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SYSTEMATIC REVIEW

DURATION OF MYOFASCIAL ROLLING FOR OPTIMAL RECOVERY, RANGE OF MOTION, AND PERFORMANCE: A SYSTEMATIC REVIEW OF THE LITERATURE

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ABSTRACT

Background: Knowledge of the body's response to and recovery from exercise is rapidly increasing. State-of-the-art equipment and facilities allow recreationally active adults to seek innovations to enhance performance and shorten recovery time. Myofascial rolling (MR) is a relatively new practice, providing acute benefits for muscle pain and range of motion (ROM). However, there is no consensus on optimal MR duration.

Purpose: The purpose of this systematic review is to determine the optimal MR duration using a foam roller or a roller massager for muscle pain, ROM, and athletic performance via qualitative review.

Study Design: Systematic Review of the Literature

Methods: A systematic search was conducted using PubMed, EMBASE, EBSCOHost and PEDro (July 2018). Twenty-two studies met the inclusion criteria and were appraised using the PEDro scale. Studies were grouped by outcome measure, with a total number of subjects of n = 328 for pain/soreness, n = 398 for ROM, and n = 241 for performance. Heterogeneity of data prohibited a formal meta-analysis: studies were manually reviewed and classified as providing evidence for benefit of MR (i.e., significant positive effect) or not (i.e., null or negative effect) for each of the studied outcomes.

Results: The most evidence-based benefit of MR is the alleviation of muscle soreness; seven of eight studies assessing pain/soreness resulted in a short-term reduction, and a minimum dose of 90 seconds per muscle appeared beneficial. While ten of 17 studies involving ROM showed acute improvements, the results were inconsistent and highly variable. No significant effects on performance were detected.

Conclusion: Available data indicate that MR for 90 seconds per muscle group may be the minimal duration to achieve a short-term reduction in pain/soreness, with no upper limit found. Results do not support increases in chronic ROM or performance, and data are insufficient to provide a conclusive recommendation for impacting acute ROM. The heterogeneity of the literature highlights the need for additional research to determine optimal dose of MR.

Level of evidence: 2a- (Systematic Review with heterogeneity).

Keywords: Athletic performance; dose; movement system; myofascial rolling; pain; range of motion

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INTRODUCTION

Performance among high-level athletes is undeniably improving. While there are many factors involved, advancements in technology and understanding of anatomy and physiology are the largest contributors.[1–3] These advancements in high-level athletics have downstream effects on the wider population: recreationally active people at all ages and levels seek new information to improve their personal training regimens, whether it is based on clinical recommendation or athlete/celebrity endorsement. When a new training system or recovery tool is introduced and promoted, it is rapidly and widely adopted by people anxious to improve their performance or shorten their subsequent recovery. Importantly, clinicians rely on these therapeutic advancements to expedite their patients' return to function and improved quality of life.

Myofascial rolling (MR) using a foam roller (FR) or a roller massager (RM) is a relatively new treatment method, accompanied by a recent surge in new literature. MR with a FR involves rolling along the length of the targeted muscle belly on the device, using one's body weight in a laying or seated position to determine the desired treatment pressure. The same concept is applied to MR with a RM, except the individual handles the device and rolls it along the targeted muscle belly, dictating the applied pressure using their upper limbs. A typical FR and a typical RM are shown in Figure 1. Despite the widespread use of MR, there is currently no agreement on the physiological effects of FR or RM-assisted MR, though it has been postulated that applying deep pressure can reduce fascial adhesions,[4,5] improve fascial viscosity and mobility,[6,7] and alter mechanoreceptor response in the myofascial unit.[6,8,9]

Research examining the clinical effects of MR has increased considerably over the past decade; however, a true consensus on the benefits and potential risks of MR has not been established. Some available data suggest that MR acutely increases range of motion (ROM) and/or reduces pain or soreness while simultaneously limiting decrements to athletic performance.[4,9–11] However, the existing data are highly heterogeneous, making a true quantitative review challenging. Therefore, a qualitative review of quantitative data is needed to determine true effects.

Figure 1. *Example of a typical foam roller (left) and a roller massager (right).*

To date, a handful of literature reviews have been conducted on the effectiveness of MR using rollers.[4,9–12] While these have indicated that MR is useful in improving pain/soreness and ROM outcomes, there is little information to establish the optimal MR treatment duration. In the clinical setting, practitioners have limited time with their clients: in order to optimize time in training or rehabilitation, clinicians need information on the minimum duration of treatment to confer benefit, and on whether extending the duration of treatment produces more benefit. If a clinician knows that devoting one minute to a treatment versus 10 minutes will yield the same outcome, they can use the extra time for other treatment, increasing rehabilitation efficiency. Consequently, this systematic review aimed to determine the optimal MR duration using a FR or a RM for reducing muscle pain/soreness, increasing ROM, and improving athletic performance.

METHODS

Systematic literature review

This review was conducted in accordance with PRISMA guidelines.[13] In July 2018, a systematic search of PubMed, EMBASE, and EBSCOHost was conducted, using the following search terms: foam roll; roller massager; time; duration; pressure; pain; myalgia; delayed-onset muscle soreness; range of motion;

athletic performance; acute pain; chronic pain; musculoskeletal pain. The terms were then combined with the appropriate Boolean connectors according to a PICO search table: each term under "population", "intervention", "comparison", and "outcome" (PICO) were combined within groups with "OR", while each term between groups were combined with "AND". The search strategy did not target a specific population; however, only apparently healthy populations (i.e., no special populations) were included. A manual search of the Physiotherapy Evidence Database (PEDro) was also conducted using the same strategy. No date or language restrictions were implemented when searching the databases.

Exclusion criteria

One reviewer screened titles and abstracts. Studies were excluded if they did not satisfy the following: i) Were published in an English language, peer-reviewed journal; ii) Incorporated FR or RM (or both) as the primary intervention(s); iii) Directly compared the intervention to an independent control group; iv) Considered at least one of the following primary outcome measures: acute pain, chronic pain, muscle soreness, range of motion, athletic/muscular performance; v) Specified the duration of treatment in the Methods; and vi) Studied healthy participants or those with no existing chronic conditions that might influence results of an athletic test (e.g. arthritis or cardiovascular disease). Articles that passed the screening then underwent a full-text review by two reviewers to be further examined for eligibility.

The systematic and manual searches identified 113 articles. From there, 69 studies were removed due to being duplicates (n = 57), reviews (n = 8) or abstracts (n = 4). The remaining 44 studies were considered for full review; after applying the inclusion criteria, 16 studies were removed after abstract review, and six additional studies were removed after full-text review. The flow chart summarizing the systematic review can be found in Figure 2.

