject stood directly underneath the vane stack which was lowered to the subject's hand stretched overhead to establish maximum overhead reach height. The subject was instructed to perform a maximal effort countermovement jump, tapping the highest vane possible, without stepping into the jump. Subjects were given three attempts with 1 min rest between attempts. The best of the three attempts was recorded to the nearest ½ inch.

The PA was measured with a Smart Speed laser timing system (Fusion Sport, Coopers Plains, Australia) using the protocol of Healey and associates (2014). The PA has been shown to have an ICC of .90 and a coefficient of variation of 2.19% (Stewart, Turner, & Miller, 2014). The test was set up using three cones in a line separated 5 yards apart. The participant started with either hand on the middle cone until an auditory signal was given. The subject then ran five yards to the cone to their left and touched the cone with their hand. They then sprinted 10 yards to the cone furthest to their right, touched the cone, and then sprinted all the way past the middle cone. The time of each attempt was recorded from the start to when the person passed back through the middle cone. The subjects were given two timed attempts with 1 min rest between attempts. The best of the two attempts was used for data analysis and times were recorded to the nearest thousandth of a second.

Performance on the WBL was measured using a tape measure secured to the ground perpendicular to a wall. The protocol was similar to that used by Hoch and associates (2011) except the only difference was that measurements were recorded from the heel instead of the great toe. Intra-tester reliability for the WBL has been found to be excellent with intraclass correlation coefficients .98-.99 and a minimal detectable change of 1.6 cm (Powden, Hoch, & Hoch, 2015). The subjects removed their shoes and placed their right heel at a starting point of 30 cm from the wall with their right toe and knee pointing straight at the wall and in line with the tape measure. The left foot was placed approximately one foot length behind the right foot and the hands were placed on the wall in front in order to provide stability. Subjects were instructed to keep their right heel flat on the floor and move their right knee forward to touch the wall with their anterior knee. The foot was backed away from the wall or moved forward until they could no longer touch the wall with their knee while maintaining full heel contact to the ground. The maximum distance between the heel and the wall was narrowed to the nearest .5 cm and recorded. One trial on the right limb was used for data analysis.

Figure 1. *WBL technique. This illustrates the way in which subjects were set up and then kept their heel flat to the floor while moving the anterior knee towards the wall.*

The MKL was performed with the subject in a lunge position with the left foot forward and flat on the ground (MacDonald et al., 2013). Although no research on the reliability of the MKL exists, goniometry is shown to have an intratester error of up to 5% (Gajdosik & Bohannon, 1987). The right leg was positioned behind left leg with the right knee on a mat. The right foot was raised in the air and ankle dorsi-flexed. The subject pushed their right hip forward to establish a stretch on the hip flexors and the torso was in an upright position. In this position, angles of the right knee and hip were taken using a goniometer and recorded to ensure similar angles were used throughout all testing conditions. The subject's right heel was then pushed in towards the gluteals until a point of mild discomfort while maintaining the same upright torso angle. The angle of the knee was recorded with a goniometer to the nearest degree. The change in knee angle from the initial position to the final position was calculated and used for data analysis.

Figure 2. *MKL technique. This illustrated the setup for the WBL where the heel was pushed to the gluteals until mild discomfort. Photograph with permission from MacDonald et al., 2013.*

Foam Rolling

The FR treatment used a dense foam roller (PB Elite Level Foam Roller; Perform Better, Inc., West Warwick, RI, USA) with the same roller used throughout the study. Subjects rolled the quadriceps and calves for 1 min or 5 min continuously from the proximal end of the muscle, to the distal end, and then back to the proximal end. This was done at a rate of one roll every 6 s (10 rolls/min) and was controlled by a metronome. The subjects switched between five positions targeting the IT band, vastus lateralis, vastus intermedius and rectus femorus, vastus medialis, and adductor group. They switched between these positions medial-laterally every 2 rolls to ensure all heads of the muscle were rolled. Subjects were instructed to transition as quickly as possible (15-30 s) between muscle groups starting with the left quadriceps, moving to the right quadriceps, then to the left calf, and finally the right calf.

To roll the quadriceps, the subject was face down with the foam roller positioned just below the hip joint supporting themselves with the hands or elbows in a plank position. They rolled the foam roller towards the knee and returned to the hip after reaching the knee. The subjects were instructed to roll in five different positions medial-laterally starting with the outside of the thigh and working towards the inside. Once the most medial position was reached, the subjects switched back to the most lateral position and repeated this pattern until the allotted time had been reached.

Figure 3. *Quadriceps foam rolling technique. This shows how the subjects were set up and then asked to roll from the knee to the hip.*

The calves were rolled from seated position with their calf supported on the foam roller with their hands underneath their shoulders. They pushed down into the ground to lift their hips off the floor and then flexed and extended at the shoulder to move themselves forward and backward. By moving their body forward and backward, they rolled proximal to distal on the calves and after every two rolls, switched their toe angle from pointing laterally to pointing medially to roll a different portion of the muscle. The calves were rolled from just below the knee to just below the ankle and rolled for the allotted time before switching to the other limb.

Figure 4. *Calves foam rolling technique. This shows how subjects were set up and then asked to roll from the ankle to just below the knee.*

Control

The control condition was performed with one limb supported on risers with a mat and heating pad on top with the subject's body in the same planking positions of the FR conditions. This controlled for a warm-up effect of holding the positions necessary for foam rolling and to control for the fatigue of holding one's bodyweight for as much as 5 min. The heating pad was set on the lowest setting as to not create a heating effect, but to create an illusion of a treatment. The subjects positioned themselves so that the middle of the muscle group was at the edge of the riser to represent an average of where the person would be positioned rolling proximal to distal, allowing the subject to have some of their bodyweight supported just as they would while foam rolling. A soft mat on top of the risers attempted to prevent any potential myofascial release from pressing the muscles into a hard surface. The subjects were instructed to rotate their body position from lateral to medial every 12 s to emulate the same positions as the FR condition. These positions were held for 5 min for each side for each muscle group for a total of 20 min. This control using a plank and heating pad served as a sham treatment and was not introduced to subjects as a control. The intention was reduce potential performance bias in the study.

