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THE EFFECTS OF A SINGLE BOUT OF SELF-MYOFASCIAL RELEASE ON FLEXIBILITY AND MAXIMUM VOLUNTARY CONTRACTION

By

Jonathan Robert Garcia

Bachelor of Science

Arizona State University

2009

A thesis submitted in partial fulfillment

of the requirements for the

Master of Science – Exercise Physiology

Department of Kinesiology and Nutrition Sciences

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University of Nevada, Las Vegas
May 2014

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THE GRADUATE COLLEGE

We recommend the thesis prepared under our supervision by

Jonathan Robert Garcia

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May 2014

ABSTRACT

The Effects of a Single bout of Self-Myofascial Release on Range of Motion and Maximum Voluntary Contraction

by

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Purpose: The purpose of this study was to determine the effect of foam rolling on hamstrings flexibility, isometric and isokinetic torque.

Participants: Thirteen female participants (N = 13; age: 28.5 ± 6.8 years of age; height: 165.5 ± 6.7 cm; mass: 64.2 ± 8.4 kg) volunteered to participate in the study.

Methods: Hamstring flexibility was assessed using a sit and reach test; muscle strength was assessed by having participants complete a maximal voluntary isometric contraction (MVIC) of the hamstrings and maximal effort isokinetic knee flexion test using an isokinetic dynamometer. Participants completed these tests prior to any intervention (pre-rolling 1), after sitting quietly for 3 minutes (pre-rolling 2), and after completing a bout of foam rolling (post-rolling). Foam rolling was performed for two one-minute sets, with one minute rest in between. Each dependent variable (flexibility, MVIC, peak isokinetic torque) was assessed using a repeated measures analysis of variance with Time (i.e., pre-rolling 1, pre-rolling 2, post-rolling) as the independent variable. A Bonferroni post-hoc was used when there was a significant omnibus F-ratio.

Results: Flexibility was different across tests ($p<0.05$) with flexibility during post being greater than pre-rolling 2 ($p<0.05$). Average isometric torque was not influenced by Time ($p = 0.356$). Peak isokinetic torque was not influenced by Time ($p = 0.958$).

Conclusions and Recommendations: Hamstring flexibility was greater following a single bout of foam rolling without negatively influencing isometric or isokinetic maximum voluntary contraction.

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CHAPTER 1

INTRODUCTION

Health/fitness professionals and athletes alike are looking to massage and myofascial release to improve performance and relieve pain (Clark and Lucett 2007; Barnes 2005; Barnes 1995; Phillips). Myofascial release is a form of massage used as a therapeutic and performance enhancing technique (Clark and Lucett 2007; Barnes 2005; Barnes 1995; Phillips). Self-myofascial release is self-administered myofascial release (Clark and Lucett 2007). When this technique is applied it typically requires varying amounts of sustained pressure on the soft tissue (Clark and Lucett 2007; Barnes 2005; Barnes 1995). Myofascial release techniques can be applied by practitioners and also be self-administered, with varying types of rollers (Clark and Lucett 2007; Barnes 1995; Phillips). Anecdotally, massage and myofascial release can relax muscles, break up adhesions, and improve flexibility, circulation and recovery (Clark and Lucett 2007; Barnes 2005; Barnes 1995; Phillips).

A prominent proponent of foam rolling, a form of self-myofascial release, is the National Academy of Sports Medicine (NASM) (Clark and Lucett 2007). The NASM uses self-myofascial release as an “inhibitory technique” for corrective exercise (Clark and Lucett 2007). The NASM uses the term corrective exercise to encompass its strategy for improving posture and muscle function (Clark and Lucett 2007). The NASM claims that self-myofascial release can alleviate active, or latent, trigger points and influence the autonomic nervous system (Clark and

Lucett 2007). The NASM recommends using self-myofascial release on "overactive" muscles, before static stretching, in order to facilitate improvements in resting muscle function of opposing muscle groups (Clark and Lucett 2007).

Self-myofascial release can be performed using foam rollers, sometimes called myofascial rollers, and massage rollers (Curran, Fiore, & Crisco 2008; Healey, Hatfield, Blanpied, Dorfman, Riebe 2013; MacDonald, Penney, Mullaley, Cuconato, Drake, Behm, & Button 2013; Sullivan, Silvey, Button, & Behm 2013). Foam rollers have grown in popularity and are now widely available in health/fitness centers, physical therapy clinics, and though commercial retailers. Foam rollers themselves are cylinder shaped and vary greatly in size, texture, density, and composition. Many people use them because they claim they perceive an improvement in pain and athletic performance. Anecdotally, foam rolling is sometimes considered a more comfortable alternative to static stretching. In some areas of the health/fitness field, massage and myofascial release are being considered alternatives, or supplemental, to static stretching for improving flexibility (Clark and Lucett 2007; Barnes 1995; Phillips).

Static stretching is currently the most recommended and supported exercise for improving flexibility. Static stretching is effectively being used in all forms of athletic activity to improve range of motion (ROM), flexibility, and prevent injury (Amiri-Khorasani, Abu Osman, & Yusof 2011; Godges, MacRae, Longdon, Tinberg, & MacRae 1989; Murphy, Nagle, Robertson, & McCrory 2010; Özengin, Yildirim, Baltaci, Masiulis 2011; Rubini, Souza, Mello, Bacurau, Cabral, & Farinatti 2011; Young, Clothier, Otago, Bruce, & Liddell 2004). Although static

stretching has long been the conventional method of improving flexibility, there is still an ongoing search for alternative methods. Recent research has demonstrated that static stretching can have an adverse effect on force production (Gurjao, Goncalves, De Moura, & Gobbi 2009). In certain instances this would negate the possibility of performing with maximum flexibility and maximum force production simultaneously after static stretching. Anecdotally, many people would also rather receive myofascial release or perform self-myofascial release, than static stretch to improve flexibility. Lay resources often refer to myofascial release as equivalent to static stretching for improving flexibility (Barnes 2005; Barnes 1995; Phillips).

The limitations of static stretching have spurred additional interest into massage and myofascial release as a comparable addition to a training program. Since therapist mediated massage and myofascial release are not a viable option for many people, then a large portion of the exercising community has resorted to self-myofascial release. The focus of this study will be on foam rollers.

Thus far the research is limited supporting the effects of myofascial release on improving muscular performance (Healey et al., 2013; MacDonald et al., 2013; Sullivan et al., 2013). Research on the use of foam rolling, specifically, as a means of self-myofascial release is particularly limited and yet foam rollers continue to rise in popularity. Some research exists supporting self-myofascial release to improve flexibility (MacDonald et al., 2013; Sullivan et al., 2013). Although the NASM uses self-myofascial release to inhibit muscle force, some research is demonstrating no significant effect of self-myofascial release on force

production (Clark and Lucett 2007; Healey et al., 2013; MacDonald et al., 2013; Sullivan et al., 2013).

Therefore, the purpose of this study will be to determine the acute effects of foam rolling on flexibility and torque production. The hamstrings group was chosen as the point of application of foam rolling due to the importance of the hamstrings group in performing athletic and daily activities. Although there is research observing the effects of self-myofascial release on the hamstrings, more research is needed (Sullivan et al., 2013). If hamstring flexibility and torque production are measured before and after a bout of foam rolling, then a conclusion can be drawn about the acute effect of foam rolling on muscle function.

Purpose of the Study

The purpose of this study is to determine the acute effects of a single bout of self-myofascial release on flexibility and torque.

Research Questions

Question #1

Will a single bout of self-myofascial release affect flexibility at the hamstrings?

Question #2

Will a single bout of self-myofascial release affect isometric or isokinetic torque of the knee flexors?

Significance of the Study

Pending the results of this study, health and fitness professionals will be able to provide an evidence based rationale for using, or not using, foam rollers. Also, such professionals would have more insight into the protocol for incorporating foam rolling into a training or rehabilitation program. The analysis of data has the potential to show that foam rolling before a training session may inhibit MVC, providing evidence to support the NASM's stance on foam rolling for corrective exercise. Contrarily, a lack of effect on MVC from foam rolling may show that the activity may be performed without an effect to muscle performance. Additionally, the effects of foam rolling may demonstrate a potential alternative to static stretching alone to improve flexibility. As a result, a different approach to improving flexibility can provide variety to the common practice of multiple static stretching sessions or the possibility of further increasing range of motion where static stretching was insufficient.

Definition of Terms

The following definitions are given for the purpose of clarification:

Self-myofascial release (SMR) – a form of self-massage with a tool such as a foam roller or massage roller.

Foam Rolling – self-myofascial release using a foam roller

Foam Roller – foam cylinder used for self myofascial release

Massage Roller – handheld roller for self-myofascial release

Myofascial Roller – synonym for foam roller

Myofascial Compression – synonym for self-myofascial release

MVC – maximum voluntary contraction

ROM – range of motion

CHAPTER 2

REVIEW OF RELATED LITERATURE

Self-Myofascial Release

Foam rolling, or self-myofascial release (SMR), is a relatively new approach to improving muscular performance, so the research and interest in this area is relatively new as well. Until recently, most information about this topic has been anecdotal and not evidence-based. As the practice of foam rolling grows in popularity in recreational, athletic, and clinical settings, more research in the area is surfacing. Currently, very few studies have been published that observe the effects of SMR on muscular performance, more specifically in the form of foam rolling. It is still unclear what effects any form of myofascial release (MR), including foam rolling, has on muscle performance. Existing studies have observed the effects of various forms of MR, but the results are as inconsistent as the measures tested. This review will include literature related to MR and massage as they relate to improving muscular performance for activities of daily living and sport.

Foam Rollers

A recent study was able to determine that foam rollers exert pressure on soft tissue proportionate to the foam roller density (Curran et al., 2008). Although many commercial foam rollers have similar dimensions, the material they consist of varies. Some are composed of more compressible foams and others are composed of firmer foams or solid materials, such as polyvinyl chloride (PVC)

piping. Curran et al. (2008) tested the pressure applied to subjects via a bio-foam roller and multilevel rigid roller (Curran et al., 2008). The multilevel rigid foam roller applied pressure over a smaller surface area, since its shape was retained during foam rolling (Curran et al., 2008). Contrarily, the softer more compressible bio-foam roller deformed when used, and force was distributed over a larger surface area (Curran et al., 2008). As a result, Curran et al. (2008) observed that pressure exerted on the soft tissue increased with the density of the roller. Interestingly, Curran et al. (2008) reported no correlation between subjects' body weight and the amount of pressure placed over either roller. Curran et al. (2008) concluded that this was due to differences in rolling technique. Although each subject was given identical instructions for performing SMR with the rollers, the actual amount of weight placed over the rollers was controlled by the individual. The reason for the lack of correlation between body weight and pressure exerted on the roller can be explained by subjects' pain threshold. Subjects may have elected not to apply additional pressure to the roller, via the lateral thigh, because of discomfort. This possibility is justified by the fact that a heavier subject has the potential to apply more pressure over a roller, but chooses to support more body weight over body parts not contacting the roller. If the amount of weight placed over the roller can be strongly manipulated by the subject, then relative weight placed over the roller may have the potential to influence pressure on soft tissue, separate from roller density. This is an important point to take into account when foam rolling different muscle groups. This would imply that a person using a dense foam roller may or may not be able to adjust the pressure over a roller, to

influence the effect on muscle performance. Furthermore, the surface area of the multilevel rigid roller in contact with subjects' thigh was less than that of the bio-foam roller, indicating sustained integrity of the multilevel rigid roller (Curran et al., 2008). This lack of deformation of the multilevel rigid roller indicates the potential to apply additional pressure to soft tissue. Although this study only tested the pressures applied by two very different rollers, other roller densities and designs must be tested to determine the amount of pressure they apply to soft tissue. Likewise, varying designs of rollers and the claims in support of their use must be tested for efficacy.