Data Quality and Analysis

The quality of included studies was assessed by two independent reviewers according to the Physiotherapy Evidence Database (PEDro) scale, developed to rate the quality of RCTs evaluating physical therapist interventions based on their methodological quality and reliability (Table 1).[14–16] Among the available data, the population demographics, intervention type and protocol, outcome measures, and results were extracted for analysis. Studies were grouped by outcome measure for analysis of their interventions' effect on the study population. Upon grouping, each study's intervention duration and their general study conclusion (positive, negative, or null result) were combined to construct a linear plot illustrating dose-response indications in the literature.

RESULTS

The results of the 22 qualifying studies were grouped according to outcome measure (i.e., ROM, pain/soreness, and performance). Including studies analyzing multiple outcomes, there were eight studies examining pain/soreness, 17 measuring ROM, and 12 that assessed some aspect of athletic performance. In total, 16 studies involved a FR as their main intervention, while the remaining six used a RM. Areas treated by either a FR or a RM and used for subsequent test/retest in the qualifying studies included the gluteals (n = 4), the hip flexors (n = 1), the quadriceps (n = 12), the hamstrings (n = 10), the iliotibial band (n = 4), the adductors (n = 4), and the plantar flexors (n = 8). Similar to previous reviews on this topic, 4, 10, 12 even with separated outcome measures the heterogeneity of studies made data consolidation and meta-analysis invalid.

Population Characteristics

The combined population of participants in the 22 studies was n = 644. One study17 did not disclose the sex of their subjects (n = 40) and was therefore not included in analysis of sexual distribution. Of the remaining 604 subjects, 62.9% were male (n = 380) and 37.1% were female (n = 224). Separated by outcome measure, there were n = 328 subjects (63.4% male, n = 208 and 36.6% female, n = 120) in studies relating to pain/soreness,18–25 n = 398 for ROM (72.3% male, n = 259 and 27.7% female, n = 139),[8,19,20,22,23,26–36] and n = 241 (60.2% male, n = 145 and 39.8% female, n = 96) for athletic performance.[8,19,21,23,24,26,28–30,32,34,37] The typical study participant across all outcomes was a recreationally active adult (e.g. moderately active two to three times per week), aged between 18 to 47 years (mean +/- standard deviation [SD] = 25.0 +/- 5.54 years).

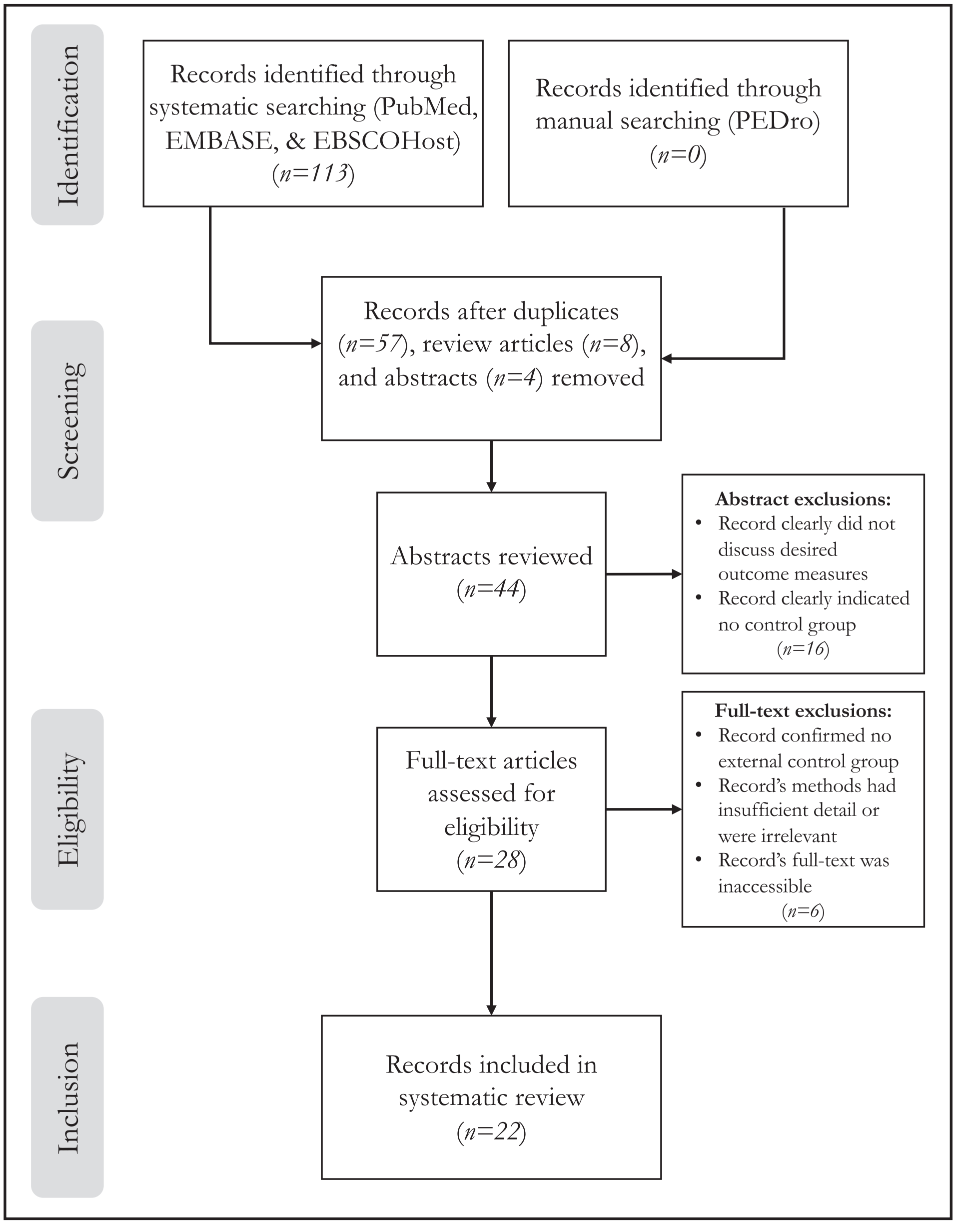

Figure 2. *Selection Strategy Flowchart.*

One study18 did not disclose the ages of their participants (n = 150) beyond describing them as university-aged; they were therefore omitted from the age distribution analysis. For pain/soreness, ages ranged from 19 to 47 years (26.0 +/- 5.34 years), with 93% of the participants (n = 306) being at least recreationally active on a regular basis. ROM participant ages ranged from 18 to 47 years (24.9 +/- 5.98 years), the large majority (93.0%, n = 370) of which were also at least recreationally active on a regular basis. Finally, subjects in studies relating to athletic performance had no age range available (24.0 +/- 4.05 years), with 97.5% of the participants (n = 235) being at least recreationally active on a regular basis.