Data Analysis

Data were analyzed using four 3 x 2 repeated measures analysis of variance (ANOVA) to determine whether there were statistically significant differences between the three groups (1-min FR, 5-min FR, control) at two times (pre-treatment and post-treatment) in VJ height, PA run time, WBL length, or MKL angle. If statistical significance was found between the three conditions, they were then analyzed for difference at each time point using a one-way ANOVA to determine significance between conditions. If statistically significant differences were found between the three conditions, paired samples t-tests were used for post-hoc analysis. All statistics were set using alpha at .05 and run using IBM SPSS.

RESULTS

There was a significant interaction (Appendix D ANOVA tables) in VJ performance ($p < .01$) on the VJ test. Post-hoc analysis revealed a significant decrease of .94 cm pre-post in VJ height in the control ($p < .01$, effect size (d) = .09) and 2.54 cm in the 5-min FR condition ($p < .01$, d = .26). The 5-min FR group was significantly different than the control ($p < .01$) and showed a greater change in mean pre-post condition. There was no significant change in VJ performance in the 1-min condition (see figure 5).

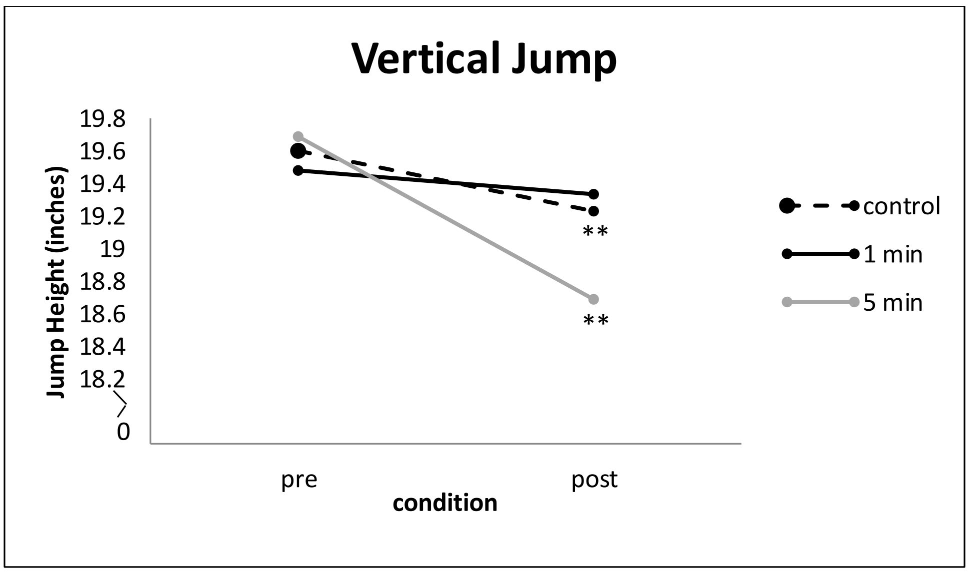

Figure 5. *Change in VJ height across conditions pre and post treatment. ** represents a significant change of p < .01 in the control and 5-min FR from pre-post test.*

There was a significant interaction (Appendix D ANOVA tables) in the PA performance ($p < .05$) and post-hoc analysis showed that there was a significant increase in performance of .058 s pre to post condition in the 1-min condition ($p < .05$, d = .14) and a significant decrease in performance of .067 s in the control ($p < .05$, d = .13). There was no significant difference pre to post in the 5 min condition (see figure 6).

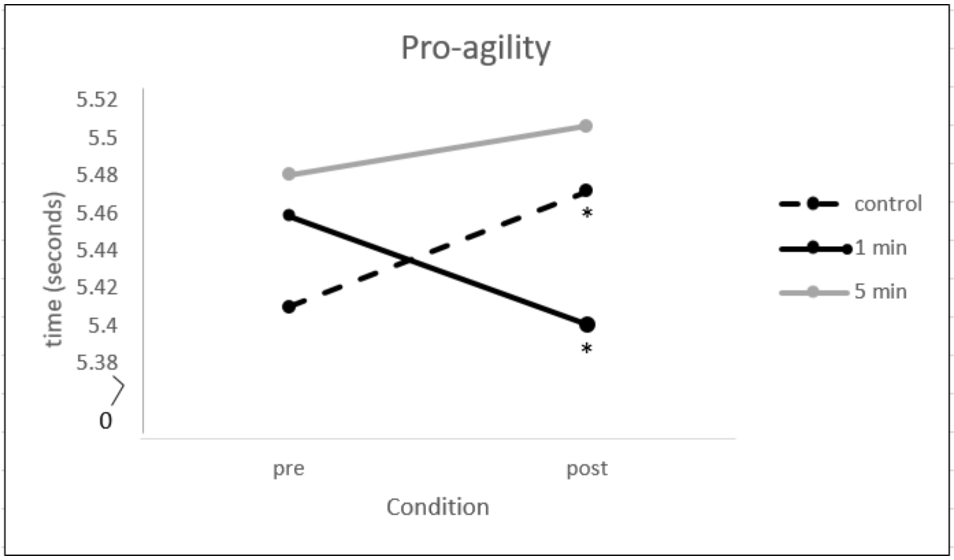

Figure 6. *Change in PA across conditions pre and post treatment. * denotes a significant difference of p < .05 in the control and 1-min condition from pre to post test.*

There were significant interactions (Appendix D ANOVA tables) in the WBL ($p < .05$) and MKL ($p < .01$). As seen in Figure 7, there was a significant increase in score of .28 cm for the 1-min FR ($p < .05$, d = .06) and also an increase of .65 cm in the 5-min FR condition ($p < .01$, d = .15). However, the WBL scores for the 1-min FR and 5-min FR were not significantly different than each other at post-test. The control group showed no significant change in WBL. There was a significant increase of 6.91° in MKL ROM in the 1-min FR ($p < .01$, d = .59) and an increase of 9.08° in the 5-min FR condition ($p < .01$, d = .86). The 5-min FR condition yielded significantly greater MKL (see Figure 8) scores than the 1-min condition post-test. Conversely, there was a significant decrease of .92° ($p < .05$, d = .07) in knee ROM for the control condition over time. All raw data from the project are seen in Appendix E.