MacDonald et al. (2013) tested the acute effects of SMR on range of motion (ROM), muscle activation, tetanic force, twitch force, maximum voluntary contraction (MVC) and rate of force development (MacDonald et al., 2013). MacDonald et al. (2013) accomplished this using a foam roller very similar to the multilevel rigid roller used by Curran et al. (2008). The rollers used in both studies were composed of a hollow PVC pipe covered in a thin layer of neoprene foam (Curran et al., 2008; MacDonald et al., 2013). The neoprene covering the rollers used by Curran et al. (2008) and MacDonald et al. (2013) were measured at 0.32 cm and 1.0 cm of thickness, respectively (Curran et al., 2008; MacDonald et al., 2013). The subjects who participated were eleven healthy, physically active, males (MacDonald et al., 2013). With respect to testing ROM and MVC, subjects performed the control and foam roller condition for each measure on four separate days, which were scheduled 24-48 hours apart (MacDonald et al., 2013). MacDonald et al. (2013) tested subjects' right knee extensors for each

condition. During the control conditions subjects sat and rested for 2 minutes, whereas subjects foam rolled the quadriceps for the SMR conditions (MacDonald et al., 2013). During the SMR conditions, subjects rolled their quadriceps for two one-minute bouts, with one minute rest between bouts (MacDonald et al., 2013). Subjects were tested and measured immediately before, then two and ten minutes after, their respective conditions (MacDonald et al., 2013). Analysis of the data revealed a significant increase ($p<0.001$) in ROM at two and ten minutes after SMR, without a decrease in force production at the knee extensors (MacDonald et al., 2013). Subjects did not demonstrate significant improvements in ROM after completing the control condition (MacDonald et al., 2013). The practical application of these results imply that foam rolling can be used as a means of improving ROM while maintaining force production at the quadriceps (MacDonald et al., 2013). These components of muscular performance are an important combination in everyday living as well as in sport.

In another foam rolling study, researchers observed the effects of SMR, in the form of foam rolling, on vertical jump height and power, isometric force and a pro agility test (Healey et al., 2013). Muscle soreness, fatigue and perceived exertion were also measured (Healey et al., 2013). Healey et al. (2013) used a foam roller similar to those used by Curran et al. (2008) and MacDonald et al. (2013), in that the rollers were composed of a PVC pipe surrounded by a thin layer of compressive material. This study is unique from the prior two SMR studies because of the various muscle groups that were foam rolled and the comprehensiveness of testing. 13 female and 13 male, healthy, college-aged

subjects were recruited for this foam rolling, randomized crossover study (Healey et al., 2013). Measurements were completed over two experimental testing days, in which half the subjects began with foam rolling for the first day and the other half began with a planking exercise (Healey et al., 2013). During a single day of familiarization, subjects were instructed on foam rolling technique for their quadriceps, hamstrings, calves, latissimus dorsi, and rhomboids (Healey et al., 2013).

On the first day of experimentation, subjects were asked to foam roll the assigned muscle groups for one 30-second bout each, for the SMR condition (Healey et al., 2013). In the control condition, subjects were asked to hold planking positions, similar to each of the foam rolling positions, for one 30-second set per position (Healey et al., 2013). Isometric tests for each condition were in the form of an isometric squat, standing over force plates with the knees flexed between 100-135 degrees (Healey et al., 2013). Each subjects' knee angle was measure using a goniometer and duplicated for both conditions (Healey et al., 2013). Subjects pressed themselves between a stationary bar placed over their shoulders and force plates at their feet, for a single ten-second bout (Healey et al., 2013). Researchers measured jump height with a Vertec (Perform Better, Cranston, RI) (Healey et al., 2013). Subjects performed a countermovement before jumping and reaching to the highest vanes on the Vertec (Healey et al., 2013). Subjects were not allowed to take a preparatory, or stutter, step before jumping (Healey et al., 2013). Jump height was calculated as the greatest difference between standing reach height and maximal jump height

reached, of three attempts (Healey et al., 2013). Subjects were given a three minute rest period between jumps (Healey et al., 2013). As for jump power, subjects were instructed to stand over force plates and perform three quick, consecutive jumps with their hands on their hips (Healey et al., 2013). These three jumps were considered a single set and subjects performed three sets with three minutes rest between sets (Healey et al., 2013). Researchers recorded the highest power among the three sets (Healey et al., 2013). Agility was scored as the lowest time to complete the 5-10-5 yard shuttle run, between two attempts (Healey et al., 2013). Subjects started at a center line until prompted, then sprinted five yards to their left, ten yards to the right, then five yards back to the center (Healey et al., 2013). Subjects were required to touch cones at each end before changing directions (Healey et al., 2013). A five minute rest was given between the two attempts (Healey et al., 2013).

Analysis of the study by Healey et al. (2013) revealed no significant differences for isometric force, vertical jump height, jump power, or agility between foam rolling and planking conditions (Healey et al., 2013). There was, however, a significant difference in all performance variables between men and women who participated (Healey et al., 2013). The only significant differences observed between pre- and post-measures for both control and SMR conditions were the ratings for fatigue, soreness, and exertion (Healey et al., 2013). These findings indicate that a single 30-second bout of foam rolling may not affect performance for agility, power, or isometric strength (Healey et al., 2013). Furthermore, both 30-seconds of foam rolling and planking on each of the

muscles tested will have similar effects on fatigue, soreness, and exertion (Healey et al., 2013).

Massage Rollers

In the latest study on MR, researchers tested the effects of a massage roller on the flexibility and performance of the hamstrings group (Sullivan et al., 2013). The study consisted of 17 subjects, seven men and ten women, who were recruited to participate in the study (Sullivan et al., 2013). Nine of the subjects, three men and six women, were assigned to the control group as well (Sullivan et al., 2013). Each subject was injury-free within the last year, and participated in recreational activity at least three days per week (Sullivan et al., 2013). The study was arranged into a pre/post-test design in which subjects performed measurements for four interventions over two days (Sullivan et al., 2013). A third day of testing was required for participants also assigned to the control group (Sullivan et al., 2013).

The interventions included 1 5-second set, 1 10-second set, 2 5-second sets, and 2 10-second sets of MR with massage rolling (Sullivan et al., 2013). Within each intervention testing day, sessions were divided into two sessions and consisted of two interventions chosen at random (Sullivan et al., 2013). During each session one of the two interventions were applied to each leg, and then switched for the next session (Sullivan et al., 2013). Subjects were required to rest 30 minutes between testing sessions on the same day (Sullivan et al., 2013). Researchers required time between the testing sessions to minimize neural

interference between sides (Sullivan et al., 2013). The remaining two interventions were applied on the second testing day (Sullivan et al., 2013).

MR was applied to the hamstrings group by a custom made rolling device (Sullivan et al., 2013). The unique device consisted of a hand-held massage roller secured to railing that ran parallel to the subjects' legs (Sullivan et al., 2013). The roller was aligned perpendicular to the upper thigh and was pressed onto subjects with a constant 13 kg, applied by weights (Sullivan et al., 2013). For each five- or ten-second set of MR, a 120 bpm rate was used to control for the number of cycles of the intervention (Sullivan et al., 2013). This rate allowed for a single cycle of MR, passing from the distal to proximal hamstring and back, each second (Sullivan et al., 2013). The rate of rolling was controlled using a metronome (Sullivan et al., 2013).

As for the pre- and post-test measures, Sullivan et al. (2013) tested flexibility, MVC of knee flexion, electromyography (EMG), and evoked contractile force. The test for MVC was in the form of an isometric knee flexion for two four-second sets, with one minute rest between sets (Sullivan et al., 2013). Subjects were instructed to lie prone on a padded table with a strain gauge secured to the ankle (Sullivan et al., 2013). The strain gauge was mounted on the ground below the table (Sullivan et al., 2013). The upper leg was secured to the table to prevent non-tested muscle groups from contributing to the readings (Sullivan et al., 2013). The maximum reading between the two sets for the MVC was recorded (Sullivan et al., 2013). Since the muscles being treated with the MR intervention were the hamstrings group, the test chosen for assessing flexibility

was the sit and reach test (Sullivan et al., 2013). Subjects were instructed to sit with the test leg extended and the opposing leg flexed, with that foot by the test knee (Sullivan et al., 2013). Subjects were given two attempts for pre-and post-test measures, respectively (Sullivan et al., 2013). The highest score for pre- and post-test was recorded (Sullivan et al., 2013). Subjects performed each test before and after their respective conditions (Sullivan et al., 2013).

Statistical analysis revealed no significant differences between male and female subjects for any of the test measures (Sullivan et al., 2013). There was a significant main effect ($p < 0.001$) between pre- and post-test measures and duration of massage rolling (Sullivan et al., 2013). Sullivan et al. (2013) noted a trend toward greater improvement of flexibility after ten seconds of massage rolling than five seconds, for one and two sets of application ($p = 0.069$). All subjects' hamstring flexibility improved after the application of massage rolling, regardless of the duration or number of sets (Sullivan et al., 2013). Subjects assigned to the control group did not see improvements in flexibility ($p = 0.68$) after the control condition (Sullivan et al., 2013). Pre- and post-MVC did not demonstrate a statistically significant difference in hamstring force ($p = 0.64$) (Sullivan et al., 2013). EMG, which was measured simultaneously with MVC tests, also showed no significant difference ($p = 0.71$) after massage rolling of any duration or number of sets (Sullivan et al., 2013). Evoked contractile force tests yielded a main effect ($p = 0.016$) between the number of sets applied, where one set decreased force over the decrease in force from two sets (Sullivan et al., 2013). There was also a main effect ($p = 0.001$) for time and ROM,

between pre- and post-tests (Sullivan et al., 2013). The number of sets of rolling and duration exhibited a significant interaction ($p = 0.044$) in evoked twitch force (Sullivan et al., 2013). There was a decrease in twitch for a single 10-second set of rolling compared to a single 5-second set of rolling (Sullivan et al., 2013). Two 10-second sets of rolling appeared to increase evoked twitch force versus two 5-second sets of rolling (Sullivan et al., 2013). These results suggest that 1 or 2 5-10 second sets of SMR with 13 kg of pressure can significantly improve flexibility without a significant change in muscular performance (Sullivan et al., 2013).