Dose-Response Analysis

Appendices 1-3 describe the design and results of the 22 included studies relating to (1) pain/soreness, (2) ROM, and (3) athletic performance. The results column includes only the results that are pertinent to the selected outcomes of this review; they are not an exhaustive list of all the outcome measures assessed by the original study authors. Figures 3 and

Table 1. *PEDro scores for included studies.*

	1	2	3	4	5	6	7	8	9	10	11	Total Score
Aboodarda et al	Y	Y	N	Y	Y	N	Y	Y	Y	Y	Y	9
Bradbury-Squires et al	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	7
Bushell et al	Y	N	N	Y	Y	N	N	Y	Y	Y	Y	7
Casanova et al	Y	N	N	Y	N	N	N	Y	Y	Y	Y	6
Cheatham et al	Y	Y	N	Y	Y	N	N	Y	Y	Y	Y	8
D'Amico & Paolone	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	7
Fleckenstein et al	Y	Y	N	Y	Y	N	N	Y	Y	Y	Y	8
Jay et al	Y	Y	N	Y	N	N	Y	Y	Y	Y	Y	8
Junker & Stoggl	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	7
Kelly & Beardsley	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	7
MacDonald et al (2014)	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	7
MacDonald et al (2013)	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	7
Macgregor et al	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	7
Mohr et al	Y	Y	N	Y	Y	N	N	Y	Y	Y	Y	8
Monteiro et al	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	7
Morales-Artacho et al	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	7
Pearcey et al	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	7
Phillips et al	Y	Y	N	Y	Y	N	N	Y	Y	Y	Y	8
Smith et al	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	7
Sullivan et al	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	7
Wilke et al	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	7
Young et al	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	7

PEDro scale: 1 = eligibility criteria was specified; 2 = subjects were randomly allocated to groups; 3 = allocation was concealed; 4 = similar groups at baseline; 5 = all subjects were blinded; 6 = all therapists were blinded; 7 = all assessors were blinded; 8 = at least one outcome measure obtained from >85% of allocated subjects; 9 = all subjects received either intervention or control; 10 = results of between-group statistical comparisons reported for at least one outcome; 11 = point measures and measures of variability for at least one outcome were reported

4 illustrate the linear distribution of studies grouped by outcome based on their MR intervention duration. Green circles denote statistically significant positive results and red X's denote null or statistically negative results. In Figure 3, MR durations in each study have been summed to generate a value equal to the total duration of one MR session across all assessed muscle groups. Conversely, Figure 4 displays the duration of MR per muscle group, as some studies involved the rolling of multiple muscle groups for a set amount of time each.

Pain/Soreness

Overall, results for the recovery from muscle pain/soreness indicated that the use of MR for any duration would improve a subject's outcome. When analyzed by total time spent treating the subject (Figure 3), no dose-response is present and the single non-significant result[21] can be considered an outlier. However, when separated by total time treating a single muscle group (Figure 4), the data points shift slightly and a minimum dose can be observed. Foam rolling a single muscle group for under 45 seconds may indeed be insufficient for adequate recovery from muscle pain or acute/chronic muscle soreness. Further, the positive result seen at 45 seconds per muscle group[24] draws conclusions based upon magnitude-based inferences[38] (% likelihood) as opposed to including effect sizes (Cohen's d) or tests of significance (p-value) like many of the other experiments. More robust results were seen in studies that intervened for durations between 90 and 600 seconds per muscle group,[18–20,22,23,25] suggesting that a minimum dose of 90 seconds is most reliable and is best suited for recovery of muscle pain/soreness.

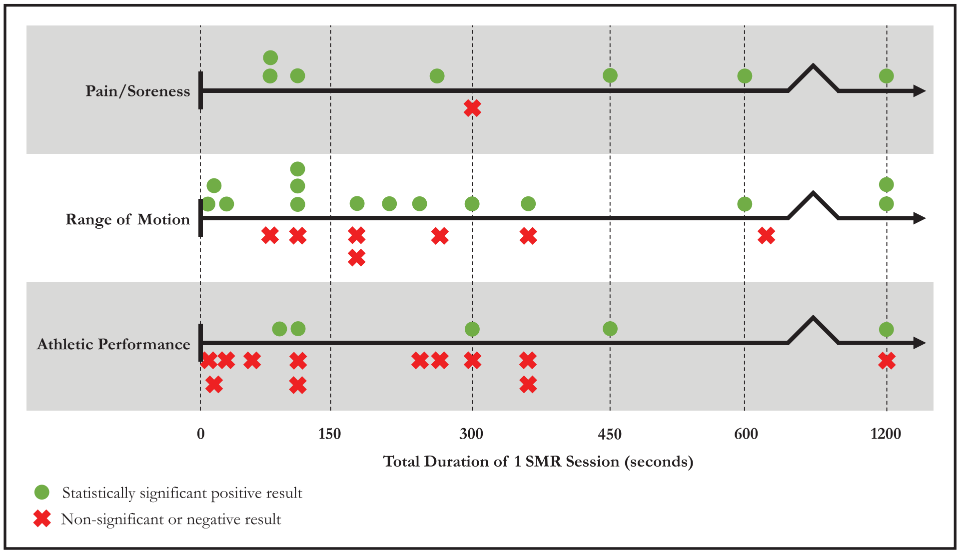

Figure 3. *Effect of total Self-Myofascial Release (SMR) duration using a foam roller or a roller massager, in seconds, on each of the three indicated outcome measures. Each green circle or red X denotes a unique study result. Some studies appear in multiple outcomes, and some studies have multiple SMR durations per outcome.*

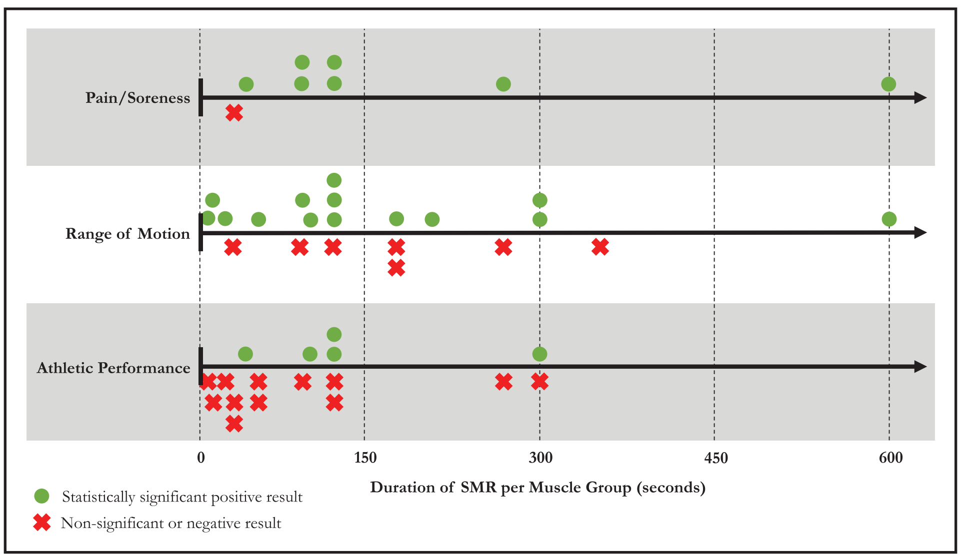

Figure 4. *Effect of Self-Myofascial Release (SMR) duration per muscle group using a foam roller or a roller massager in seconds on each of the three indicated outcome measures. Each green circle or red X denotes a unique study result. Some studies appear in multiple outcomes, and some studies have multiple SMR durations per outcome.*