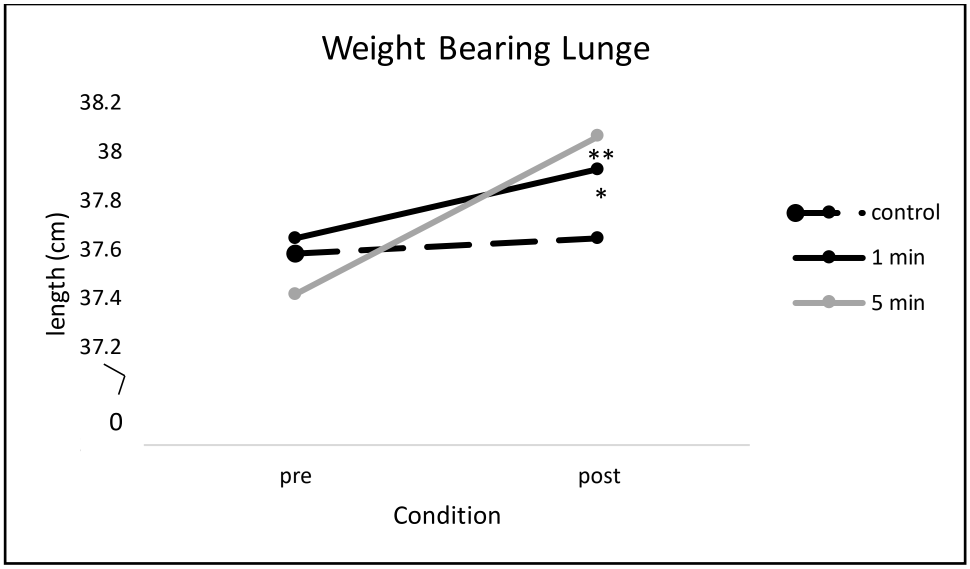

Figure 7. *Change in WBL across conditions pre and post treatment. * represents a significant difference of p < .05 in the 1-min FR and the ** represents a significant change of p < .01 in the 5-min FR from pre to post test.*

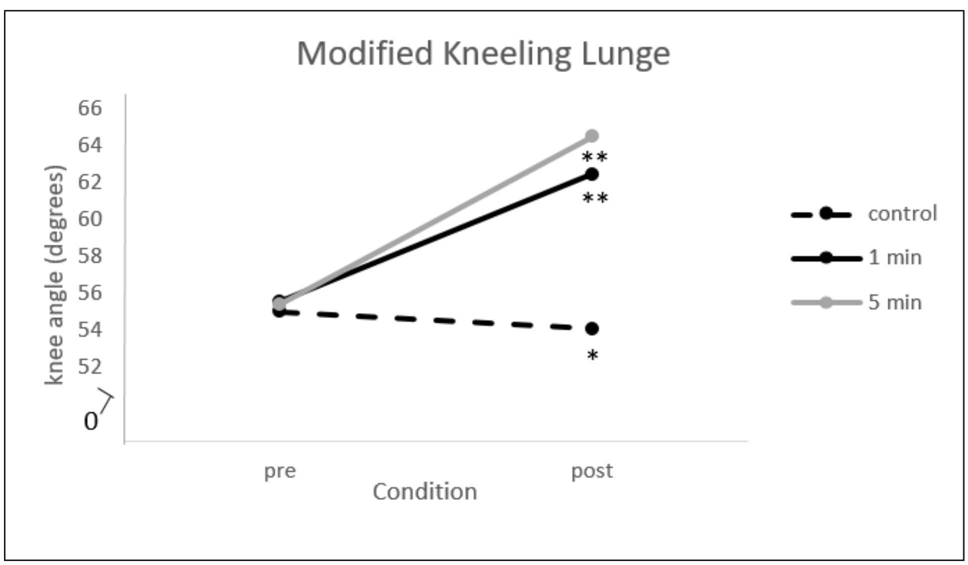

Figure 8. *Change in MKL knee angle across conditions pre and post treatment. * represents a significant difference of p < .05 in the control from pre to post test. ** represents a significant change of p < .01 in the 1-min FR and 5-min FR from pre to post test.*

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DISCUSSION

The most important finding of this study was that the long duration FR (5-min) may decrease subsequent power output compared to the short duration FR (1-min). However, long duration foam rolling may increase ROM to a greater degree than short duration foam rolling. Both FR durations elicited an increase in ROM but the long duration FR decreased VJ performance. Foam rolling is a commonly used form of SMR with potential ability to improve recovery and act as an additional form of warm-up making understanding of how foam rolling duration affects performance important (Arabaci, 2008; MacDonald et al., 2013). Foam rolling may be beneficial before exercise to increase ROM and provide an alternative to static stretching, which may decrease subsequent power performance (Shrier & McHugh, 2012). Previous literature has shown foam rolling to increase ROM without decreasing performance (Healey et al., 2014; MacDonald et al., 2013). However, the durations used have been less than 2 min of total foam rolling (2 x 1 min bouts) despite general foam rolling guidelines recommending up to 5 min durations (MacDonald et al., 2013; Paolini, 2009). This is the first study examining the effects of foam rolling durations greater than 2 min on subsequent power performance. If an increased duration of foam rolling causes a decrease in subsequent exercise performance, this may be important for athletes, coaches, and exercise professionals to understand.