Limitations in Research

Research in the area of MR and SMR is amounting and beginning to provide evidence to demonstrate the effects of treatment on muscle performance. The organization of testing muscle performance after MR and SMR must combine practicality with control. The more control there is during each testing session, the more limits there are on the variables tested. Conversely, the more practical the assessment, the more confounding variables can conflict with the results. Since this area of research is in its infancy, then future studies will need to validate the current findings and fill in gaps in the research. The current thesis will attempt address some of the gaps observed in the research listed in this chapter.

Since there are very few studies available observing the effects of MR and SMR on muscle performance, it follows that the muscle groups tested are also very few. Albeit Healey et al. (2013) did apply SMR to multiple muscle groups. As mentioned above Curran et al. (2008), Healey et al. (2013) and MacDonald et al.

(2013) have observed the effects of foam rolling on pressure, flexibility and performance of the knee extensors, or the quadriceps group. Sullivan et al. (2013) focused the SMR and testing on the knee flexors; hamstrings group. Although SMR by foam rolling may be have similar effects for varying muscle groups, these effects must be quantified.

The study by MacDonald et al. (2013) observed the effects of SMR on both ROM and force production, but the application of these findings is specific to the testing on separate days (MacDonald et al., 2013). These test days were separated by intervention conditions and test measures, respectively (MacDonald et al., 2013). In the field, ROM and force production will be required simultaneously. As a means of testing each variable independently and controlling for confounding variables, MacDonald et al. (2013) was able to single out the acute effects of SMR on the knee extensors group. Among the strengths of the study by Healey et al. (2013) include the ability of the research group to test multiple variables on a single day, for each condition. Sullivan et al. (2013) was also able to test various measures of muscle performance each day, but separating days by condition. The approach by Healey et al. (2013) and Sullivan et al. (2013) seems to be a more practical method to observe the effects of foam rolling, as it is purported to affect multiple variables of performance.

The studies by Healey et al. (2013) and MacDonald et al. (2013) both used similar rollers to the multilevel rigid roller used by Curran et al. (2008). The argument has been made that higher pressure SMR will be more effective because of the ability of the denser rollers to penetrate deeper into soft tissue

(MacDonald et al., 2013). Although Curran et al. (2008) demonstrated that a denser roller will apply more pressure than a less dense roller; many other intermediate density rollers exist that apply more variable degrees of pressure. Therefore, the efficacy of other types of rollers may yield different results. For example, the study by Sullivan et al. (2013) used a custom made device and massage roller to apply the treatment to the study group. This device was effectively able to apply a consistent treatment, but is not commercially available and requires an operator to use it (Sullivan et al., 2013). In terms of practicality, using such a device is not feasible for many people who intend to perform SMR. Also, researchers in this study used 13 kg of pressure for the SMR protocol, an amount that would be difficult to duplicate in the field (Sullivan et al., 2013). This would require individuals to somehow calculate their own force placed over a roller, or the roller applied to them, during treatments. However difficult is may be to duplicate the treatment applied by Sullivan et al. (2013), subjects still demonstrated immediate improvements in flexibility.

The duration of rolling is another variable that was controlled during each of the previously mentioned studies (Healey et al., 2013; MacDonald et al., 2013; Sullivan et al., 2013). The SMR conditions in the study by MacDonald et al. (2013) required subjects to foam roll for two one-minute bouts, so the results are also specific to that rolling protocol. The two minutes combined was enough to demonstrate acute improvements in ROM (MacDonald et al., 2013). Likewise, Sullivan et al. (2013) observed significant improvements in flexibility with as little as a single 5-second set, up to two 10-second sets of massage rolling. Healey et

al. (2013), on the other hand, required subjects to foam roll multiple muscle groups for one 30-second set each. Healey et al. (2013) did not assess flexibility or ROM. Although the duration of rolling between the studies by Healey et al. (2013), MacDonald et al. (2013), and Sullivan et al. (2013) were very different, neither study observed a significant effect on muscle performance. Foam rolling various muscles groups for five seconds to two-minutes does not appear to significantly invoke an effect on muscle performance for force or power (Healey et al., 2013; MacDonald et al., 2013; Sullivan et al., 2013). Different foam rolling durations and number of repetitions may have different effects.

Besides controlling for the duration of rolling, the number of passes seems to contribute to the effect of rolling. Sullivan et al. (2013) standardized the number of passes per set of rolling. There were 5 and 10 passes over the hamstrings group for each 5- and 10-second set, respectively (Sullivan et al., 2013). In the study by MacDonald et al. (2013) the SMR sets were one minute, but only 3-4 passes were completed per set, 6-8 per treatment. Although the durations of rolling were different, the number of passes completed was similar in the studies by MacDonald et al. (2013) and Sullivan et al. (2013). Likewise, both Sullivan et al. (2013) and MacDonald et al. (2013) observed improvements in flexibility and ROM. The similar number of rolling passes in these two studies appears to have contributed to the similar results. Therefore, the number of rolling passes may be a factor affecting the efficacy of SMR.

Healey et al. (2013), MacDonald et al. (2013), and Sullivan et al. (2013) assessed the effects of SMR on the muscles treated with some form of an

isometric contraction. After testing isometric force with an isometric knee extension, knee flexion, or squat, there was no significant changed observed in any study compared to a control (Healey et al., 2013; MacDonald et al., 2013; Sullivan et al., 2013). Although there was no significant effect isometric contractions, muscle performance should also be assessed with movement (Healey et al., 2013; MacDonald et al., 2013; Sullivan et al., 2013). Activities of daily living and sport performance all require variable duration, intensity and speed of knee extension. The effects of SMR on a fitness test for muscle power may be more applicable to people using SMR.

Healey et al. (2013) also tested isometric strength differently than MacDonald et al. (2013) by using an isometric squat versus an isometric knee extension (Healey et al., 2013). The isometric squat is more functional and practical than an isolated movement like a knee extension, but the complexity of the squat adds more variables to account for. For example, not every muscle group that acts as a prime mover in the squat was foam rolled, one in particular being the gluteus maximus. The gluteus maximus contributes a great deal of force to performing a squat, isometric or otherwise, so not foam rolling this muscle group may have affected the results. Furthermore, foam rolling the gluteus maximus may result in different scores for the jump height and jump power tests between the SMR and control conditions. Contrarily, many of the primary muscle groups used for an isometric squat were treated with SMR, so the outcome of the test may still be due to the neutral of effect of SMR. The apparent lack of change of isometric force production in the lower extremity

exhibited by Healey et al. (2013) parallels the force production findings of MacDonald et al. (2013) and Sullivan et al. (2013) for isometric knee extension and knee flexion, respectively.

Lastly the agility test used by Healey et al. (2013) is another assessment in which multiple variables were tested, those being combined speed and coordination. When compared to isometric single joint tests and squats, an agility test is far more applicable to field conditions. Although there was not a statistically significant difference between conditions for the agility test, this does not mean that foam rolling has no effect on sprint performance (Healey et al., 2013). Scores for agility tests are highly dependent on coordination and the complexity of the route. All subjects performed the agility test after each condition, but their ability to execute the drill maybe have affected their score in both instances (Healey et al., 2013). Performing a timed sprint in a single direction would at least ameliorate the complexity of requiring subjects to change direction. This would allow researchers to assess speed performance of the muscles tested, without requiring subjects to run a pattern.

The results of SMR through foam rolling are still far from conclusive, especially considering the limitations of each study. The different tests make comparison across the studies more difficult, however the previously mentioned studies were able to come to similar conclusions. MR and SMR appears to have no significant acute effect on muscle force or power production (Healey et al., 2013; MacDonald et al., 2013; Sullivan et al., 2013). Massage rolling and foam

rolling do, however, appear to improve flexibility and ROM in the studies that tested it (MacDonald et al., 2013; Sullivan et al., 2013).

Massage

The closest form of therapy to SMR can be considered massage therapy or MR by a massage therapist. Both SMR and massage have been, and are being used, as means of improving muscular performance before and after athletic events (Crosman, Chateauvert, & Weisberg, 1984; Goodwin, Glaister, Howatson, Lockey, & McInnes, 2007; Hunter, Watt, J.M., Watt, V., & Galloway, 2006; Wiktorsson-Moeller, Oeberg, Ekstrand, & Gillquist, 1983; Zainuddin, Newton, Sacco, & Nosaka, 2005; Zelikovski, Kaye, Fink, Spitzer, & Shapiro, 1993). The follow section will summarize the literature relating to massage's effect on flexibility, ROM and force production.

Crosman et al. (1984) demonstrated that a 9-12 minute massage significantly ($p = 0.05$) increased ROM at the hip immediately after treatment. The treatment was standardized for all subjects and applied to the back of the thigh, focusing on the hamstring muscle group (Crosman et al., 1984). Hunter et al. (2006) applied a 30 minute massage therapy to subjects and assessed force production. This massage was applied to the anterior and posterior thigh of both legs and lasted about 7 minutes and 30 seconds per area (Hunter et al., 2006). Hunter et al. (2006) concluded that the massage intervention only significantly decreased force when assessing isokinetic knee extension at 60 degrees per second. Greater velocities of isometric knee extension, up to 240 degrees per second, and vertical jump height were not significantly decreased from the

massage intervention (Hunter et al., 2006). Goodwin et al. (2007) concluded that a 15 minute massage applied to the lower limbs, before warm-up, did not affect sprint performance compared to a control.

Although static stretching does not pertain directly to this thesis, massage and MR are being used as alternatives to and in conjunction with static stretching (Clark and Lucett, 2007; Phillips, 2013; Wiktorsson-Moeller et al., 1983). In a study by Wiktorsson-Moeller et al. (1983), researchers observed the effects of warming up, massage and stretching on ROM and strength. Wiktersson-Moeller et al. (1983) concluded that massage only significantly increased ROM for ankle dorsiflexion, but decreased force at the hamstrings at velocities of 30 and 180 degrees per second.

These studies imply that massage may decrease force at velocities at or less than 180 degrees per second (Hunter et al., 2006; Wiktorsson-Moeller et al., 1983). Furthermore, massage may have the potential to acutely increase ROM (Crosman et al., 1984; Wiktorsson-Moeller et al., 1983).

Scientific Approach

In order to remain consistent with previous studies, this study used the Grid 2.0 Foam Roller. This roller was donated by SPRI Products, Inc. (Libertyville, IL.). It is a non-uniform cylinder that is commercially available and advertised as being 26 inches in length by five inches in diameter. The Grid roller, like the rollers used by Curran et al. and MacDonald et al., is composed of a PVC pipe with a compressive cover. The Grid, however, has an ethylene vinyl acetate (EVA) foam cover and the rollers used by Curran et al. and MacDonald

et al. used neoprene foam. This type of roller is considered high density and using a higher density roller is considered high pressure rolling (Curran et al., 2008; MacDonald et al., 2013). Based on previous studies it is unclear whether high pressure or low pressure foam rolling will ultimately be more effective. To speculate on the efficacy of various pressures of rolling compared to the other is beyond the scope of this thesis. Likewise, this thesis will not speculate on the efficacy on one roller compared to another. This study will report the acute effects of SMR with the Grid 2.0 foam roller on flexibility and knee joint torque. Similar to the study by Sullivan et al. (2013), this study will observe the effects of MR on the hamstrings group. The hamstrings are another muscle group commonly treated with MR and SMR, but there is not enough research to form conclusions about its efficacy. As a muscle group opposing the knee extensors, the hamstrings play a significant role in posture, daily living and sport performance (Gajdosik, Albert, & Mitman, 1994).