In terms of a true dose-response trend (i.e. longer MR sessions leading to more lasting effects), the heterogeneity of studies made this difficult to discern. For example, the study with the longest single-muscle MR duration (hamstrings for one set of 600 seconds)[22] measured the effects up to 60 minutes post-MR. While they achieved a statistically significant reduction in muscle soreness versus both their control and within-subject control groups, another study intervened with only 120 seconds per muscle (five hip and thigh muscles, bilaterally)[23] and observed a decrease in muscle soreness lasting 72 hours post-MR. However, these studies differed in many areas, including the SMR tool they used (FR versus RM), fitness level of their study population, muscle groups that they treated, muscle soreness data collection method (algometer versus rating scale), and statistics that they analyzed (p-value versus Cohen's d). It is worth noting, meanwhile, that when considering the total duration of a single MR session (Figure 3), the study with the longest total MR duration (1200 seconds)[23] also resulted in the longest lasting significant effect (72 hours). Otherwise, most studies assessing muscle pain and soreness[18,19,24,25] noted the acute and transient nature of their results, suggesting that MR is an effective option only for short-term relief.

Range of Motion

The results for MR's effect on ROM are much less clear. In total, 10 of 17 studies reported statistically significant ROM improvements of some kind,[17,20,22,23,26,28–30,32,35] with no ideal MR duration apparent. Similarly, when split by studies that tested ROM by active versus passive means, five of nine studies measuring active ROM showed significant improvements[22,28–30,35] while five of eight studies measuring passive ROM studies noted the same.[17,20,23,26,32] Among the methods used to assess ROM, the kneeling lunge test (for the hip flexors) was the most common with five studies opting for that technique;[8,23,26,28,32] however, the fact that a total of ten different methods were used in 17 different studies to assess ROM about various joints demonstrates that the variation is too large to directly compare results. In terms of MR duration, the results were spread evenly across all time points. There was also a near equal split of positive and negative trials appearing on both sides of the MR duration line when considering both the total MR session duration and the total time spent on one muscle (Figures 3 & 4). From this, it is not possible to provide conclusive support of an optimal MR duration, and further trials are needed to rigorously test and retest (using similar testing protocols) the effect of MR on ROM.

Athletic Performance

Athletic performance was minimally affected by MR. While ROM was difficult to interpret due to its wide array of testing techniques, assessing MR's effect on performance is challenging as there are multiple operational definitions of "athletic performance" and many ways to measure it. Included among the outcome measures are dynamic tests like the vertical jump test or an 800-meter run test. Likewise, tests of maximal voluntary contraction (MVC) and submaximal electromyography (EMG) were also used as measures of athletic performance, exacerbating the challenge of combining data. Assessing results as either a significant positive result, a non-significant result, or a significant negative result (as in Figures 3 & 4), demonstrates that MR using either a FR or a RM does not typically provide an individual with a performance increase. Both positive and negative results are spread out along the duration line, so it is not possible to discern a recommended MR duration time for optimal athletic performance. Three of the four studies that reported a performance increase post-MR[8,23,24] noted that the effects lasted up to 72 hours post treatment (the fourth did not perform follow-up testing)[32]. Conversely, the results of another study[19] directly contradicted this finding, showing no effect on performance versus control at any time point for 72 hours. One study,[37] however, analyzed the effects of two different FR durations of the hamstring (60 or 120 seconds) on the maximum number of subsequent consecutive knee extension repetitions. While both FR durations resulted in a decrease in repetitions versus control, they noted a dose-response: the longer the FR duration, the fewer repetitions their subjects were able to perform.

DISCUSSION

This systematic review sought to determine a consensus on MR duration for optimal muscle pain/soreness recovery, ROM, and athletic performance. The results of this review suggest that MR using a FR or a RM for at least 90 seconds per muscle will acutely alleviate muscle soreness; the current literature also suggests that a longer treatment duration extends the duration of analgesic effects, although this effect is non-linear. Nonetheless, more robust data are needed to confirm these findings, as the data studied here are highly heterogeneous. While many studies did report an acute positive effect at varying intervention durations, the long-term effectiveness of MR for ROM remains inconclusive. As the underlying physiological effect of MR is still uncertain, improving subject ROM via MR may vary across individuals, and whether ROM is restricted by pain or by true myofascial stiffness (discussed later in the Nociceptor Involvement section). Finally, the literature indicates that MR has little effect on improving or enhancing athletic performance at any duration, and actually suggests that performance may begin to suffer progressively with longer treatment. Although the effects of MR are inconclusive for acute and chronic ROM, and MR may be detrimental to athletic performance, the authors suggest that MR for approximately 90 seconds per unilateral muscle group may be the most efficient duration to achieve a reduction in muscle pain/soreness.

With the rise in MR popularity over the past decade, research on the topic is recent but remains limited in scope: all 22 studies included in this review were published between 2013 and 2018. Recent reviews examining measurable effects of FR and RM's have come to similar conclusions;[4,9,10,12] however, a common theme was the emphasis on determining the optimal duration of MR. Therefore, this review analyzed the topic by separating the literature into three main outcome measures: muscle pain/soreness recovery, ROM, and athletic performance.

The current consensus in the literature regarding MR is that it reduces soreness and improves ROM with limited decrements in performance.[4,9–11] The available data indicate that MR is a recovery tool rather than a performance enhancer; consequently, negative plot points (those indicating no effect, not those indicating a negative effect) on Figures 3 and 4 can be considered a positive result assuming the main goal is an reduction in soreness or an increase in ROM. Since data from one study indicate a negative MR dose-response for performance[37] and the available evidence indicates that muscle pain and soreness can decrease after approximately 90 seconds of MR, the authors believe an MR duration of roughly 90 seconds per muscle is ideal to maximize the positive benefit of pain/soreness recovery while minimizing the decrement to performance.

Nociceptor Involvement

The mechanism(s) underlying the analgesic effects of MR are ill-defined. Recent findings have identified nociceptors within multi-layered fascia in rats, with researchers postulating that these nociceptors may play a role in chronic muscle pain.[39] As is well established, pain is often associated with limited ROM, while non-neurological tension signs in addition to pain further limit ROM.[40,41] When considering this in the context of recent data on MR, a persistent question emerges: does MR truly mobilize the myofascial unit, or does it simply dampen the nociceptive response, allowing those with limited ROM due to pain to move beyond their baseline measurements?