Foam rolling for 5 min decreased subsequent performance in the VJ by 5.2%. However, this decrease in VJ performance may be partially due to fatigue as seen by the .94 cm (1.9%) decrease in performance in the control condition. Although the effect size was trivial in the control, it may suggest that fatigue from supporting one’s bodyweight for a duration of 5 min could be partially responsible for a decrease in VJ. Whether or not the decrease of 2.54 cm in the 5-min FR is meaningful may also be questionable due to the small effect size and intrasession coefficients of variations in the VJ being 4.6%-5.5%. In massage studies where fatigue is likely not present, a decrease in subsequent power performance has also been reported with long treatment durations (Arroyo-Morales et al., 2008; Fletcher, 2010; Wiktorsson-Moller et al., 1983). This decrease in power performance is thought to be caused by a parasympathetic response that decreases motor unit recruitment, action potential amplitude, and firing rate (Arroyo-Morales et al., 2008).

These results are similar to responses observed in static stretching literature where longer duration stretching can result in a loss of power or strength (Shrier & Mchugh, 2012). Meta-analysis has shown that static stretching for durations less than 30 s does not affect performance but durations greater than 1 min had a negative impact on strength, speed, and power (Shrier & McHugh, 2012). While not fully understood, a similar mechanism for diminishing power output after prolonged foam rolling may be at play. Both foam rolling and static stretching may change viscoelastic properties of the muscle (Avela, Finni, Liikavainio, Niemelä, & Komi, 2004; MacDonald et al., 2013), which may be responsible for a decrease in muscle stiffness and the ability to transfer force effectively (Avela et al., 2004). Although some investigators have postulated that changing the length-tension relationship in a muscle may be beneficial, others have noted that the change in sarcomere length may decrease force production (Rossi, Pereira, Simão, Brandalize, & Gomes, 2010). It is possible that foam rolling or static stretching for short durations affect ROM, length-tension relationships, and muscle stiffness to a lesser degree than long durations and, therefore, do not elicit negative effects on power performance. While there was a decrease in VJ performance, long duration foam rolling did not affect agility performance. This finding may be because more muscles are responsible for PA performance and that technique during the PA may have a greater impact on performance compared to the VJ.

The ROM results of this study are consistent with previous literature in that foam rolling increases ROM (Healey et al., 2014; MacDonald et al., 2013). Although statistically significant, the increase of ROM in the WBL may not be meaningful due to the small effect sizes and increases that are less than the minimal detectable change of 1.6 cm. In the MKL, however, it appears clear that both FR groups increased ROM to a meaningful degree. The increases of approximately 7° (12.4%) and 9° (16.4%) in the 1-min FR and 5-min FR (respectively) are larger than the measurement error and greater than the 6° change in ROM deemed as improvement (Gajdosik & Bohannon, 1987). Statistically, the 5-min FR increased ROM in MKL more than the 1-min FR suggesting that prolonged foam rolling duration could be better than short duration foam rolling to improve quadriceps ROM. However, the MKL difference between the 1-min and 5-min was only 2° (3.9% increase) and it is questionable whether this may make a substantial practical difference.

The short duration FR used in this study had similar results as reported in the literature providing an increase in ROM without a decrease in subsequent power performance (Healey et al., 2014; MacDonald et al., 2013). The 1-min FR saw an increase in ROM in the WBL and MKL while VJ performance did not change. This could have potentially increased fascial pliability and caused an increase in ROM without a negative effect on VJ. Along with the increase in ROM, the 1min FR unexpectedly yielded a statically significant increase in performance in PA. Although foam rolling is speculated to improve performance by restoring proper length-tension relationships and improving neuromuscular efficiency (MacDonald et al., 2013), this is the first study to show a statistical increase in subsequent agility performance. However, the effect size was small and the change pre-condition to post-condition was 1.0%. Given that the coefficient of variation for the PA has been shown to be 2.19% (Stewart, Turner, & Miller, 2014), it is likely that the changes in performance seen in this study are due to normal error associated with the test.

One limitation of the study was that only two foam rolling durations were used (1 min and 5 min) and they differed greatly. This makes it challenging to identify at what exact foam rolling duration a decrease in power performance takes place. Future research should investigate durations between 1 min and 5 min to determine a maximum FR duration without negative impact. Another limitation is that subjective measures of fatigue were not collected to determine if subjects felt the control or 5-min FR to be harder than the other. Since fatigue may have been responsible for part of the decrease in VJ performance, determining the perceived exertion of the three conditions would have been beneficial. Additionally, the amount of pressure that was put into the roller may have differed between subjects. Since they were instructed to put as much bodyweight into the roller as they could tolerate, differences in pain threshold and bodyweight may have caused different pressures to be applied to the muscle. Finally, only four specific performance measures were taken and the effects of foam rolling duration on strength and endurance performance are still not fully understood. Despite these limitations, our results do indicate that foam rolling duration may be an important factor to consider when designing a warm-up and that extensive foam rolling can diminish subsequent power performance. This factor may be an important consideration for athletes, as well as, strength and conditioning coaches.

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PRACTICAL IMPLICATIONS

In conclusion, it appears as though long duration foam rolling (5 min) causes a decrease in subsequent VJ performance and should be avoided before a competition or high-level exercise. Foam rolling for a long duration may increase ROM more than shorter duration foam rolling, but if explosive power is the main concern, the athlete might be better off avoiding prolonged foam rolling before competition. Since short duration foam rolling (1 min) did not decrease VJ performance while still increasing ROM, it appears acceptable to use FR before most types of events if duration is 1 min or less per limb. Short duration foam rolling is also more time efficient and can be recommended when foam rolling is warranted for athletes, and casual exercisers, during a warmup due to the increase in ROM without decrease in subsequent power performance.

REFERENCES

Arabaci, R. (2008). Acute effects of pre-event lower limb massage on explosive and high speed motor capacities and flexibility. *Journal of Sport Science and Medicine*, *7*(4), 549–555.

Arroyo-Morales, M., Fernandez-Lao, C., Ariza-Garcia, A., Toro-Velasco, C., Winters, M., & Diaz-Rodriguez, L. (2011). Psychophysiological effects of preperformance massage before isokinetic exercise. *Journal of Strength & Conditioning Research*, *25*(2), 481–488.