In order to assess the acute effect of SMR on flexibility and knee flexion torque, all tests were performed in a single session. Flexibility at the hamstrings was assessed with a sit and reach test (Armstrong, Balady, Berry, Davis, Davy, & Davy, 2006). An isometric MVC and maximal effort isokinetic knee flexion test was used to measure changes in knee torque (Healey et al., 2013; Hunter et al., 2006; MacDonald et al., 2013; Sullivan et al., 2013; Wiktorsson-Moeller et al., 1983).

CHAPTER 3

METHODOLOGY

Participant Characteristics

The participants in this study were thirteen adult women (N = 13, age: 28.5 ± 6.8 years of age; height: 165.5 ± 6.7 cm; mass: 64.2 ± 8.4 kg). Each participant was apparently healthy. Participants did not have any injury or condition that could have impaired their ability to stretch, forcefully flex, or foam roll the test legs as instructed. To determine eligibility for participation, potential participants completed a questionnaire solely pertaining to the muscle groups and joints needed for the study (See Appendix II). Participants were instructed to not perform any structured exercise 12 hours prior to the study session.

Setting and Equipment

Data collection took place in the Sports Injury Research Center (SIRC) lab. A yard stick was used to assess flexibility at the hamstrings. Knee flexion torque was measured using an isokinetic dynamometer (Biodex Medical Systems: Shirley, New York). The foam roller used for the treatment portion of the study was the Grid 2.0 roller (Trigger Point Performance: Austin, Texas), which is a non-uniform roller consisting of a polyvinyl chloride (PVC) pipe covered by a thin layer of EVA foam. The cylinder roller is advertised with the dimensions of a 5 inch diameter and 26 inch length, and is commercially available. A metronome was used to control the pace of rolling during the foam rolling condition.

Figure 1: Image of the foam roller used for all participants

Procedure

Participants were scheduled for a one hour test session, to allow ample time to complete the test protocol. Once participants arrived at the SIRC, the study procedures were explained to them in detail, and then they were asked to review the informed consent approved by the university and complete the participant eligibility questionnaire (See Appendix I and II). Participants interested in volunteering their time were allowed to review the eligibility questionnaire before scheduling a test session. Participants were also encouraged to ask any questions they may have about the study. If the participant agreed to participate in the study, she was asked to sign the informed consent.

Participants' demographics (height, weight, and age) were measured and recorded first. Testing began by having participants warm up on a treadmill located inside the SIRC lab. Participants performed a 5 minute self-guided walking warm-up (Armstrong et al., 2006).

Collection of the Data

Participants were asked to use their dominant leg for the study tests (Ogura, Miyahara, Naito, Katamoto, & Aoki, 2007). To determine the dominant leg, participants were asked which leg they are most likely to kick a ball with and the kicking leg was used (Oldfield, 1971). All torque measurements were performed using the dominant side, whereas the foam rolling and sit-and-reach portion were performed using both sides. All participants completed three tests for each assessment over the course of one test day. Each session consisted of pre-rolling 1, control condition, pre-rolling 2, foam rolling condition, and finally the post-rolling tests and conditions.

Pre-rolling 1 began with the assessment of flexibility, immediately followed by maximum voluntary isometric and then isokinetic repetitions. Hamstring flexibility was determined with a sit-and-reach test and measured with a yard stick taped to the floor.

Sit-and-Reach Test

This assessment measured changes in flexibility that occurred as a result of each condition. A yard stick was placed on the floor with a length of tape placed across the 15 inch mark (Armstrong et al., 2006). The tape was perpendicular to the yard stick and indicated a barrier for the participants' foot placement (Armstrong et al., 2006). The participant was first asked to remove her shoes and sit with the yard stick between her feet, on the "0" inch side of the stick (Armstrong et al., 2006). The participant sat with their legs extended and heels

behind the tape (Armstrong et al., 2006). Participants then attempted to reach forward and place their fingertips as far as possible on the yard stick (Armstrong et al., 2006). Participants did this while keeping their legs extended and hands even with one another (Armstrong et al., 2006). In order to control for the possibility of subjects competing with themselves, subjects were asked to look straight ahead and not at the measuring tape, as they reached forward. Each participant took three attempts of the sit and reach during each test (Baltaci, Un, Tunay, Besler, Gerçeker 2003). The best attempt during each test was be recorded to the nearest half-inch (Sullivan et al., 2013). Encouragement was given for each attempt of each test, along with identical instruction for each test (See Appendix III).

Knee Flexor Torque Tests

Immediately after hamstrings flexibility was assessed, participants performed the tests for knee flexion torque (Ogura et al., 2007). Participants performed two tests of knee flexion torque: 1) isometric maximum voluntary contraction (MVC) and 2) maximal effort isokinetic test (Wiktorsson-Moeller et al., 1983; Zainuddin et al., 2005). All tests were done using the Biodex Systems 3 isokinetic dynamometer. MVC tests preceded isokinetic tests (Zainuddin, et al., 2005). Participants were seated upright and secured to the device, with the axis of the knee in-line with the axis of the machine. The resistance arm was secured to the participant's dominant leg, one inch superior to the ankle joint. For the isometric contractions, participants were asked to flex the dominant knee with maximal effort for 5 seconds with the joint fixed at 90 degrees of flexion (Gurjao,

Goncalves, De Moura, & Gobbi, 2009; MacDonald et al., 2013; Ogura et al., 2007). The angle of knee flexion was measured using a goniometer, with full knee extension set as zero degrees and flexing the knee to 90 degrees from full extension. The MVC was repeated three times with one-minute rest between each MVC (MacDonald et al., 2013; Papadopoulos, Kalapotharakos, Noussios, Meliggas, Gantiraga, 2006; Sullivan et al., 2013; Zainuddin et al., 2005). During testing of the isometric contractions, participants were verbally encouraged to flex their knee with maximal effort for the entire 5 seconds.

Following the isometric MVC test, the participants then performed three isokinetic repetitions of knee flexion (Zainuddin et al., 2005). The isokinetic repetitions began with the knee fully flexed. Once the repetitions were initiated, the participants extended their knee with minimal effort at a velocity of 60 degrees per second, until the knee if fully extended, then flexed the knee (Hunter, Watt, Watt, & Galloway, 2006). The participants were encouraged to flex their knee with as much force as possible, despite the fixed velocity of the device. Participants were also instructed to exert minimal effort to extend their knee. Once the pre-rolling 1 measures are complete, participants performed the protocol for the control condition.

Control and Foam Roll Conditions

The control condition was a rest condition and consisted of sitting for three minutes, until pre-rolling 2 began (MacDonald et al., 2013). The intervention was a foam rolling condition and required the participant to foam roll the hamstrings group of both legs for two one-minute bouts, with one minute rest between bouts

(Sullivan et al., 2013, MacDonald et al., 2013). The participant was asked to steadily roll the foam roller over the portion of the hamstrings between the ischial tuberosity and the popliteal area. Participants foam rolled the hamstrings at a rate of four passes, up and down the thigh, per minute (MacDonald et al., 2013). This rate was controlled with a metronome set at 16 bpm, with a beat at the lower, middle, and upper thigh, respectively. In order to familiarize each subject with the foam rolling protocol each subject was shown a video demonstration, written instructions, and was given verbal cues during the foam rolling (See Appendix IV). A member of the research team kept track of the time and number of foam rolling passes for each minute, as well as the rest between sets.

Figure 2a, 2b, 2c: Images from the demonstration video shown to all participants.

Participants performed pre-rolling 2 and post-rolling in the same order as the pre-rolling 1 measurements.

Data Reduction

Flexibility was reduced to the best score of the three attempts, during each test of the sit-and-reach (Sullivan et al., 2013). Isometric repetitions were reduced to the highest average torque of three attempts, for each test

(MacDonald et al., 2013). Isokinetic repetitions were reduced to the highest peak torque produced of the three repetitions, for each test (Zainuddin et al., 2005) (See Appendix V).

Data Analysis Methods

SPSS (SPSS, IBM Inc. V21) was used to perform a Repeated Measures One-Way Analysis of Variance (ANOVA) for each dependent variable (Flexibility, Isometric torque, and Isokinetic torque) with Time (pre-rolling 1, pre-rolling 2, post-rolling) as the independent variable. When the omnibus F-ratio was significant, pairwise comparisons were performed using Bonferroni Comparisons between Pre-rolling 1 and Pre-rolling 2, as well as between Pre-rolling 2 and Post-rolling.

CHAPTER 4

RESULTS

Flexibility was influenced by Time ($p < 0.001$). Using Bonferroni for pairwise comparisons as a post-hoc, flexibility was different between Pre-rolling 2 and Post-rolling measures ($p < 0.001$). There was no difference between Pre-rolling 1 and Pre-rolling 2 tests ($p = 0.098$). Average isometric torque was not influenced by Time ($p = 0.356$). Peak isokinetic torque was not influenced by Time ($p = 0.958$).

	Pre-rolling 1	Pre-rolling 2	Post-rolling	p-value
Flexibility (cm)	47 ± 7.2	48.4 ± 7.5	50.2 ± 7.4*	< 0.001
Isometric Torque (Nm)	62.8 ± 9.8	63.1 ± 12.6	59.9 ± 14.8	0.356
Isokinetic Torque (Nm)	78.8 ± 19.4	79.2 ± 15.6	78.8 ± 18.4	0.958

Table 1: Illustration of means and standard deviation for all tests: Sit and Reach flexibility, average isometric knee flexor torque, and peak isokinetic knee flexor torque, respectively. The Pre-rolling 1 measure preceded a 3 minute rest, Pre-rolling 2 preceded foam rolling intervention, and Post-rolling was after foam rolling. * indicates a significant difference between Pre-rolling 2 and Post-rolling (See Appendix V-XI).

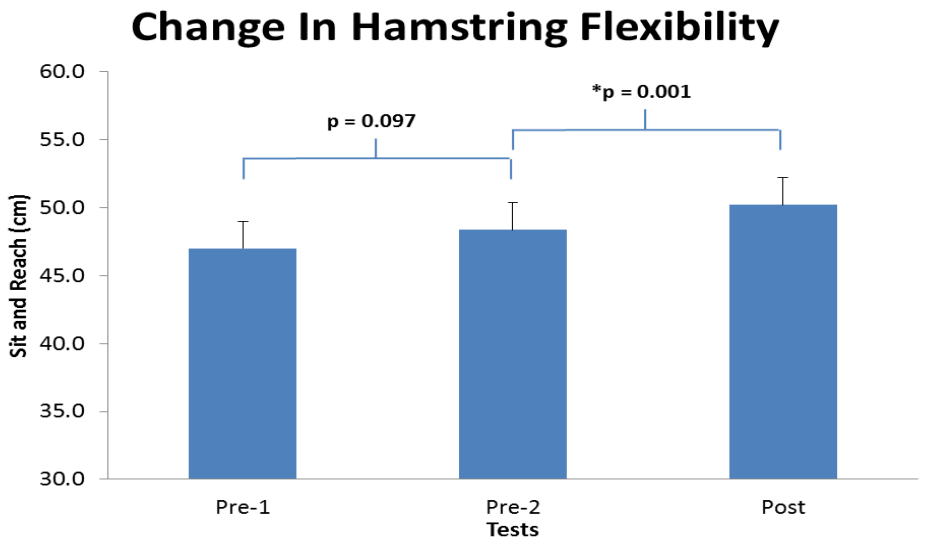


Figure 3: Hamstring flexibility. * indicates a significant difference in between Pre-rolling 2 and Post-rolling.