The study by Young et al[25] (included within the pain/soreness section, Appendix 1) examined this phenomenon, assessing whether or not using a RM on the plantar flexors would reduce spinal excitability, thus increasing a subject's pain-pressure threshold (PPT). They determined that spinal excitability decreased post-RM, with a pressure-dependent response observed (i.e., more pressure led to more neurological inhibition). This response suggested a fast-adaptation: spinal excitability quickly recovered from its response-dampened state in under three minutes. This result appeared as a consistent trend in the majority of studies that observed a significant increase in ROM post-MR; although flexibility improves, the results were transient and only remained significant for a short period of time after MR. One possible interpretation of these findings is that restricted ROM derived from pain/soreness is amenable to improvement via MR, while ROM that is truly restricted by myofascial tightness is non-responsive. Clearly, further research is required to test this hypothesis.

Additionally, studies by both Aboodarda et al[18] and Cavanaugh et al[42] have found evidence of a global pain modulatory system through their observed effects of roller massaging. Both author's results noted that with three, 30-second RM treatments on the same muscle, there was a significantly smaller increase in pain experienced post-RM intervention in both the ipsilateral and contralateral limb, even though the contralateral limb had not been touched by the intervention. As this directly contradicts early ideas of purported MR mechanisms (i.e., reduced fascial adhesions, improved fascial viscosity and mobility, and altered mechanoreceptor response in the myofascial unit), this further supports the notion that the effects of MR are grounded in cross-over effects of neurological basis. If, conversely, the effects of MR were due to alterations in the mechanical properties of the tissue, one would expect to see ipsilateral effects, local only to the tissue treated. However, as evidence has shown transient, non-local effects in the reduction of pain/soreness, it suggests that MR acts on a neurological basis, with recent evidence suggesting the presence of a global pain modulatory system likely within the central nervous system.

Limitations

Several factors limit the conclusiveness of these findings. As demonstrated above, the heterogeneity of MR research is the overarching issue in the relevant literature. When searching for a consensus on the optimal MR duration, no significant number of studies were similar enough for direct comparison; as testing protocols contained too much variation. Studies often analyzed different muscle groups and utilized different muscle soreness/ROM/performance measurements (e.g., testing active versus passive ROM, or measuring pain on a subjective rating scale versus using an algometer). Similarly, there was minimal statistical consistency: not all studies included the same statistics to permit data pooling. This did not allow for true quantitative data analysis, which restricted this review to a qualitative investigation. Another uncertainty among MR research is in regard to the potential lasting effects. Unfortunately, most studies did not assess their subjects with long-term follow-ups to determine if the effects were retained, but rather conducted a same-day test/retest protocol and collected data solely in the acute setting.

CONCLUSION

Available data indicate that MR for 90 seconds per unilateral muscle group may be the minimal duration to achieve a reduction in pain/soreness, with no upper limit found. While the analgesic effects were transient in nature, the longer time spent on MR, the longer the effects seemed to last; however, these results are non-linear and require further investigation to arrive at a consensus. Results do not support increases in chronic ROM or performance, and data are insufficient to provide a conclusive recommendation regarding acute ROM. The heterogeneity of the literature highlights the need for additional research to determine optimal dose of MR.

REFERENCES

1. Haake SJ. The impact of technology on sporting performance in Olympic sports. *J Sports Sci*. 2009;27(13):1421-1431.
2. Balmer N, Pleasence P, Nevill A. Evolution and revolution: gauging the impact of technological and technical innovation on Olympic performance. *J Sports Sci*. 2012;30(11):1075-1083.
3. Tjønndal A. Sport innovation: developing a typology. *Eur J Sport Soc*. 2017;14(4):291-310.
4. Schroeder AN, Best TM. Is self myofascial release an effective preexercise and recovery strategy? A literature review. *Curr Sports Med Rep*. 2015;14(3):200-208.
5. Dommerholt J, Finnegan M, Hooks T, Chou LW. A critical overview of the current myofascial pain literature – October 2017. *J Bodyw Mov Ther*. 2017;21(4):902-913.
6. Schleip R. Fascial plasticity - a new neurobiological explanation. Part 2. *J Bodyw Mov Ther*. 2003;7(2):104-116.
7. Barnes MF. The basic science of myofascial release: morphologic change in connective tissue. *J Bodyw Mov Ther*. 1997;1(4):231-238.
8. Macgregor LJ, Fairweather MM, Bennett RM, Hunter AM. The effect of foam rolling for three consecutive days on muscular efficiency and range of motion. *Sport Med - Open*. 2018;4(26).
9. Beardsley C, Škarabot J. Effects of self-myofascial release: a systematic review. *J Bodyw Mov Ther*. 2015;19(4):747-758.
10. Cheatham SW, Kolber MJ, Cain M, Lee M. The effects of self-myofascial release using a foam roll or roller massager on joint range of motion, muscle recovery, and performance: a systematic review. *Int J Sports Phys Ther*. 2015;10(6):827-838.
11. Kalichman L, David C Ben. Effect of self-myofascial release on myofascial pain, muscle flexibility, and strength: A narrative review. *J Bodyw Mov Ther*. 2017;21(2):446-451.
12. Laimi K, Mäkilä A, Bärlund E, et al. Effectiveness of myofascial release in treatment of chronic musculoskeletal pain: a systematic review. *Clin Rehabil*. 2018;32(4):440-450.
13. Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gøtzsche PC, John PA. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions: explanation and elaboration. *BMJ*. 2009:339-342.
14. Herbert R, Moseley A, Sherrington C. PEDro: a database of randomised controlled trials in physiotherapy. *Heal Inf Manag*. 1998;28(4):186-188.
15. De Morton NA. The PEDro scale is a valid measure of the methodological quality of clinical trials: a demographic study. *Aust J Physiother*. 2009;55(2):129-133.