Arroyo-Morales, M., Olea, N., Martínez, M. M., Hidalgo-Lozano, A., Ruiz-Rodríguez, C., & Díaz-Rodríguez, L. (2008). Psychophysiological effects of massage-myofascial release after exercise: A randomized sham-control study. *Journal of Alternative and Complementary Medicine*, *14*(10), 1223–1229.

Avela, J., Finni, T., Liikavainio, T., Niemelä, E., & Komi, P. V. (2004). Neural and mechanical responses of the triceps surae muscle group after 1 h of repeated fast passive stretches. *Journal of Applied Physiology*, *96*(6), 2325–2332.

Barnes, M. (1997). The basic science of myofascial release: Morphologic change in connective tissue. *Journal of Bodywork & Movement Therapies*, *1*(4), 231–238.

Bushell, J., Dawson, S., & Webster, M. (2015). Clinical relevance of foam rolling on hip extension angle in a functional lunge position. *Journal of Strength & Conditioning Research*, *29*(9), 2397–2403.

Butterfield, T. A., Zhao, Y., Agarwal, S., Haq, F., & Best, T. M. (2008). Cyclic compressive loading facilitates recovery after eccentric exercise. *Medicine and Science in Sports and Exercise*, *40*(7), 1289–1296.

Curran, P., Fiore, R. D., & Crisco, J. J. (2008). A comparison of the pressure exerted on soft tissue by 2 myofascial rollers. *Journal of Sport Rehabilitation*, *17*(4), 432–442.

Fletcher, I. (2010). The effects of precompetition massage on the kinematic parameters of 20-m sprint performance. *Journal of Strength & Conditioning Research*, *24*(5), 1179–1183.

Gajdosik, R. L., & Bohannon, R. W. (1987). Clinical measurement of range of motion review of goniometry emphasizing reliability and validity. *Physical Therapy*, *67*(12), 1867–1872.

Halperin, I., Aboodarda, S. J., Button, D. C., Andersen, L. L., & Behm, D. G. (2014). Roller massager improves range of motion of plantar flexor muscles without subsequent decreases in force parameters. *International Journal of Sports Physical Therapy*, *9*(1), 92–103.

Healey, K., Hatfield, D., Blanpied, P., Dorfman, L., & Riebe, D. (2014). The effects of myofascial release with foam rolling on performance. *Journal of Strength & Conditioning Research*, *28*(1), 61–68.

Hoch, M., Staton, G., & McKeon, P. (2011). Dorsiflexion range of motion significantly influences dynamic balance. *Journal of Science and Medicine in Sport*, *14*(1), 90–92.

Huang, S., Di Santo, M., Wadden, K., Cappa, D., Alkanani, T., & Behm, D. (2010). Short-duration massage at the hamstrings musculotendinous junction induces greater range of motion. *Journal of Strength & Conditioning Research*, *24*(7), 1917–1924.

MacDonald, G., Penney, M., Mullaley, M., Cuconato, A., Drake, C., Behm, D., & Button, D. (2013). An acute bout of self-myofascial release increases range of motion without a subsequent dcrease in muscle activation or force. *Journal of Strength & Conditioning Research*, *27*(3), 812-821.

Macdonald, G. Z., Button, D. C., Drinkwater, E. J., & Behm, D. G. (2014). Foam rolling as a recovery tool after an intense bout of physical activity. *Medicine and Science in Sports and Exercise*, *46*(1), 131–142.

Nuzzo, J., Anning, J., & Scharfenberg, J. (2011). The reliability of three devices used for measuring vertical jump height. *Journal of Strength & Conditioning Research*, *25*(9), 2580–2590.

Paolini, J. (2009). Review of myofascial release as an effective massage therapy technique. *Athletic Therapy Today*, *14*(5), 30–34.

Pearcey, G. E. P., Bradbury-Squires, D. J., Kawamoto, J. E., Drinkwater, E. J., Behm, D. G., & Button, D. C. (2015). Foam rolling for delayed-onset muscle soreness and recovery of dynamic performance measures. *Journal of Athletic Training*, *50*(1), 5–13.

Powden, C. J., Hoch, J. M., & Hoch, M. C. (2015). Reliability and minimal detectable change of the weight-bearing lunge test: A systematic review. *Manual Therapy*, *20*(4), 524–532.

Rossi, L. P., Pereira, R., Simão, R., Brandalize, M., & Gomes, A. R. S. (2010). Influence of static stretching duration on quadriceps force development and eletromyographic activity. *Human Movement*, *11*(2), 137–143.

Shrier, I., & McHugh, M. (2012). Does static stretching reduce maximal muscle performance? A review. *Clinical Journal of Sport Medicine*, *22*(5), 450–451.

Stewart, P. F., Turner, A. N., & Miller, S. C. (2014). Reliability, factorial validity, and interrelationships of five commonly used change of direction speed tests. *Scandinavian Journal of Medicine and Science in Sports*, *24*(3), 500–506.

Sullivan, K., Silvey, D., Button, D., & Behm, D. (2013). Roller-massager application to the hamstrings increases sit-and-reach range of motion within five to ten seconds without performance impairments. *International Journal of Sports Physical Therapy*, *8*(3), 228-236.

Waters-Banker, C., Dupont-Versteegden, E., Kitzman, P., & Butterfield, T. (2014). Investigating the mechanisms of massage efficacy: The role of mechanical immunomodulation. *Journal of Athletic Training*, *49*(2), 266–273.

Weerapong, P., Hume, P. a, & Kolt, G. S. (2005). The mechanisms of massage and effects on performance, muscle recovery and injury prevention. *Sports Medicine*, *35*(3), 235–256.

Wiktorsson-Moller, M., Oberg, B., Ekstrand, J., & Gillquist, J. (1983). Effects of warming up, massage, and stretching on range of motion and muscle strength in the lower extremity. *American Journal of Sports Medicine*, *11*(4), 249–252.