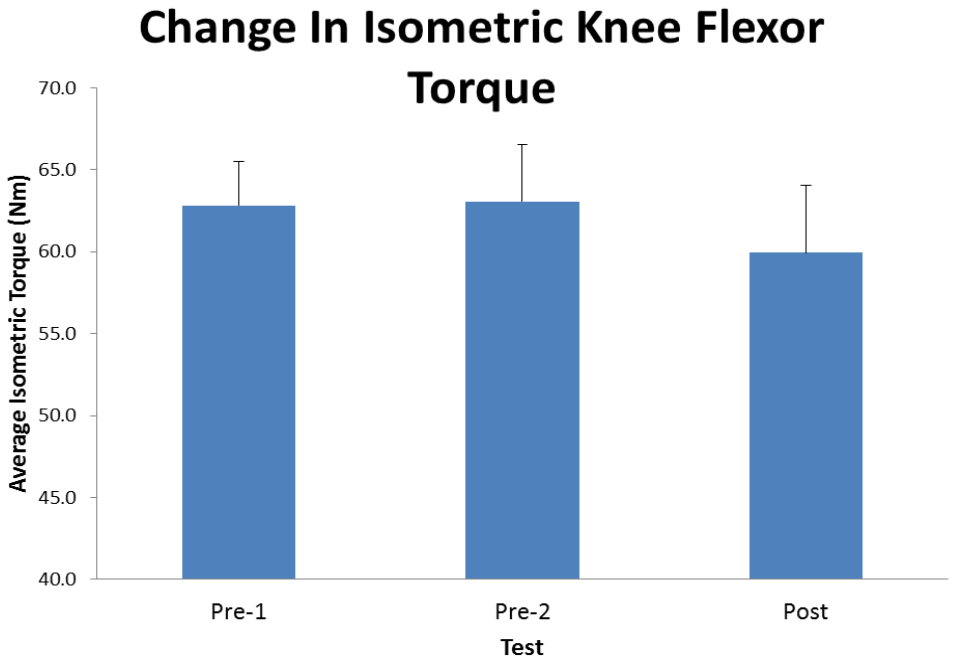


Figure 4: Average isometric knee flexor torque.

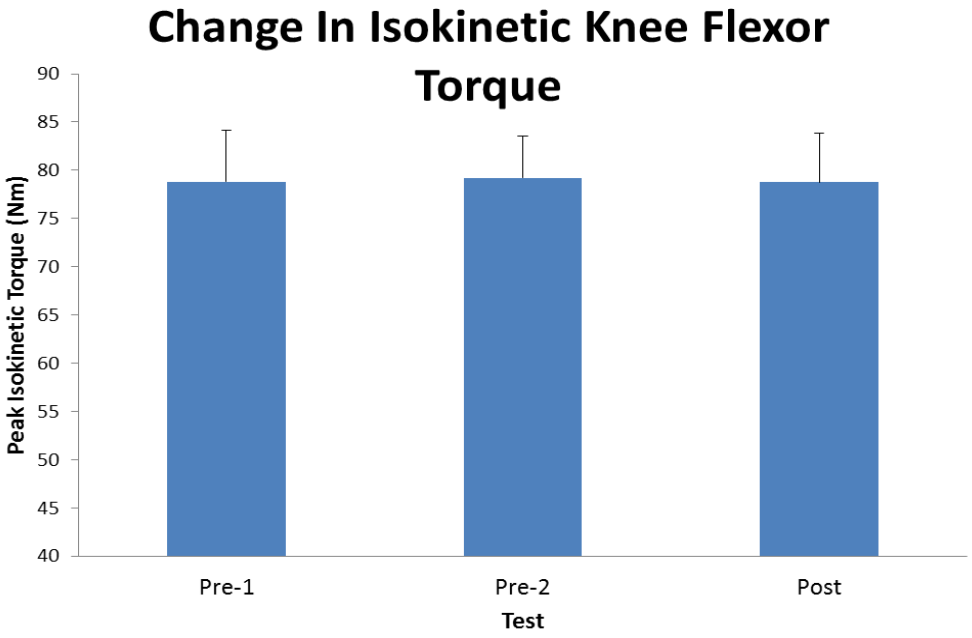


Figure 5: Peak isokinetic knee flexor torque.

CHAPTER 5

DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

Discussion of Results

The most important observation of this study was that a single bout of foam rolling significantly improved hamstrings flexibility. The average increase in distance reached for the sit and reach after foam rolling was 4% or about 2 centimeters. This indicates that foam rolling does have the ability to influence flexibility. Conversely, average isometric torque and peak isokinetic torque were not affected by the foam rolling condition.

These results are consistent with previous findings in that flexibility improved after foam rolling, massage rolling, and massage respectively (Barlow, Clarke, Johnson, Seabourne, Thomas, & Gal 2004; MacDonald et al., 2013; Sullivan et al., 2013). The 4% percent change after foam rolling recorded for the sit and reach test is comparable to other studies measuring hamstring flexibility in healthy individuals after massage and massage rolling (Barlow et al., 2004; Sullivan et al., 2013). MacDonald et al. (2013) observed a 12.7% increase in range of motion after foam rolling, however, the muscles treated were the quadriceps. These observations imply that changes muscular flexibility after foam rolling may be specific to the muscles treated and the joints surrounding those muscles. Notwithstanding the differences in methods, massage, massage rolling, and foam rolling have been shown to increase flexibility between 4-12%

immediately after treatment (Barlow et al., 2004; MacDonald et al., 2013; Sullivan et al., 2013).

There were no significant changes in isometric or isokinetic torque for this study. The changes recorded for isometric MVC at the knee joint were similar to previous studies measuring isometric MVC after myofascial release (Healey et al., 2013; MacDonald et al., 2013; Sullivan et al., 2013). Contrarily, Hunter et al. (2006) observed a decrease in isokinetic torque after a massage condition, when the velocity was also set at 60 degrees per second. The study by Hunter et al. (2006) observed the effects on the knee extensors group, as opposed to the hamstrings group in this study. The effects of massage on muscle strength may also be different than this study as a result of the differing amounts of pressure applied from the foam roller and the massage therapist used by Hunter et al. (2006). Likewise, the direction and duration of the massage treatment applied to the knee extensors were not consistent with this study (Hunter et al., 2006).

The effects of foam rolling observed in this study are specific to this protocol. Since the hamstrings group was rolled for two one-minute sets, then any improvement in flexibility may be different if the foam rolling protocol is changed. This includes the effects of foam rolling on any strength measures. Factors that may have influenced the effect of foam rolling on muscular performance may be the duration of rolling, number of sets of rolling, rate of rolling, type of roller, muscle group rolled, amount of pressure applied to the roller, and the frequency of rolling. The present study was designed to control these many of these factors. This study attempted to control for the consistency

of the rolling condition by requiring all subjects to watch a recorded foam rolling demonstration. This video ensured that all subjects would start the foam rolling condition with their hands and the foam roller in the same position. The roller used was chosen to resemble the rollers used by in previous studies (Curran et al., 2008; Healey et al., 2013; MacDonald et al., 2013). Additionally, the rate of rolling was controlled with a metronome and verbal cues to maintain tempo. A rate of four passes up and down the thigh per minute was chosen to mimic the rate of rolling by MacDonald et al. (2013). It is not known if the outcome of the study would be different if the foam rolling protocol was different.

The factors that were controlled for in this study may have also limited the effects from the foam rolling. The pace of foam rolling for this study may have been too slow to elicit a more exaggerated effect on flexibility, and possibly knee flexor torque. The study by Sullivan et al. (2013) used a rate of one pass per second up and down the thigh, for five and ten second sets. The number of passes may be been similar between this study and the study by Sullivan et al. (2013), but the duration was very different. The rate of rolling combined with the duration of rolling may represent a method of quantifying the myofascial release treatment. The pressure exerted by the roller over the hamstrings group was consistent between participants, due to the protocol and the roller used. There is, however, another method of rolling the hamstrings with a foam roller that applies additional pressure. When one leg is crossed over the leg that is being rolled, then the participant's weight is applied over a single leg rather than both, as the hamstrings are rolled. This method has not been tested in any peer reviewed

studies as of now, but presents an alternative method of rolling that may yield different effects on muscle performance.

Since each participant was scheduled for a single session, then learning the procedure was an important concern. Every subject was given the ability to practice each of the tests, sub-maximally, before data collection began. Moreover, the procedure for each test was reviewed briefly before each recorded attempt. Encouragement was given for every individual attempt to promote maximal effort for the flexibility and knee flexor torque assessments. Participants were also performed three attempts or repetitions of each assessment. The highest peak or average repetition was recorded. This ensured that any unintentional submaximal efforts were not included in the analysis. During the rolling condition, there was a single participant lowered her hips to the ground momentarily and then raised them to continue rolling. This participant's hamstrings remained over the roller for the entire set. All other participants rolled continuously for each of their two minute sets.

There was not a significant change ($p = 0.097$) in flexibility from Pre-rolling1 to Pre-rolling 2 compared to the 4% increase ($p < 0.001$) between Pre-rolling 2 and Post-rolling. The difference between Pre-rolling 1 and Pre-rolling 2 indicates variability between tests, but the combination of flexibility, MVC assessments and control condition did not significantly influence flexibility or MVC. There was a significant difference ($p = 0.001$) between Pre-rolling 1 and Post-rolling, but this indicates the change over the course of the entire testing protocol, not solely from the foam rolling condition.

Conclusions and Recommendations

In conclusion, foam rolling can be used to improve hamstring flexibility. When used before exercise, foam rolling may not affect athletic performance when the activity involves isokinetic or isometric contractions. If foam rolling is performed after exercise, then flexibility may still improve as well. More research is needed to observe the effects of foam rolling after exercise. It is unknown how long the effects of foam rolling last. Future studies must determine how long the effects of foam rolling last, whether before or after exercise. Initial studies, like this one, demonstrate the potential to determine a dose-response relationship for myofascial release and muscle performance. More research is needed to determine the effects of myofascial release on muscle performance and factors that influence those effects.

APPENDIX I

UNIVERSITY OF NEVADA LAS VEGAS

INFORMED CONSENT

Department of Kinesiology and Nutrition Sciences

TITLE OF STUDY: Acute Effects of a Single Bout of Self-Myofascial Release on Hamstring Maximum Voluntary Contraction and Flexibility

INVESTIGATOR: John Mercer, Ph.D.