16. Macedo L, Elkins M, Maher C, Moseley A, Herbert R, Sherrington C. There was evidence of convergent and construct validity of Physiotherapy Evidence Database quality scale for physiotherapy trials. *J Clin Epidemiol*. 2010;63(8):920-925.
17. Mohr AR, Long BC, Goad CL. Effect of foam rolling and static stretching on passive hip-flexion range of motion. *J Sport Rehabil*. 2014;23:296-299.
18. Aboodarda SJ, Spence AJ, Button DC. Pain pressure threshold of a muscle tender spot increases following local and non-local rolling massage. *BMC Musculoskelet Disord*. 2015;16.
19. Casanova N, Reis JF, Vaz JR, et al. Effects of roller massager on muscle recovery after exercise-induced muscle damage. *J Sports Sci*. 2018;36(1):56-63.
20. Cheatham SW, Stull KR, Kolber MJ. Comparison of a vibrating foam roller and a non-vibrating foam roller intervention on knee range of motion and pressure pain threshold: a randomized controlled trial. *J Sport Rehabil*. 2017.
21. Fleckenstein J, Wilke J, Vogt L, Banzer W. Preventive and regenerative foam rolling are equally effective in reducing fatigue-related impairments of muscle function following exercise. *J Sport Sci Med*. 2017;16:474-479.
22. Jay K, Sundstrup E, Søndergaard SD, et al. Specific and cross over effects of massage for muscle soreness: randomized controlled trial. *Int J Sports Phys Ther*. 2014;9(1):82-91.
23. MacDonald GZ, Button DC, Drinkwater EJ, Behm DG. Foam rolling as a recovery tool after an intense bout of physical activity. *Med Sci Sports Exerc*. 2014;46(1):131-142.
24. Pearcey GEP, Bradbury-Squires DJ, Kawamoto J-E, Drinkwater EJ, Behm DG, Button DC. Foam rolling for delayed-onset muscle soreness and recovery of dynamic performance measures. *J Athl Train*. 2015;50(1):5-13.
25. Young JD, Spence A-J, Behm DG. Roller massage decreases spinal excitability to the soleus. *J Appl Physiol*. 2018;124:950-959.
26. MacDonald GZ, Penney MDH, Mullaley ME, et al. An acute bout of self-myofascial release increases range of motion without a subsequent decrease in muscle activation or force. *J Strength Cond Res*. 2013;27(3):812-821.
27. Morales-Artacho AJ, Lacourpaille L, Guilhem G. Effects of warm-up on hamstring muscles stiffness: cycling vs foam rolling. *Scand J Med Sci Sport*. 2017;27:1959-1969.
28. Phillips J, Diggin D, King DL, Sforzo GA. Effect of varying self-myofascial release duration on subsequent athletic performance. *J Strength Cond Res*. 2018;0(0):1-8.
29. Smith JC, Pridgeon B, Hall MC. Acute effect of foam rolling and dynamic stretching on flexibility and jump height. *J Strength Cond Res*. 2018;32(8):2209-2215.
30. Sullivan KM, Silvey DBJ, Button DC, Behm DG. Roller-massager application to the hamstrings increases sit-and-reach range of motion within five to ten seconds without performance impairments. *Int J Sports Phys Ther*. 2013;8(3):228-236.
31. Wilke J, Niemeyer P, Niederer D, Schleip R, Banzer W. Influence of foam rolling velocity on knee range of motion and tissue stiffness: a randomized, controlled crossover trial. *J Sport Rehabil*. 2018.
32. Bradbury-Squires DJ, Noftall JC, Sullivan KM, Behm DG, Power KE, Button DC. Roller-massager application to the quadriceps and knee-joint range of motion and neuromuscular efficiency during a lunge. *J Athl Train*. 2015;50(2):133-140.
33. Bushell JE, Dawson SM, Webster MM. Clinical relevance of foam rolling on hip extension angle in a functional lunge position. *J Strength Cond*. 2015;29(9):2397-2403.
34. D'Amico A, Paolone V. The effect of foam rolling on recovery between two eight hundred metre runs. *J Hum Kinet*. 2017;57:97-105.
35. Junker DH, Stöggl TL. The foam roll as a tool to improve hamstring flexibility. *J Strength Cond Res*. 2015;29(12):3480-3485.
36. Kelly S, Beardsley C. Specific and cross-over effects of foam rolling on ankle dorsiflexion range of motion. *Int J Sports Phys Ther*. 2016;11(4):544-551.
37. Monteiro ER, Škarabot J, Vigotsky AD, Brown AF, Gomes TM, Novaes J da S. Maximum repetition performance after different antagonist foam rolling volumes in the inter-set rest period. *Int J Sports Phys Ther*. 2017;12(1):76-84.
38. Welsh AH, Knight EJ. '"Magnitude-based inference"': a statistical review. *Med Sci Sports Exerc*. 2015;47(4):874-884.
39. Mense S, Hoheisel U. Evidence for the existence of nociceptors in rat thoracolumbar fascia. *J Bodyw Mov Ther*. 2016;20(3):623-628.
40. Pearcy M, Portek I, Shepherd J. The effect of low-back pain on lumbar spinal movements measured by three-dimensional x-ray analysis. *Spine (Phila Pa 1976)*. 1985;10(2):150-153.
41. Holmes B, Leggett S, Mooney V, Nichols J, Negri S, Hoeyberghs A. Comparison of female geriatric lumbar-extension strength: asymptomatic versus chronic low back pain patients and their response to active rehabilitation. *J Spinal Disord*. 1996;9(1):17-22.
42. Cavanaugh MT, Döweling A, Young JD, et al. An acute session of roller massage prolongs voluntary torque development and diminishes evoked pain. *Eur J Appl Physiol*. 2017;117(1):109-117.

Appendix 1. *Description of Included Studies: Outcomes Relating to Pain/Soreness.*

Author	Tool	Study Population	Muscle(s) Treated	Duration of FR/RM#	Results
***Aboodarda et al**[15]	RM	• n=150 (80 males, 70 females) • Recreationally active adults • Exhibited point tenderness on plantar flexors	• Plantar flexors	• 3 sets of 30s, with 30s rest between sets • 90s total	• Increase in PPT in ipsilateral and contralateral RM group at 30s post (p<0.03) and 15m post (p<0.05) vs control and sham • Acute, transient, and non-localized effect
***Casanova et al**[16]	RM	• n=20 (18 males, 2 females) • Adult athletes with occasional resistance training experience and no recent ankle injuries	• Plantar flexors	• 6 sets of 45s with 20s rest between sets • 270s total	• Increase in PPT (p=0.032) immediately after exercise-induced muscle damage stimulus vs no RM • Acute, transient effect
***Cheatham et al**[17]	FR	• n=45 (27 males, 18 females) • Recreationally active adults	• Quadriceps	• 1 set of 120s • 120s total	• Increase in PPT (p<0.001) immediately post-FR in non-vibrating FR group vs control • No analysis of chronic effects
Fleckenstein et al[18]	FR	• n=45 (23 males, 22 females) • Regularly active adults	• Quadriceps, hamstrings, adductors, plantar flexors, and iliotibial band	• 1 set of 30s on each muscle group, bilaterally • 300s total	• No significant difference of FR on pain sensation in the preventative nor the regenerative groups vs control
***Jay et al**[19]	RM	• n=22 (all male) • Untrained adults with no prior history of knee, low back, or neck pain	• Hamstrings	• 1 set of 600s • 600s total	• Decrease in muscle soreness for RM group at 0, 10, 30, and 60 (all p<0.0001) minutes vs control, and for RM group at 0 (p=0.0001), 10 (p<0.0001), 30 (p=0.0003), and 60 (p<0.0001) minutes vs within-subject control • Increase in PPT for RM group at 0 (p=0.0002), 10 (p<0.0001), and 30 (p<0.0001) minutes vs control, and for RM group at 0 (p<0.0001), 10 (p=0.0002), 30 (p=0.0005), and 60 (p=0.002) minutes vs within-subject control
***MacDonald et al (2014)**[20]	FR	• n=20 (all male) • All regularly resistance trained 3 or more days/week	• Quadriceps, hamstrings, adductors, iliotibial band, and gluteals	• 2 sets of 60s per region, bilaterally • 1200s total	• Decrease in muscle soreness for FR group at 24 (Cohen's d=0.66), 48 (d=1.03), and 72 (d=1.01) hours vs control
***Pearcey et al**[21]	FR	• n=8 (all male) • Recreational resistance-training adults, classified as moderately to very physically active	• Quadriceps, hamstrings, adductors, iliotibial band, and gluteals	• 1 set of 45s per region, bilaterally, with 15s rest in between • 450s total	• Moderate effect of FR on decreasing quadriceps soreness at 24h (74% likely) and large effect on decreasing quadriceps soreness at 48h (94% likely) post-exercise • Acute, transient effect
***Young et al**[22]	RM	• n=18 (10 males, 8 females) • Recreationally active adults	• Plantar flexors	• 3 sets of 30s, with 30s of rest in between • 90s total	• Decrease in H-reflex amplitude in RM groups (p<0.001, d=0.87) vs sham, implying significantly reduced muscle pain sensation and increased PPT • Acute, transient effect