APPENDIX A

Medical History and Health Habit and 24 hour Recall Questionnaire

Name: ___________________________ **Date: _______________________**

Age: ________ **Weight:______________** **Height:___________**

Sex:_____

1. Medical/Health History:

Check if you ever had?

Heart disease/ Stroke	
Heart Murmur	
Skipped, rapid beats, or irregular heart rhythms	
High blood Pressure	
High Cholesterol	
Rheumatic Fever	
Lung Disease	
Diabetes	
Epilepsy	
Injuries to back, hips, knees, ankles, or feet	

Other conditions/comments:

Present Symptoms: Check within the box if you have you had these symptoms within the last 6 months?

Chest Pain	
Shortness of Breath	
Lightheadedness	
Heart Palpitations	
Loss of Consciousness	
Illness, surgery, or hospitalization	
Ankle/Leg swelling	
Joint/muscle injury requiring medical treatment	
Allergies (if yes please list under comments)	

Other conditions/comments:

List all medications presently taking:

2. Exercise habits:

Do you presently engage in physical activity? (circle one)

Yes **No**

What kind of exercise do you do? (circle one)

Cardiovascular **Strength Training** **Both**

How hard do you exercise? (circle one)

Easy **Moderate (can carry on conversation)** **Hard (can't carry on conversation)**

How many days a week do you work out?

How long each day do you work out?

On average, what is the total time you spend working out each week (list in minutes)

Did you ever have or you do you currently have discomfort, shortness of breath, or pain when exercising? (circle one)

Yes **No**

3. Have you consumed alcohol in the last 24 hours? (circle one)

Yes **No**

4. Have you used caffeine (e.g., coffee) or nicotine (e.g., cigarettes) in the last 3 hours? **(circle one)**

Yes **No**

5. Did you eat any food in the last 3 hours? (circle one)

Yes **No**

6. Did you exercise in the last 24 hours? (circle one)

Yes **No**

APPENDIX B

Informed Consent Form

The Effects of Foam Rolling Duration on Subsequent Power Performance

Purpose of the Study

The purpose of this study is to examine what effects, if any, foam rolling before exercise may have on performance.

Benefits of the Study

You will benefit by knowing your performance and physical fitness levels for the tests used in the study. You will also learn how to foam roll and how it effects your performance on these tests. Participating in this study will benefit the scientific community by adding to the literature on foam rolling and learning specifically how the duration of foam rolling may or may not affect performance. For the researcher, this is a thesis project which is a requirement for graduation. It will also give the student valuable research experience.

What You Will Be Asked to Do

You will be asked to visit the Ithaca College Exercise Physiology Lab four times with each visit lasting about one hour. The first day will be a familiarization day in which you will learn the pro-agility, vertical jump, modified kneeling lunge and sit-and reach tests as well as the foam rolling procedure. The following testing days you will be asked to arrive at the facility dressed in athletic/workout attire. You will perform a warmup and be tested on a vertical jump test, pro-agility test, modified kneeling lunge and sit and reach test. You will also be asked to foam roll or perform a plank for 5 minutes or less.

Participation in this study requires that you currently exercise at least three times per week for at least a total of 150 minutes. You must also be healthy and have no current injuries that cause pain with exercise or have had a serious injury within the last 6 months.

Risks

As with any exercise, there is always the potential for injury during physical activity. Due to the nature of the vertical jump and pro-agility test, there may be a chance of injury to the muscles, tendons or joints during testing. There is also a chance for cardiovascular complications when heart rate is elevated during testing. These risks exist but are not of high probability in young, healthy participants. We are minimizing risk by providing instruction on the exercises and evaluating your medical health history. If you are injured, standard first aid or CPR will be provided. If needed, emergency help will be summoned or you will be referred to the health center as appropriate.

Compensation for Injury

If you suffer an injury that requires any treatment or hospitalization as a direct result of this study, the cost for such care will be charged to you. If you have insurance, you may bill your insurance company. You will be responsible to pay all costs not covered by your insurance. Ithaca College will not pay for any care, lost wages, or provide other financial compensation.

If You Would Like More Information about the Study

If you would like more information or would like to know your foam rolling results, you may ask the researchers (Jake Phillips or Dr. Sforzo) before, during or after testing. You may also contact them via e-mail at jphillips2@ithaca.edu or sforzo@ithaca.edu

Withdraw from the Study

You are free to withdraw from the study for any reason with no penalty of any kind. If extra credit is being offered, you will be given credit for the portion of the study completed and there will be other ways to receive extra credit in the course if you choose not to participate.

How the Data will be Maintained in Confidence

All data collected during testing will be kept confidential and only the researchers will have access to personal information. Data may be used for presentation but your name will not be used and will be kept confidential. The data will be stored on a password protected computer and will be kept for a minimum of 5 years. Data sheets will also be stored in a locked cabinet in room CHS 312 and will only be accessed by the researchers. The names of the participants will not be used and the files will be number coded. The collection instruments will be kept separately from Informed Consent Forms, Health History Questionnaires or any other items that may contain personal information.

I have read the above and I understand its contents. I agree to participate in the study. I acknowledge that I am 18 years of age or older.

____

Print or Type Name

______________________________________ ______________________

Signature Date

APPENDIX C

Testing Instructions

Prior to each testing date, please adhere to these instructions to ensure accurate testing results:

1. Do not perform intense lower body exercise in the 48 hours before your test.

2. Do not drink alcohol in the 24 hours before your test.

3. Do not use caffeine (e.g. coffee) or nicotine (e.g. cigarettes) within 4 hours before your test.

4. Do not eat in the 3 hours before the test.

5. Do not eat any food that may cause you discomfort the day of the test.

6. Avoid over-the-counter medications for the 12 hours preceding the test. (However, cancel appointment if you are ill and treat yourself accordingly; we can always reschedule).

7. Wear comfortable athletic clothing (shorts, t-shirt, running shoes).

8. Be sure to wear the same footwear to each of the three testing sessions.

Thank you for your cooperation.

APPENDIX D

ANOVA TABLES

Table.

