

Accepted Manuscript

Effects of Self-Myofascial Release: A Systematic Review

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PII: S1360-8592(15)00217-X

DOI: [10.1016/j.jbmt.2015.08.007](https://doi.org/10.1016/j.jbmt.2015.08.007)

Reference: YJBMT 1260

To appear in: *Journal of Bodywork & Movement Therapies*

Received Date: 20 April 2015

Revised Date: 12 August 2015

Accepted Date: 15 August 2015

Please cite this article as: Chris, B., Škarabot, J., Effects of Self-Myofascial Release: A Systematic Review, *Journal of Bodywork & Movement Therapies* (2015), doi: 10.1016/j.jbmt.2015.08.007.

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TITLE PAGE

Title

Effects of Self-Myofascial Release: A Systematic Review

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ABSTRACT

Background: Self-myofascial release (SMFR) is a type of myofascial release performed by the individual themselves rather than by a clinician, typically using a tool.

Objectives: To review the literature regarding studies exploring acute and chronic clinical effects of SMFR.

Methods: PubMed and Google Scholar databases were searched during February 2015 for studies containing words related to the topic of SMFR.

Results: Acutely, SMFR seems to increase flexibility and reduce muscle soreness but does not impede athletic performance. It may lead to improved arterial function, improved vascular endothelial function, and increased parasympathetic nervous system activity acutely, which could be useful in recovery. There is conflicting evidence whether SMFR can improve flexibility long-term.

Conclusion: SMFR appears to have a range of potentially valuable effects for both athletes and the general population, including increasing flexibility and enhancing recovery.

TEXT

Introduction

Myofascial release (MFR) has been described as an umbrella term for a wide variety of manual therapy techniques in which pressure is applied to muscle and fascia (McKenney et al 2013). By extension, self-myofascial release (SMFR) is a type of MFR that is performed by the individual themselves rather than by a clinician, often using a tool. The most common tools used for SMFR are the foam roller (Kim et al 2014; Okamoto et al 2014; MacDonald et al 2013; MacDonald et al 2014; Healey et al 2014; Janot et al 2014; Roylance et al 2013; Peacock et al 2014; Škarabot et al 2015; Peacock et al 2015) and the roller massager (Sullivan et al 2013; Jay et al 2014; Halperin et al 2014; Bradbury-Squires et al 2015). SMFR appears to have a wide range of effects. It is perhaps most well-known for increasing flexibility acutely (Mikesky et al 2002; MacDonald et al 2013; Sullivan et al 2013; Roylance et al 2013; Jay et al 2014; Halperin et al 2014; Bradbury-Squires et al 2015; Peacock et al 2014; Grieve et al 2014; Škarabot et al 2015) and chronically (Miller & Rockey 2006; Mohr et al 2014; Ebrahim & Elghany 2013) by reference to changes in joint range of motion (ROM), although it has also been utilized to reduce delayed onset muscle soreness (DOMS) (MacDonald et al 2014; Pearcey et al 2014; Jay et al 2014), affect arterial function and vascular endothelial function (Okamoto et al 2014), and modulate autonomic nervous system activity (Kim et al 2014; Chan et al 2015).

Although SMFR appears to have various acute and chronic effects, there is currently no consensus regarding the exact mechanism or mechanisms by which SMFR leads to these effects, although many mechanisms have been suggested and reviewed in detail (Schleip 2003; Simmonds et al 2012). Most proposals regarding the potential mechanisms of action have focused on the nature of fascia itself (Schleip 2003). However, exactly what is meant by fascia is difficult to specify because there are multiple definitions currently in use (Schleip et al 2012; Langevin & Huijing 2009), because fascial research is still in its infancy (Benjamin 2009), and because the meaning of the word has changed over time (Langevin & Huijing, 2009). Fascia was recently defined in a review as 'fibrous collagenous tissues, which are part of a body wide tensional force transmission system' (Schleip et al 2001). Indeed, the ability of fascia to transmit force has some support in the literature (Rijkkelijkhuizen et al 2007; Meijer et al 2007; Huijing & Jaspers 2005; Stecco et al 2008). Moreover, this

definition may be helpful, as it differentiates fascia from connective tissue in general (Langevin & Huijing 2009).