*** -** Statistically significant positive conclusion
FR - Foam Roller
RM - Roller Massager
PPT - Pain-Pressure Threshold
 # reported as s/m/h - Denotes the indicated number of seconds (s), minutes (m), or hours (h)

Appendix 2. *Description of Included Studies: Outcomes Relating to Range of Motion (ROM).*

Author	Tool	Study Population	Muscle(s) Treated	Duration of FR/RM#	Results
*Bradbury-Squires et al[29]	RM	• n=10 (all male) • Recreationally active adults	• Quadriceps	• 5 sets of 20s or 5 sets of 60s with 60s rest between sets • 100s or 300s total	• Increase in ROM in both the 20 and 60s conditions (both p<0.05) vs control • No analysis of chronic effects
Bushell et al[30]	FR	• n=31 (19 males, 12 females) • Adults who were physically active at least 1.5 hours per week who hadn't recently foam rolled	• Quadriceps	• 3 sets of 60s with 30s rest in between sets • 180s total • 1 FR session during each of sessions 1 & 2, and 5x in 7 days between 1 & 2	• No significant difference in ROM for the FR group vs control across all 6 lunges performed at each of the 3 sessions
Casanova et al[16]	RM	• n=20 (18 males, 2 females) • Adult athletes with occasional resistance training experience and no recent ankle injuries	• Plantar flexors	• 6 sets of 45s with 20s rest between sets • 270s total	• No significant difference in ROM for the RM group vs control at all time points (up to 72h)
*Cheatham et al[17]	FR	• n=45 (27 males, 18 females) • Recreationally active adults	• Quadriceps	• 1 set of 120s • 120s total	• Increase in ROM (p<0.001) immediately post-FR in non-vibrating FR group vs control • No analysis of chronic effects
D'Amico & Paolone[31]	FR	• n=16 (all male) • Trained adults, able to complete an 800 metre run in under 160s	• Gluteals, hip flexors, quadriceps, iliotibial band, adductors, and calves	• 1 set of 30s per region, bilaterally • 360s total	• No significant difference in ROM for the FR group vs control
*Jay et al[19]	RM	• n=22 (all male) • Untrained adults with no prior history of knee, low back, or neck pain	• Hamstrings	• 1 set of 600s • 600s total	• Increase in ROM at 10m (p=0.03) post-RM in RM group vs control • Increase in ROM immediately (p=0.03) post-RM in RM group vs within-subject control (contralateral leg) • Acute, transient effect: no other statistically significant data on ROM
*Junker & Stoggl[32]	FR	• n=40 (all male) • Recreationally active adults who perform sport-like activity 2-3 times per week	• Hamstrings	• 3 sets of 30-40s, bilaterally • 180-240s total (mean=210s) • 3 FR sessions per week for 4 weeks	• Increase in ROM immediately (p=0.033) post FR in FR group vs control • No significant difference in ROM between FR group and PNF stretching group • No analysis of chronic effects
Kelly & Beardsley[33]	FR	• n=26 (16 males, 10 females) • Recreationally active adults performing exercise 2-3 times per week on average	• Plantar flexors	• 3 sets of 30s with 10s rest between sets • 90s total	• No significant difference in ROM in the FR group vs control
*MacDonald et al (2014)[20]	FR	• n=20 (all male) • All regularly resistance trained 3 or more days/week	• Quadriceps, hamstrings, adductors, iliotibial band, and gluteals	• 2 sets of 60s per region, bilaterally • 1200s total	• Moderate effect on increasing quadriceps passive ROM at 48 (d=0.77) and 72h (d=0.56) post FR, hamstring passive ROM at 72h (d=0.62) post FR, and hamstring dynamic ROM at 24h (d=0.57) post FR
*MacDonald et al (2013)[34]	FR	• n=11 (all male) • Recreational resistance training adults, classified as moderately to very physically active	• Quadriceps	• 2 sets of 60s, with 30s rest between sets • 120s total	• Increase in ROM at both time points of 2 and 10m (both p<0.001) post-FR vs control
Macgregor et al[23]	FR	• n=16 (all male) • Recreationally active adults	• Quadriceps	• 1 set of 120s • 120s total • 1 FR session per day for 3 consecutive days	• No significant difference in ROM in the FR group vs control

Appendix 2. *Continued.*

Author	Tool	Study Population	Muscle(s) Treated	Duration of FR/RM#	Results
***Mohr et al**[14]	FR	• n= 40 • Recreationally active adults, engaging in physical activity 1-5 hours per week	• Hamstrings	• 3 sets of 60s, with 30s rest between sets • 180s total	• Increase in ROM regardless of treatment group (p=0.001) • FR + static stretching (SS) group's ROM increased significantly more than SS (p=0.04), FR (p=0.06), or control (p=0.001)
Morales-Artacho et al[24]	FR	• n=14 (all male) • Physically active adults, performing 3-4 hours of sport per week	• Hamstrings	• 1 set of 60s bilateral FR, followed by 5 sets of 60s unilateral FR, bilaterally • 660s total	• No significant difference in ROM in the FR group vs control • Cycling + FR as a warm-up significantly increased ROM at 5 (p≤0.001) and 30m (p=0.046) vs control, but was no better than the cycling group vs control alone
***Phillips et al**[25]	FR	• n=24 (8 males, 16 females) • Physically active adults, exercising at least 3 times per week	• Quadriceps and plantar flexors	• 1 set of either 60s or 300s per region, bilaterally • 240/1200s total	• Increase in kneeling lunge knee ROM in both FR groups (p<0.01) vs control • Effects of both FR groups were statistically similar, however FR60 had a moderate effect (d=0.58), while FR300 had a large effect (d=0.85)
***Smith et al**[26]	FR	• n=29 (8 males, 21 females) • Physically active (n=23) or sedentary (n=6) adults	• Gluteals, hamstrings, quadriceps, and plantar flexors	• 3 sets of 30s per bilateral region, with 30s rest between sets • 360s total	• Increase in sit-and-reach scores immediately (p=0.003) post-FR vs control, but at no further time points • Acute, transient effect
***Sullivan et al**[27]	RM	• n=17 (7 males, 10 females) • Recreationally active adults participating in physical activity roughly 3 times per week	• Hamstrings	• 1 or 2 sets of 5 or 10s • 5, 10, or 20s total	• Increase in ROM regardless of treatment group (p=0.0001) vs control • Non-significant trend toward increase in ROM in the 10s groups (p=0.069) vs 5s groups, regardless of set number
Wilke et al[28]	FR	• n=17 (7 males, 10 females) • Physically active adults	• Quadriceps	• 4 sets of 45s, with 30s rest between sets • 180s total	• No significant difference in ROM in either FR group vs control