CONTACT PHONE NUMBER: Dr. Mercer: 895-4672

Purpose of the Study

The purpose of this study is to observe the immediate effects of a single bout of self-myofascial release, in the form of "foam rolling", on muscle force and flexibility.

Participants

You are being asked to participate in the study because you are a woman 18-55 years old, apparently healthy, you do not have any injury that would interfere with your ability to forcefully extend your knees, you can comfortably support your body weight from your hands and feet for at least a minute at a time, and you are not pregnant or think you are pregnant. We will have you complete a screening questionnaire to make sure you qualify for the study. If you decide to participate in the study, you will not be able to exercise on the day of testing.

Procedures

If you volunteer to participate in this study, you will be asked to do the following:

- Attend one testing session that will last about one hour.
- We will test how flexible you are by having you do a simple sit and reach stretch test. We will have you sit with your legs extended and slowly reach forward as far as possible, then measure the distance.
- We will also test how strong your muscles are that bend your knee (i.e., knee flexors). To do this, we will have you sit on a special machine that will measure how hard you pull as you bend your knee. The important part of this test is that you will have to try as hard as you can.
    - You will be asked to do this test several times throughout the test session.
- You will be asked to 'foam roll' the hamstrings (i.e. back of the thighs) of both legs for two one-minute bouts.
    - Foam rolling is a form of self-myofascial release, or massage, in which you will lie over a cylinder roller and pass the muscle to be tested over it, repeatedly.

You will be required to roll the hamstrings muscle continuously, while applying as much pressure as possible over the back of the thigh. You will be given one-minute rest between each minute of foam rolling.

- Please wear athletic clothes that you feel comfortable moving freely in.
- You will be given one minute to rest between bouts of foam rolling and 10-60 seconds of rest between sets of strength tests.

Benefits of Participation

There *may not* be direct benefits to you as a participant in this study. You will, however, be given instruction on foam rolling, you will learn about how much force you can make using your hamstrings, and will learn some information about flexibility. We hope to learn more about how people can best use foam rolling.

Risks of Participation

There are some risks involved in all research studies. This study may include only minimal risks. The most likely risks from the exercise sessions is muscle/tendon soreness. The discomforts you may experience during the study protocol would likely occur during the foam rolling or maximum voluntary contraction portions of the session. Some bruising may occur but is not expected since the foam rolling is done for only a short period of time. Nevertheless, if you feel any discomfort or pain or sharp pain, we ask that you stop the exercise.

To help minimize the risks, you will be given instruction on performing all aspects of the study protocol, given time to practice, and allowed to warm up before measurements begin.

Cost /Compensation

There *will not* be financial cost to you to participate in this study. The study will take about one hour of your time for each test day. *The University of Nevada, Las Vegas may not provide compensation or free medical care for an unanticipated injury sustained as a result of participating in this research study.* You will not receive any form of compensation for your participation in this study.

Contact Information

If you have any questions or concerns about the study, you may contact Dr. John Mercer at 895-4672**.** For questions regarding the rights of research subjects, any complaints or comments regarding the manner in which the study is being conducted you may contact **the UNLV Office Research Integrity, Human Subjects (702-895-2794).**

Voluntary Participation

Your participation in this study is voluntary. You may refuse to participate in this study or in any part of this study. You may withdraw at any time without prejudice to your relations with the university. You are encouraged to ask questions about this study at the beginning or any time during the study.

Confidentiality

All information gathered in this study will be kept completely confidential. No reference will be made in written or oral materials that could link you to this study. All records will be stored in a locked facility at UNLV for at least 3 years after completion of the study. After the storage time the identifying information gathered will be destroyed.

Participant Consent:

I have read the above information and agree to participate in this study. I am at least 18 years of age. A copy of this form has been given to me.

_____ _____

Signature of Participant Date

_____

Participant Name (Please Print)

Participant Note: Please do not sign this document if the Approval Stamp is missing or is expired.

APPENDIX II

Name _____Date _____

Acute Effects of a Single Bout of Self-Myofascial Release on Hamstring Maximum Voluntary Contraction and Flexibility

Participant Eligibility Questionnaire

Please highlight or underline your responses. Thank you

1. Do you have any experience "foam rolling"?
    a. Yes
    b. No
2. Do have any muscle or joint injuries, past or present, in your lower extremities?
    a. Yes
    b. No
3. If you answered "Yes" to question 2, which side was injured?
    a. Left
    b. Right
    c. Both
4. If you answered "Yes" to question 2, will this injury impair your ability to forcefully bend your knee against a device, while in a seated position?
    a. Yes
    b. No
5. If you answered "Yes" to question 2, will this injury impair your ability to sit with both legs extended and reach forward, bending at the hip and back?
    a. Yes
    b. No
6. If you answered "Yes" to question 2, will this injury impair your ability to "foam roll" your hamstrings (muscle group behind the thigh)?
    a. Yes
    b. No

Dominant Leg

1. Which leg would you use to kick a ball?
    a. Left
    b. Right

APPENDIX III

Foam Rolling Thesis Assessment Script

Flexibility -

1. Take your shoes off and sit down with both your heels just behind the colored tape
2. The measuring tape should be between your feet, with the 1-inch mark toward your body
3. Place one hand over the other, with your fingertips even
4. Next you will slowly reach forward as far as possible by bending at the hips and back
5. Keep your legs and arms extended as you reach forward
6. Look straight forward, not at the tape, as you reach to touch the tape
7. Again, you will need look straight ahead at the wall and touch the tape on the floor, and hold
8. I will record your mark as you hold the reached position. You will be allowed three attempts
9. I will be encouraging you to reach as far forward as possible, each attempt

Isometric

1. First you will need to be positioned in the Biodex chair for the next two assessments
2. For the MVC tests we will position your knee at a 90 degrees of knee flexion
3. The device will allow movement until the start button is pressed
4. Once the test is started, the device will adjust to the start position and remain stationary
5. During this test you will pull your heel backward, toward the machine as hard as possible
6. The pulling during duration will last 5 seconds and then you will be given one minute to relax
7. There are three attempts per set and you will need to pull as hard as possible all three times
8. I will be encouraging you to “pull hard!“ during each attempt

Isokinetic

1. The chair will remain in the same position as the isometric tests
2. During the isokinetic tests you will allowed to bend and extend your leg
3. Once the test has begun, you will extend your leg away from your body using minimal effort
4. When your leg is extended, immediately bend your leg, pulling as hard as possible
5. The machine will not allow you to move beyond the set speed, but still pull hard each time
6. You will complete three full repetitions of extension and flexion during each set
7. I will be encouraging you to “extend your leg easily, then pull back hard” each attempt

APPENDIX IV

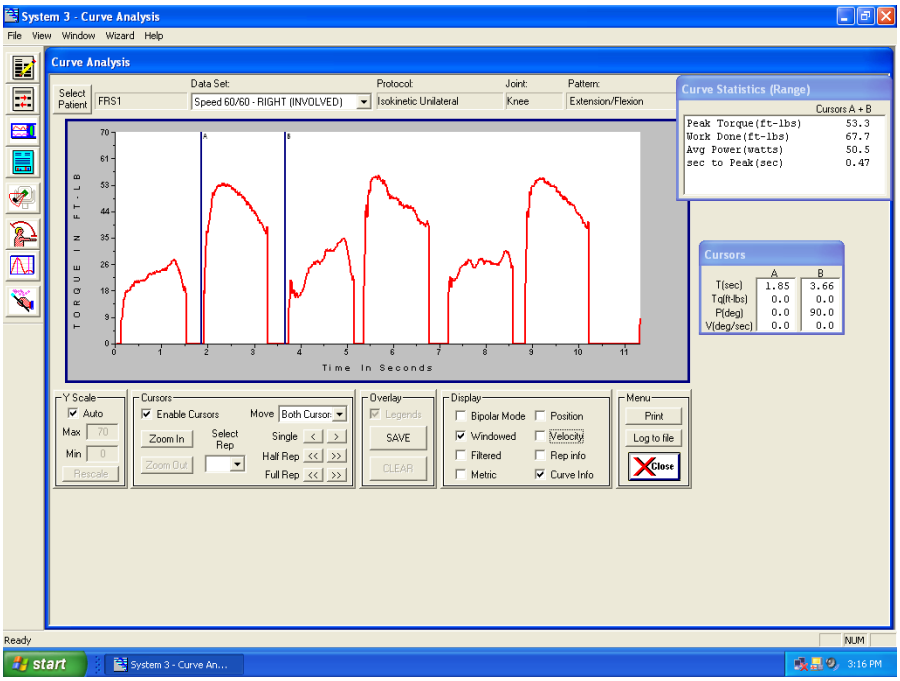
Foam Rolling (Self-Myofascial Release) Script

- First sit on the ground with your feet together and legs extended
- Place the roller underneath and perpendicular to your thighs
- Place your hands on the ground, behind your hips
- Extend your knees to raise your feet off the ground
- Press your hands down, with your arms and shoulders, to raise your hips up
- Using your arms and shoulders, roll back and forward slowly in an oscillating motion
- Roll up the back of the thigh until just before the roller reaches the hip bone, then change directions
- Continue rolling down the thigh, until the roller is almost beneath the knee
- Be sure to keep your feet and hips off the ground
- Try to put as much pressure as possible over the roller
- Keep your feet pointed upward during the entire foam rolling bout
- Roll continuously until one-minute has passed. A member of the research team will prompt you when to stop.
- You will be given one minute to rest, and then you will repeat the foam rolling protocol for a second minute.
- If you feel any discomfort or sharp pain, we want you to stop to avoid any injury.