Despite difficulties with definitions, many important findings have been made regarding fascial tissues (Remvig et al 2008) that provide clues to potential mechanisms by which SMFR might exert its effects. Fascia surrounds each muscle and organ in the body (Schleip 2003); it is formed of numerous layers of collagen fiber bundles (Stecco et al 2006); each layer contains parallel bundles while adjacent layers contain bundles at different orientations (Stecco et al 2006); layers are separated by thin layers of adipose tissue (Stecco et al 2006); and it is extremely strong (Findley et al 2012) but plastic (Schleip 2003). It has been reported that fascia displays piezoelectric effects (Yasuda 1964), alters in stiffness following changes in water content (Chaitow 2009), is richly innervated with nerve endings (Benjamin 2009; Stecco et al 2007), and contains many mechanoreceptors (Yahia et al 1992). Fascia seems to be integrally involved in the biomechanics of the musculoskeletal system (Gerlach & Lierse, 1990), may be involved in force transmission (Benjamin 2009), may contract like smooth muscle (Schleip et al 2005), and can become inflamed and potentially thereby cause pain (Bednar et al 1995).

In order to categorise the various potential mechanisms of massage, SMFR or MFR, reviewers have grouped fascia-specific mechanisms in different ways. Weerapong et al (2005) categorized possible effects of massage into four types: biomechanical, physiological, neurological and psychological. Other reviewers have differentiated between two types: mechanical and neurophysiological (Schleip 2003; Simmonds et al 2012). Mechanical mechanisms of SMFR include thixotropy (Schleip 2003), piezoelectricity (O'Connell 2003; Schleip 2003), fascial adhesions (Hedley 2010; Martínez Rodríguez & Galáandel Río 2013), cellular responses (Chen & Ingber 1999; Tozzi 2012), fluid flow (Chaitow 2009; Schleip & Müller 2013), fascial inflammation (Bednar et al 1995; Findley et al 2012), and myofascial trigger points (Gerwin 2010; Bron & Dommerholt, 2012). Many of these mechanical mechanisms have been criticized on the basis that pressures outside of normal human physiological ranges would be required in order to induce tissue deformations in most tissues (Chaudhry et al 2008). Thixotropy is a process in which heat or pressure is applied to a material, which in turns makes it less dense and more fluid (Schleip 2003). However, thixotropy is a transient and reversible effect (Mewis & Wagner, 2008). Consequently, it has been argued that thixotropy cannot explain the lasting changes that clinicians report from SMFR (Schleip 2003). In the piezoelectric model, it is suggested that fibroblasts and

fibroblasts, which create and digest the collagen fibers that are important for the biomechanical properties of the fascia, respond to electric charges created through pressure (O'Connell 2003). While piezoelectric effects have been observed in collagen fibers for many years (Yasuda 1964), it has been argued that it cannot explain the quick effects that clinicians observe (Schleip 2003), which typically occur within 90 – 120 seconds (Barnes 1997). In the fascial adhesions model, it is suggested that different fascial layers that would normally slide relative to each other alter such that they now stick to one another (Hedley 2010; Martínez Rodríguez & Galáandel Río 2013). These fascial adhesions are thought to be released by moving the body part through a full ROM under traction (Hedley 2010). In the cellular responses model, it has been suggested that mechanical loading of fascia may lead to changes at the cellular level by reference to the principle of tensegrity (Chen and Ingber 1999), in which it is proposed that cells are held in a state of continuous tension and respond to mechanical pressure by performing biochemical processes (Tozzi 2012). In the fluid flow model, it has been suggested that since the water content of fascia affects its stiffness, and since fascia extrudes water when it is compressed, SMFR could increase the pliability of fascial tissues via temporary changes in water content that allow mobilization before the tissue rehydrates (Chaitow 2009). The foam roller has been proposed as a tool particularly appropriate for this purpose (Schleip & Müller 2013). Finally, models involving effects on fascial inflammation suggest that muscle or fascia may tighten as a result of inflammation (Bednar et al 1995; Findley et al 2012) and that SMFR might reduce this inflammation by increasing blood flow. Whether muscle or fascia can alter pathologically in this way is unclear but there are indications that SMFR and manual therapy in general can affect blood flow by increasing nitric oxide production (Queré et al 2009; Okamoto et al 2014). Such fascial inflammation may be related to the concept of myofascial trigger points, which have been proposed to occur when motor endplates release excessive acetylcholine, shortening sarcomeres locally, disrupting cell membranes, damaging the sarcoplasmic reticulum, and causing inflammation (Hong and Simons 1998; Gerwin 2010; Bron & Dommerholt, 2012). However, the phenomenon of myofascial trigger points has been drawn into question by concerns over the reliability of their clinical identification (Myburgh et al 2008).