*** -** Statistically significant positive conclusion
FR - Foam Roller
RM - Roller Massager
ROM - Range of Motion
PNF - Proprioceptive Neuromuscular Facilitation
 # reported as s/m/h - Denotes the indicated number of seconds (s), minutes (m), or hours (h)

Appendix 3. *Description of Included Studies: Outcomes Relating to Performance.*

Author	Tool	Study Population	Muscle(s) Treated	Duration of FR/RM#	Results
*Bradbury-Squires et al[29]	RM	• n=10 (all male) • Recreationally active adults	• Quadriceps	• 5 sets of 20s or 5 sets of 60s with 60s rest between sets • 100s or 300s total	• Decreased vastus lateralis RMS EMG during active lunge in both the 20 and 60s conditions (both p<0.05) vs control, and dose response indicating 60s decreases lunge EMG more than 20s (p<0.05) • Results imply greater muscular efficiency post RM
Casanova et al[16]	RM	• n=20 (18 males, 2 females) • Adult athletes with occasional resistance training experience and no recent ankle injuries	• Plantar flexors	• 6 sets of 45s with 20s rest between sets • 270s total	• No significant difference in maximal voluntary isometric contraction (MVIC) for the RM group vs control at all time points (up to 72h)
D'Amico & Paolone[31]	FR	• n=16 (all male) • Trained adults, able to complete an 800 metre run in under 160s	• Gluteals, hip flexors, quadriceps, iliotibial band, adductors, and calves	• 1 set of 30s per region, bilaterally • 360s total	• No significant difference in any performance parameters for the FR group vs control
Fleckenstein et al[18]	FR	• n=45 (23 males, 22 females) • Regularly active adults	• Quadriceps, hamstrings, adductors, plantar flexors, and iliotibial band	• 1 set of 30s on each muscle group, bilaterally • 300s total	• No significant difference in jump height in the preventative nor the regenerative FR groups vs control
*MacDonald et al (2014)[20]	FR	• n=20 (all male) • All regularly resistance trained 3 or more days/week	• Quadriceps, hamstrings, adductors, iliotibial band, and gluteals	• 2 sets of 60s per region, bilaterally • 1200s total	• Increased vertical jump height with a large effect at 48h (d=0.81) post FR vs control • Increased voluntary muscle activation with a moderate effect at 24h (d=0.71) post FR, a large effect at 48h (d=1) post FR, and a moderate effect at 72h (d=0.57) post FR vs control
MacDonald et al (2013)[34]	FR	• n=11 (all male) • Recreational resistance training adults, classified as moderately to very physically active	• Quadriceps	• 2 sets of 60s, with 30s rest between sets • 120s total	• No significant difference in any neuromuscular performance parameters in FR group vs control
*Macgregor et al[23]	FR	• n=16 (all male) • Recreationally active adults	• Quadriceps	• 1 set of 120s • 120s total • 1 FR session per day for 3 consecutive days	• Maintenance of MVC across 3-day span (p=0.002) in FR group while MVC decreased in the control group • Decreased EMG RMS for a submaximal task at 0 (p=0.006), 15 (p=0.003), and 30m (p=0.002) post-FR vs control, implying greater muscular efficiency
Monteiro et al[35]	FR	• n=25 (all female) • Recreationally active adults	• Hamstrings	• 1 set of either 60s or 120s • 60/120s total • 1 FR session during each of the 2 inter-set rest periods	• Decreased average knee extension repetitions performed in the FR60 group (d=1.2) as well as the FR120 group (d=2.0) vs control • Dose response was noted: the longer the duration of FR, the fewer total knee repetitions were able to be done
*Pearcey et al[21]	FR	• n=8 (all male) • Recreational resistance-training adults, classified as moderately to very physically active	• Quadriceps, hamstrings, adductors, iliotibial band, and gluteals	• 1 set of 45s per region, bilaterally, with 15s rest in between • 450s total	• Increased recovery for sprint performance with a moderate effect at 24 (77% likely) and 72h (81% likely) post-exercise • Increased recovery for broad jump performance with a small effect at 24h (72% likely) post-exercise, and a large effect at 72h (86% likely) post-exercise vs control • Increased squat performance with a moderate effect at 48h (79% likely) post-exercise vs control
Phillips et al[25]	FR	• n=24 (8 males, 16 females) • Physically active adults, exercising at least 3 times per week	• Quadriceps and plantar flexors	• 1 set of either 60s or 300s per region, bilaterally • 240/1200s total	• Decrease in vertical jump height in all conditions (p<0.001), however significantly more decreased in FR300 than in both FR60 and control (p<0.001) • Increase in agility performance after FR60 (p<0.05) vs FR300 and control, but small effect sizes for each (d=0.06-0.15)

Appendix 3. *Continued.*

Author	Tool	Study Population	Muscle(s) Treated	Duration of FR/RM#	Results
Smith et al[26]	FR	• n=29 (8 males, 21 females) • Physically active (n=23) or sedentary (n=6) adults	• Gluteals, hamstrings, quadriceps, and plantar flexors	• 3 sets of 30s per bilateral region, with 30s rest between sets • 360s total	• No significant difference in vertical jump height in FR group vs control • Increase in vertical jump height in dynamic stretch + FR group at 0 and 5m (both p<0.001) post-dynamic stretch + FR vs control, but was not significantly different from dynamic stretching group alone
Sullivan et al[27]	RM	• n=17 (7 males, 10 females) • Recreationally active adults participating in physical activity roughly 3 times per week	• Hamstrings	• 1 or 2 sets of 5 or 10s • 5, 10, or 20s total	• No significant differences in MVC force or EMG activity in any condition vs control

*** -** Statistically significant positive conclusion
FR - Foam Roller
RM - Roller Massager
RMS - Root Mean Square
EMG - Electromyogram
MVC - Maximal Voluntary Contraction
 # reported as s/m/h - Denotes the indicated number of seconds (s), minutes (m), or hours (h)