Vertical Jump 3 x 2 Repeated Measures ANOVA Summary Table

	SS	DF	MS	F	P
Condition	1.61	2	0.80	0.76	0.48
Error	48.89	46	1.06		
Pre-Po	0.01	1	9.25	69.99	0.00
Error	3.04	23	0.13		
Condition * Pre-Post	4.69	2	2.35	10.64	0.00
Error	10.14	46	0.22		

Table.

Pro Agility 3 x 2 Repeated Measures ANOVA Summary Table

	SS	DF	MS	F	P
Condition	0.12	2	0.06	2.40	0.10
Error	1.10	46	0.02		
Pre-Post	0.01	1	0.01	1.24	0.28
Error	0.09	23	0.00		
Condition * Pre-Post	0.10	2	0.05	5.04	0.01
Error	0.44	46	0.01		

Table.

Weight Bearing Lunge 3 x 2 Repeated Measures ANOVA Summary Table

	SS	DF	MS	F	P
Condition	0.77	2	0.38	0.53	0.59
Error	33.27	46	0.72		
Pre-Post	3.93	1	3.93	23.56	0.00
Error	3.84	23	0.17		
Condition * Pre-Post	2.08	2	1.04	4.64	0.02
Error	10.32	46	0.22		

Table.

Modified Kneeling Lunge 3 x 2 Repeated Measures ANOVA Summary Table

	SS	DF	MS	F	P
Condition	802.17	2	401.03	4.59	0.15
Error	4019.83	46	87.39		
Pre-Post	910.01	1	910.01	98.28	0.00
Error	212.97	23	9.26		
Condition * Pre-Post	655.22	2	332.11	47.48	0.00
Error	321.78	46	7.00		

Table.

Vertical Jump Pre-Condition One-way ANOVA

	SS	DF	MS	F	P
Condition	0.53	2	0.26	0.40	0.67
Error	30.47	46	0.66		

Table.

Vertical Jump Post-Condition One-way ANOVA

	SS	DF	MS	F	P
Condition	5.77	2	2.89	4.65	0.02
Error	28.56	46	0.62		

Table.

Pro-Agility Pre-Condition One-way ANOVA

	SS	DF	MS	F	P
Condition	0.07	2	0.04	2.46	0.10
Error	0.68	46	0.02		

Table.

Pro-Agility Post-Condition One-way ANOVA

	SS	DF	MS	F	P
Condition	0.14	2	0.07	3.70	0.03
Error	0.87	46	0.02		

Table.

Weight Bearing Lunge Pre-Condition One-way ANOVA

	SS	DF	MS	F	P
Condition	0.68	2	0.34	0.53	0.59
Error	28.83	46	0.63		

Table.

Weight Bearing Lunge Post-Condition One-way ANOVA

	SS	DF	MS	F	P
Condition	2.17	2	1.09	3.39	0.04
Error	28.83	46	0.63		

Table.

Modified Kneeling Lunge Pre-Condition One-way ANOVA

	SS	DF	MS	F	P
Condition	3.86	2	1.93	0.04	0.96
Error	2348.14	46	51.05		

Table.

Modified Kneeling Lunge Post-Condition One-way ANOVA

	SS	DF	MS	F	P
Condition	1462.53	2	731.26	16.87	0.00
Error	1993.47	46	43.34		

Table.

Vertical Jump

	Pre-condition	Post Condition
Control	19.60 ± 3.9	19.23 ± 3.8*
1-min FR	19.48 ± 4.2	19.33 ± 4.2
5-min FR	19.69 ± 3.9	18.69 ± 3.8*

Note. Values are mean ± SD, * Represents significant difference pre-condition to post-condition ($p < .05$)

Table.

Pro-Agility

	Pre-condition	Post Condition
Control	5.410 ± .46	5.472 ± .46*
1-min FR	5.459 ± .44	5.401 ± .39*
5-min FR	5.481 ± .43	5.507 ± .46

Note. Values are mean ± SD, * Represents significant difference pre-condition to post-condition ($p < .05$)

Table.

Weight Bearing Lunge

	Pre-condition	Post Condition
Control	37.58 ± 3.9	37.64 ± 4.1
1-min FR	37.64 ± 4.1	37.93 ± 4.2*
5-min FR	37.41 ± 4.2	38.06 ± 4.2*

Note. Values are mean ± SD, * Represents significant difference pre-condition to post-condition ($p < .05$)

Table.

Modified Kneeling Lunge

	Pre-condition	Post Condition
Control	55.0 ± 13.6	54.1 ± 13.6*
1-min FR	55.5 ± 11.7	62.5 ± 12.0*
5-min FR	55.4 ± 10.1	64.5 ± 11.1*

Note. Values are mean ± SD, * Represents significant difference pre-condition to post-condition ($p < .05$)

APPENDIX E

RAW DATA

Plank Control Pre-Test

Subject	VJ	PA	WBL	MKL initial	MKL Final	MKL Change
1	14	5.411	39	110	65	45
2	25	4.912	39.5	101	65	36
3	17.5	5.477	38	102	60	42
4	18	5.213	34.5	112	40	72
5	14	6.623	37	115	49	66
6	20.5	5.478	38.5	116	72	44
7	22.5	5.743	46	98	62	36
8	22	5.237	35	101	45	56
9	17.5	5.766	41.5	106	52	54
10	18.5	5.42	31	101	34	67
11	19	5.011	34.5	111	40	71
12	18	5.051	35	105	78	27
13	22	5.072	42	113	46	67
14	17.5	6.253	36.5	128	55	73
15	28.5	4.891	41	105	65	40
16	13.5	6.267	38	112	48	64
17	22.5	5.073	46	114	45	69
18	24.5	4.92	35	100	52	48
19	24.5	5.315	30.5	107	47	60
20	24	5.032	38	106	65	41
21	15.5	5.292	32.5	114	45	69
22	17	5.356	37.5	109	48	61
23	17	5.25	37.5	105	55	50
24	17.5	5.664	38	110	48	62