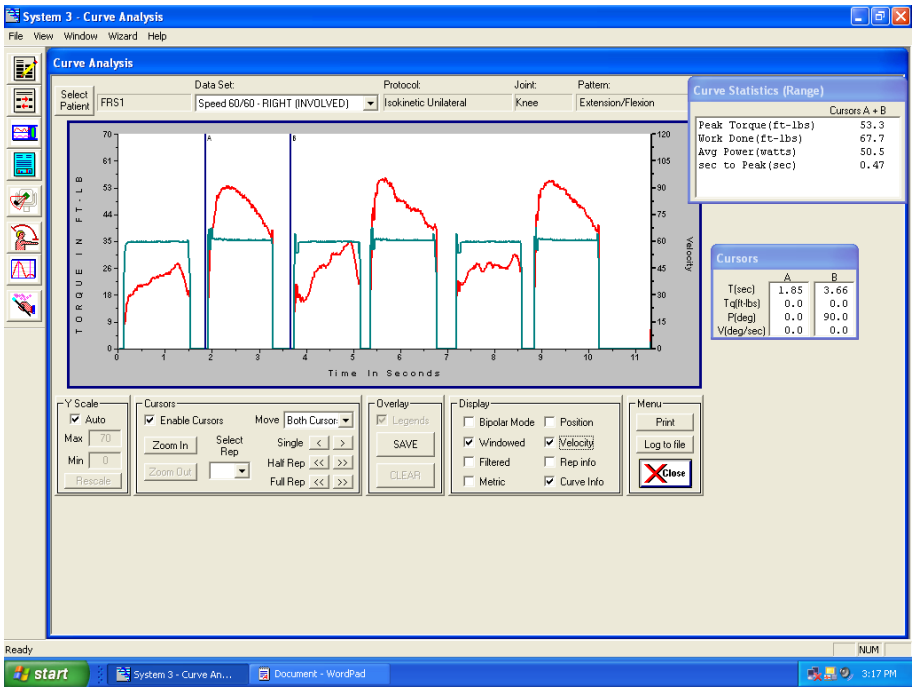
APPENDIX V

Images from Knee Flexor Torque Data Collection

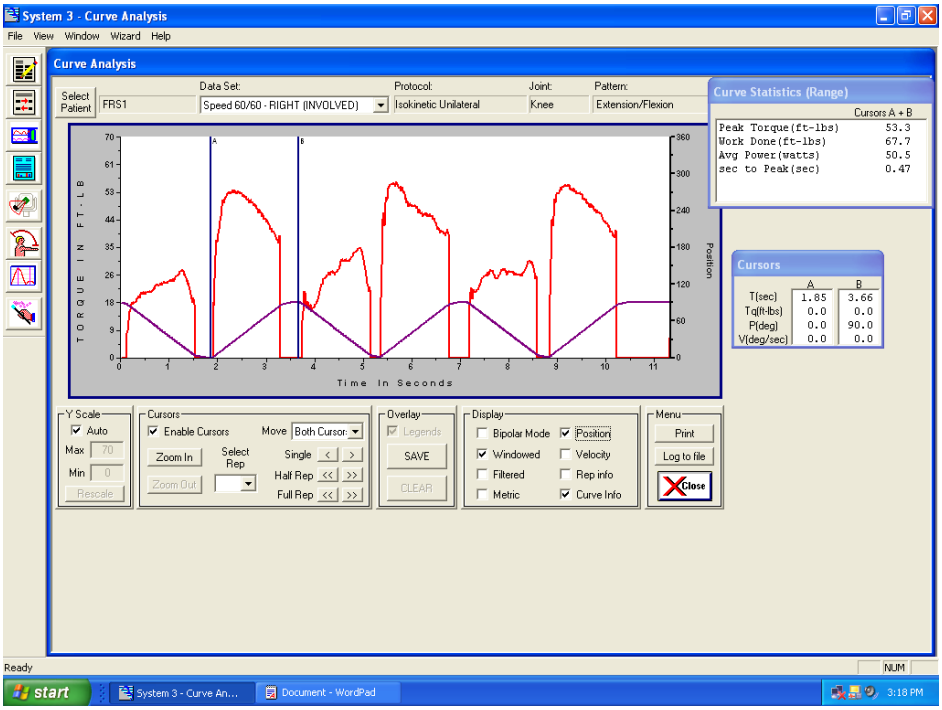
Isokinetic Test, knee flexion is highlighted



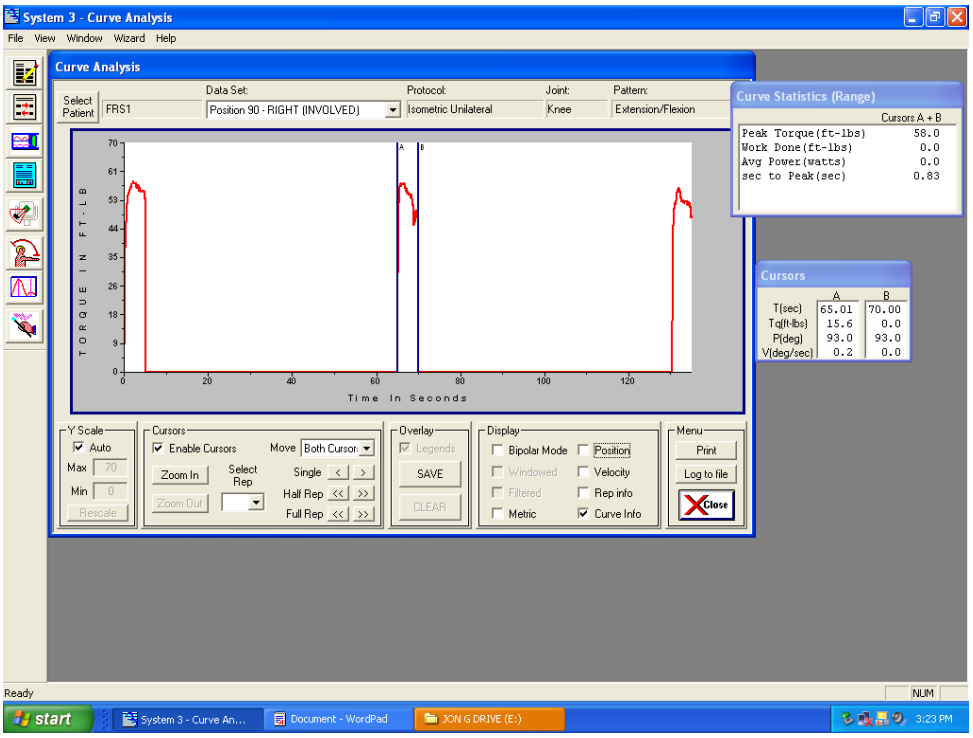
Isokinetic Test, velocity is highlighted



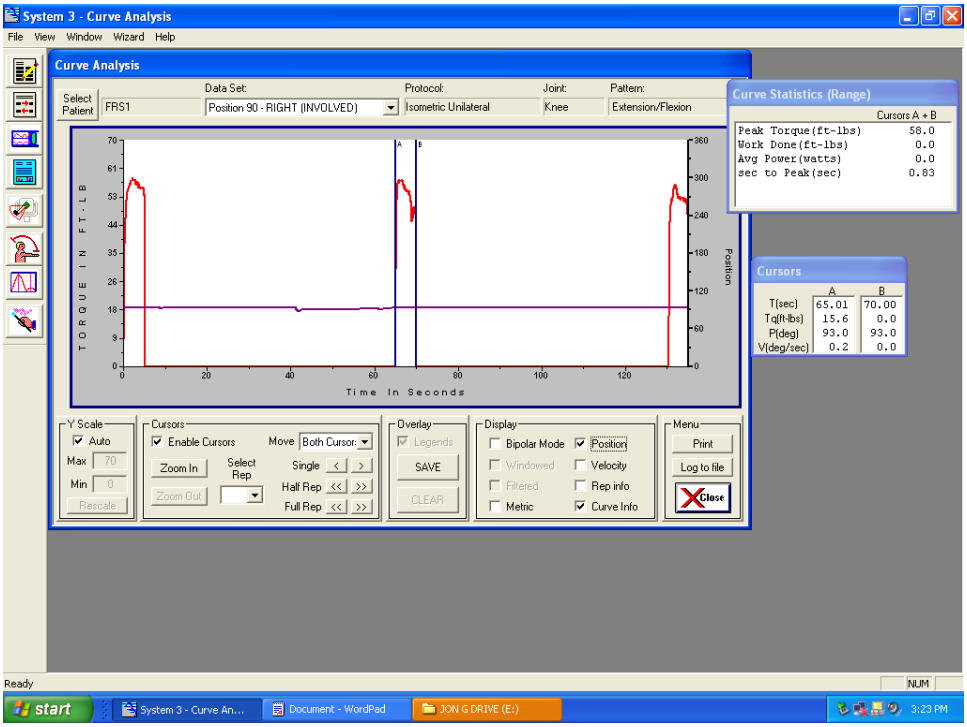
Isokinetic Test, knee position is highlighted



Isometric Test, second repetition is highlighted



Isometric Test, knee position is highlighted



APPENDIX VI

Test Data Collected

Sit and Reach Flexibility (in)

Subject	Pre-rolling 1			Pre-rolling 2			Post-rolling		
	1	2	3	1	2	3	1	2	3
FRS1	12.5	13.5	14.5	14.0	15.0	15.0	16.0	16.0	16.5
FRS2	10.0	11.0	12.0	11.0	12.0	12.5	11.0	12.0	13.0
FRS3	17.5	18.5	19.0	18.5	18.5	18.5	18.5	19.0	19.0
FRS4	20.0	20.0	20.5	21.0	22.0	22.0	21.5	22.0	23.0
FRS5	17.0	17.5	18.5	19.5	20.5	21.0	20.0	21.0	22.0
FRS6	17.0	19.0	19.0	18.0	19.0	20.0	19.0	20.0	20.0
FRS7	18.5	20.5	21.0	20.0	21.5	21.5	21.0	22.0	22.5
FRS8	20.5	21.0	21.5	21.0	21.5	22.0	21.5	22.0	22.0
FRS9	16.5	17.0	17.5	17.0	17.5	17.5	18.0	18.0	18.5
FRS10	16.5	17.0	17.5	17.0	17.0	17.5	18.0	18.0	18.0
FRS11	16.5	16.5	17.5	18.0	18.0	17.5	18.0	18.5	19.0
FRS12	18.5	20.5	22.0	20.5	21.5	22.5	21.0	23.0	23.0
FRS13	19.0	19.5	20.0	19.0	19.5	19.5	20.0	20.5	20.5

Isometric Average Torque (lb-ft)

Subject	Pre-rolling 1			Pre-rolling 2			Post-rolling		
	1	2	3	1	2	3	1	2	3
FRS1	53.5	52.2	50.4	51.9	48.6	49.1	46.9	47.3	43.8
FRS2	35.6	35.2	35.4	31.8	41.8	32.9	28.8	29.4	31.3
FRS3	37.5	43.9	46.4	44.3	46.0	47.6	45.9	50.0	50.9
FRS4	54.8	54.5	56.6	54.3	49.0	50.1	50.2	47.4	48.2
FRS5	34.4	37.1	35.2	43.9	39.1	37.5	33.1	32.9	33.3
FRS6	43.7	45.9	40.5	45.4	39.7	38.0	39.5	34.7	33.9
FRS7	50.5	48.4	48.4	48.1	45.8	45.1	47.5	42.9	39.3
FRS8	48.1	54.8	50.5	42.3	43.4	42.5	43.3	47.3	45.9
FRS9	28.8	34.8	37.2	25.9	29.6	28.9	30.1	29.4	28.7
FRS10	43.1	54.1	49.9	43.2	58.1	68.3	61.8	65.2	67.7
FRS11	33.6	41.0	38.4	37.3	37.9	30.8	27.9	31.4	33.0
FRS12	44.0	36.6	35.2	38.3	40.5	38.8	41.2	40.6	39.7
FRS13	40.7	44.5	45.6	40.4	52.1	46.7	53.3	55.4	53.9

Isokinetic Peak Torque (lb-ft)