Plank Control Post-Test

Subject	VJ	PA	WBL	MKL initial	MKL Final	MKL Change
1	13.5	5.665	39.5	108	61	47
2	25	5.064	39.5	104	69	35
3	17	5.612	37.5	103	60	43
4	18	5.283	35	112	41	71
5	14.5	6.691	37	115	47	68
6	20	5.487	39	116	76	40
7	21.5	5.578	47	98	64	34
8	22	5.452	35.5	100	45	55
9	18	5.683	42.5	107	54	53
10	19	5.387	30.5	101	35	66
11	18.5	5.181	34.5	110	41	69
12	17.5	5.065	34.5	108	83	25
13	21	5.411	42.5	112	48	64
14	16.5	6.335	36.5	128	60	68
15	27.5	4.815	40.5	105	64	41
16	13.5	6.271	37.5	112	50	62
17	23	5.123	46	115	44	71
18	24	4.915	35	100	53	47
19	24	5.323	30.5	107	51	56
20	23	5.049	38	106	65	41
21	15	5.15	33	114	45	69
22	16.5	5.413	37	109	45	64
23	16	5.473	37.5	105	56	49
24	17	5.903	37.5	110	50	60

1-min FR Pre-Test

Subject	VJ	PA	WBL	MKL initial	MKL Final	MKL Change
1	15	5.782	39.5	98	51	47
2	27	4.89	40	98	48	50
3	17.5	5.544	36	95	70	25
4	20.5	5.456	34.5	107	56	51
5	13.5	6.596	36.5	112	40	72
6	20	5.553	38	118	57	61
7	22.5	5.618	47.5	95	55	40
8	22.5	5.327	35.5	107	37	70
9	18	5.641	43	105	60	45
10	17	5.524	30.5	105	50	55
11	18.5	5.07	35.5	111	42	69
12	19	5.051	34	110	73	37
13	21.5	5.157	43	109	39	70
14	14	6.053	37.5	112	54	58
15	28	4.987	39.5	103	53	50
16	13.5	6.34	38	110	65	45
17	23	5.134	45.5	114	48	66
18	24	5.057	35.5	100	45	55
19	24	5.326	30.5	106	44	62
20	23	4.856	38	110	52	58
21	14.5	5.326	33	110	49	61
22	15.5	5.478	37	109	43	66
23	17.5	5.323	38	110	48	62
24	18	5.922	37.5	110	52	58

1-min FR Post-Test

Subject	VJ	PA	WBL	MKL initial	MKL Final	MKL Change
1	14.5	5.641	40	103	47	56
2	26.5	4.832	40	98	42	56
3	17.5	5.511	38	98	69	29
4	19.5	5.37	34	106	42	64
5	13.5	6.389	37.5	113	31	82
6	19	5.52	37.5	118	60	58
7	23	5.737	47.5	98	43	55
8	22.5	5.385	35.5	109	28	81
9	16	5.71	44.5	106	50	56
10	18	5.581	31.5	105	40	65
11	18.5	5.044	35.5	112	33	79
12	19	4.996	34	111	68	43
13	23	5.113	43.3	109	32	77
14	14	5.594	37.5	112	47	65
15	27	4.914	40	105	54	51
16	13.5	6.161	38	111	54	57
17	23	5.096	46	114	42	72
18	24.5	5.062	35.5	100	42	58
19	23.5	5.501	31.5	106	41	65
20	23.5	4.833	38	110	48	62
21	14.5	5.23	33	110	43	67
22	15.5	5.424	37	109	40	69
23	17	5.272	37.5	110	45	65
24	17.5	5.706	37.5	110	43	67

5-min FR Pre-Test

Subject	VJ	PA	WBL	MKL initial	MKL Final	MKL Change
1	14.5	5.775	39.5	99	44	55
2	25	5.128	39	100	55	45
3	18	5.828	37	107	58	49
4	19.5	5.285	36	123	56	67
5	14.5	6.728	37	115	45	70
6	19	5.977	37	104	62	42
7	23	5.658	48.5	103	54	49
8	23	5.437	35	103	45	58
9	16	5.615	43	105	55	50
10	18	5.389	30.5	100	56	44
11	20	5.289	35	103	35	68
12	20	5.007	33.5	100	66	34
13	23	5.243	42.5	112	37	75
14	16.5	5.728	34.5	125	60	65
15	28	4.899	38.5	111	60	51
16	14	6.161	37.5	115	55	60
17	23	5.194	46	115	55	60
18	25	5.077	35.5	101	56	45
19	23	5.444	32	109	51	58
20	23	4.883	38	103	57	46
21	15.5	5.287	33.5	116	53	63
22	17.5	5.386	37.5	107	46	61
23	15.5	5.313	35	105	44	61
24	18	5.807	36.5	110	56	54

5-min FR Post-Test

Subject	VJ	PA	WBL	MKL initial	MKL Final	MKL Change
1	13	5.768	39.5	101	39	62
2	24.5	5.047	39.5	99	39	60
3	17	5.691	38	116	50	66
4	18	5.198	36.5	123	48	75
5	14.5	6.714	37.5	116	28	88
6	18.5	5.961	37.5	113	63	50
7	21.5	5.986	49	103	48	55
8	21.5	5.443	36	104	36	68
9	15	5.821	44	105	49	56
10	16	5.232	31	100	35	65
11	18.5	5.247	35	105	26	79
12	18.5	4.956	34.5	104	62	42
13	22	5.245	42.5	112	35	77
14	16.5	5.844	38	128	50	78
15	26.5	5.034	39	111	55	56
16	13	6.279	38	115	51	64
17	22	5.335	47	115	42	73
18	24.5	5.01	36	101	51	50
19	21.5	5.368	31.5	109	43	66
20	21.5	4.914	38	103	54	49
21	14.5	5.377	33.5	116	44	72
22	16.5	5.41	37.5	107	36	71
23	16	5.293	36.5	105	40	65
24	17.5	5.984	38	110	49	61