Subject	Pre-rolling 1			Pre-rolling 2			Post-rolling		
	1	2	3	1	2	3	1	2	3
FRS1	53.3	55.9	55.1	56.7	59.6	55.6	57.5	54.3	57.5
FRS2	79.6	75.3	85.2	69.2	75.0	75.3	79.2	74.0	70.8
FRS3	56.6	50.4	56.6	57.2	53.0	56.4	50.1	58.3	54.1
FRS4	47.5	46.0	46.0	46.1	46.8	49.1	47.8	52.0	47.5
FRS5	50.4	42.6	52.3	58.5	54.1	54.4	61.4	54.1	51.2
FRS6	50.9	58.5	54.3	50.4	59.3	51.2	42.8	56.2	56.6
FRS7	48.2	49.9	55.1	52.4	51.0	49.1	46.1	47.2	50.4
FRS8	60.8	56.2	55.1	60.9	58.8	55.1	62.5	58.8	57.5
FRS9	37.3	37.6	35.7	39.4	37.6	35.3	39.7	39.9	37.3
FRS10	79.5	79.5	61.7	77.5	80.5	78.2	72.9	78.2	64.3
FRS11	54.9	52.0	51.2	53.0	47.8	48.2	53.6	50.9	49.1
FRS12	39.7	35.4	30.6	45.2	42.1	38.9	32.6	29.5	32.1
FRS13	74.0	62.7	55.1	63.8	62.7	69.0	68.7	69.0	73.2

APPENDIX VII

Reduced Data and Conversion to Metric Units

Subject	Sit and Reach Flexibility (in)			Sit and Reach Flexibility (cm)		
	Pre-rolling 1	Pre-rolling 2	Post-rolling	Pre-rolling 1	Pre-rolling 2	Post-rolling
FRS1	14.5	15.0	16.5	36.8	38.1	41.9
FRS2	12.0	12.5	13.0	30.5	31.8	33.0
FRS3	19.0	18.5	19.0	48.3	47.0	48.3
FRS4	20.5	22.0	23.0	52.1	55.9	58.4
FRS5	18.5	21.0	22.0	47.0	53.3	55.9
FRS6	19.0	20.0	20.0	48.3	50.8	50.8
FRS7	21.0	21.5	22.5	53.3	54.6	57.2
FRS8	21.5	22.0	22.0	54.6	55.9	55.9
FRS9	17.5	17.5	18.5	44.5	44.5	47.0
FRS10	17.5	17.5	18.0	44.5	44.5	45.7
FRS11	17.5	18.0	19.0	44.5	45.7	48.3
FRS12	22.0	22.5	23.0	55.9	57.2	58.4
FRS13	20.0	19.5	20.5	50.8	49.5	52.1

Subject	Isometric Average Torque (lb-ft)			Isometric Average Torque (Nm)		
	Pre-rolling 1	Pre-rolling 2	Post-rolling	Pre-rolling 1	Pre-rolling 2	Post-rolling
FRS1	53.5	51.9	47.3	72.5	70.4	64.1
FRS2	35.6	41.8	31.3	48.3	56.7	42.4
FRS3	46.4	47.6	50.9	62.9	64.5	69.0
FRS4	56.6	54.3	50.2	76.7	73.6	68.1
FRS5	37.1	43.9	33.3	50.3	59.5	45.1
FRS6	45.9	45.4	39.5	62.2	61.6	53.6
FRS7	50.5	48.1	47.5	68.5	65.2	64.4
FRS8	54.8	43.4	47.3	74.3	58.8	64.1
FRS9	37.2	29.6	30.1	50.4	40.1	40.8
FRS10	54.1	68.3	67.7	73.3	92.6	91.8
FRS11	41.0	37.9	33.0	55.6	51.4	44.7
FRS12	44.0	40.5	41.2	59.7	54.9	55.9
FRS13	45.6	52.1	55.4	61.8	70.6	75.1

Subject	Isokinetic Peak Torque (lb-ft)			Isokinetic Peak Torque (Nm)		
	Pre-rolling 1	Pre-rolling 2	Post-rolling	Pre-rolling 1	Pre-rolling 2	Post-rolling
FRS1	55.9	59.6	57.5	75.8	80.8	78.0
FRS2	85.2	75.3	79.2	115.5	102.1	107.4
FRS3	56.6	57.2	58.3	76.7	77.6	79.0
FRS4	47.5	49.1	52.0	64.4	66.6	70.5
FRS5	52.3	58.5	61.4	70.9	79.3	83.2
FRS6	58.5	59.3	56.6	79.3	80.4	76.7
FRS7	55.1	52.4	50.4	74.7	71.0	68.3
FRS8	60.8	60.9	62.5	82.4	82.6	84.7
FRS9	35.7	39.4	39.9	48.4	53.4	54.1
FRS10	79.5	80.5	78.2	107.8	109.1	106.0
FRS11	54.9	53.0	53.6	74.4	71.9	72.7
FRS12	39.7	45.2	32.6	53.8	61.3	44.2
FRS13	74.0	69.0	73.2	100.3	93.6	99.2

APPENDIX VIII

Participant Demographics

Subject	Height (cm)	Weight (kg)	Age	Dominant Leg
FRS1	168.5	60.9	30	Right
FRS2	175	78.6	23	Right
FRS3	165.5	64.5	27	Right
FRS4	167	55.9	37	Right
FRS5	168.5	64.5	39	Right
FRS6	162	51.8	18	Right
FRS7	169.5	70.5	20	Right
FRS8	165	65.0	23	Right
FRS9	152	62.3	31	Right
FRS10	177	79.5	37	Right
FRS11	160	55.9	30	Right
FRS12	159	57.3	23	Left
FRS13	162	67.7	32	Right

APPENDIX IX

Analysis of Flexibility

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
Height	13	152.0	177.0	165.462	6.6972	-.140	.616	.336	1.191
Weight	13	51.8	79.5	64.185	8.4056	.577	.616	-.191	1.191
Age	13	18	39	28.46	6.790	.076	.616	-1.141	1.191
Valid N (listwise)	13								

Descriptive Statistics

	Mean	Std. Deviation	N
FlexPre1	47.008	7.1620	13
FlexPre2	48.369	7.5314	13
FlexPost	50.223	7.3873	13

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[c]
Time	Pillai's Trace	.763	17.658[b]	2.000	11.000	.000	.763	35.317	.997
	Wilks' Lambda	.237	17.658[b]	2.000	11.000	.000	.763	35.317	.997
	Hotelling's Trace	3.211	17.658[b]	2.000	11.000	.000	.763	35.317	.997
	Roy's Largest Root	3.211	17.658[b]	2.000	11.000	.000	.763	35.317	.997

a. Design: Intercept

Within Subjects Design: Time

b. Exact statistic

c. Computed using alpha = .05

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Time	.496	7.703	2	.021	.665	.717	.500

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

a. Design: Intercept

Within Subjects Design: Time

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

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Time	Sphericity Assumed	67.727	2	33.863	18.082	.000	.601	36.164	1.000
	Greenhouse-Geisser	67.727	1.330	50.915	18.082	.000	.601	24.052	.993
	Huynh-Feldt	67.727	1.433	47.254	18.082	.000	.601	25.916	.995
	Lower-bound	67.727	1.000	67.727	18.082	.001	.601	18.082	.973
Error (Time)	Sphericity Assumed	44.947	24	1.873					
	Greenhouse-Geisser	44.947	15.962	2.816					
	Huynh-Feldt	44.947	17.199	2.613					
	Lower-bound	44.947	12.000	3.746					

a. Computed using alpha = .05

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	Time	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Time	Linear	67.202	1	67.202	23.048	.000	.658	23.048	.992
	Quadratic	.525	1	.525	.633	.442	.050	.633	.114
Error (Time)	Linear	34.988	12	2.916					
	Quadratic	9.958	12	.830					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	91863.893	1	91863.893	578.332	.000	.980	578.332	1.000
Error	1906.113	12	158.843					

a. Computed using alpha = .05

Estimates

Measure: MEASURE_1

Time	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	47.008	1.986	42.680	51.336
2	48.369	2.089	43.818	52.920
3	50.223	2.049	45.759	54.687

Pairwise Comparisons

Measure: MEASURE_1

(I) Time	(J) Time	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	-1.362	.564	.098	-2.928	.205
	3	-3.215*	.670	.001	-5.077	-1.354
2	1	1.362	.564	.098	-.205	2.928
	3	-1.854*	.313	.000	-2.725	-.983
3	1	3.215*	.670	.001	1.354	5.077
	2	1.854*	.313	.000	.983	2.725

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

APPENDIX X

Analysis of Isometric Torque

Descriptive Statistics

	Mean	Std. Deviation	N
IsomPre1	62.808	9.7697	13
IsomPre2	63.069	12.5969	13
IsomPost	59.931	14.8072	13

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[c]
Time	Pillai's Trace	.205	1.421[b]	2.000	11.000	.282	.205	2.842	.242
	Wilks' Lambda	.795	1.421[b]	2.000	11.000	.282	.205	2.842	.242
	Hotelling's Trace	.258	1.421[b]	2.000	11.000	.282	.205	2.842	.242
	Roy's Largest Root	.258	1.421[b]	2.000	11.000	.282	.205	2.842	.242

a. Design: Intercept

Within Subjects Design: Time

b. Exact statistic

c. Computed using alpha = .05

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Time	.846	1.838	2	.399	.867	1.000	.500

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

a. Design: Intercept

Within Subjects Design: Time

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

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Time	Sphericity Assumed	78.845	2	39.423	1.080	.356	.083	2.160	.217
	Greenhouse-Geisser	78.845	1.733	45.489	1.080	.349	.083	1.872	.202
	Huynh-Feldt	78.845	2.000	39.424	1.080	.356	.083	2.160	.217
	Lower-bound	78.845	1.000	78.845	1.080	.319	.083	1.080	.160
Error (Time)	Sphericity Assumed	876.142	24	36.506					
	Greenhouse-Geisser	876.142	20.799	42.123					
	Huynh-Feldt	876.142	23.999	36.507					
	Lower-bound	876.142	12.000	73.012					

a. Computed using alpha = .05

APPENDIX XI

Analysis of Isokinetic Torque

Descriptive Statistics

	Mean	Std. Deviation	N
IsokPre1	78.800	19.4333	13
IsokPre2	79.208	15.5704	13
IsokPost	78.769	18.3866	13

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[c]
Time	Pillai's Trace	.007	.041[b]	2.000	11.000	.960	.007	.082	.055
	Wilks' Lambda	.993	.041[b]	2.000	11.000	.960	.007	.082	.055
	Hotelling's Trace	.007	.041[b]	2.000	11.000	.960	.007	.082	.055
	Roy's Largest Root	.007	.041[b]	2.000	11.000	.960	.007	.082	.055

a. Design: Intercept

Within Subjects Design: Time

b. Exact statistic

c. Computed using alpha = .05

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Time	.999	.013	2	.993	.999	1.000	.500

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

a. Design: Intercept

Within Subjects Design: Time

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

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Time	Sphericity Assumed	1.557	2	.779	.043	.958	.004	.086	.056
	Greenhouse-Geisser	1.557	1.998	.780	.043	.958	.004	.086	.056
	Huynh-Feldt	1.557	2.000	.779	.043	.958	.004	.086	.056
	Lower-bound	1.557	1.000	1.557	.043	.839	.004	.043	.054
Error (Time)	Sphericity Assumed	434.189	24	18.091					
	Greenhouse-Geisser	434.189	23.971	18.113					
	Huynh-Feldt	434.189	24.000	18.091					
	Lower-bound	434.189	12.000	36.182					

a. Computed using alpha = .05

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