Although mechanical mechanisms were the first to be proposed (Barnes 1997; Schleip 2003), neurophysiological mechanisms have in fact been proposed to explain the effects of manual therapy for over 20 years, with pilot studies reporting different effects between treatments on conscious and anesthetized subjects (Schleip 1989). There are two main branches of neurophysiological mechanisms, one involving the

Golgi reflex arc and another involving other mechanoreceptors. In the Golgi reflex arc model, it is noted that Golgi receptors are found in all connective tissues, although they are only called Golgi tendon organs (GTOs) at the muscle-tendon junction. When a muscle is stretched, GTOs provide afferent feedback to the spinal cord. It is thought that pressure exerted during MFR or SMFR might stimulate the GTOs, reduce motor unit firing rate and subsequently decrease muscle tension (Tozzi 2012). However, it seems likely that muscles must be active in order for GTOs to be stimulated (Jami 1992). It has been argued that this may be because the GTO is in series with the muscle (Schleip 2003). During a passive stretch, the muscle likely absorbs most of the change in length of the muscle-tendon unit whereas during an active stretch, this does not occur (Schleip 2003). The other main neurophysiological mechanism involves Ruffini and Pacini corpuscles and interstitial muscle receptors, which are mechanoreceptors commonly found in fascia (Stecco et al 2007). Pressure applied to mechanoreceptors might stimulate the nervous system and thereby lead to reduced muscular tension (Schleip 2003). Some investigations have shown that massage causes H-reflex inhibition (Morelli et al 1990; Morelli et al 1991; Goldberg et al 1992; Sullivan et al 1991; Morelli et al 1999), which is an indirect measure of alpha motor-neuron excitability. This phenomenon has also been attributed to the activation of mechanoreceptors, which are believed to inhibit the central nervous system during massage (Morelli et al 1999). It is noteworthy that, Bradbury-Squires et al (2015) reported reduced electromyographic (EMG) activity during a bodyweight lunge exercise when it followed a bout of SMFR.

In contrast to the above mechanisms that have traditionally been put forward to explain the effects of SMFR and MFR, static stretching is thought to be effective primarily by means of its effects on stretch tolerance (Weppler & Magnusson 2010). It is possible that SMFR may also prove to be effective through a similar mechanism, as manual therapies in general are typically reported as having a number of potentially pain-relieving effects (Bialosky et al 2009; Voogt et al 2014). Such analgesic effects have been described as being mediated by either peripheral, spinal, or supraspinal mechanisms (Bialosky et al 2009). Peripheral mechanisms might involve the release of local inflammatory mediators (Bialosky et al 2009). Spinal mechanisms could involve signals along large, primary afferent nerve fibers interfering with pain signals transmitted along slow-conducting, tertiary fibers. These could then inhibit pain feedback in the spinal cord (Bialosky et al 2009). Both peripheral and spinal mechanisms might be expected to occur based on the gate control theory of pain (Melzack 1982). Supraspinal mechanisms are much less clear. Bialosky et al (2009) suggested they might

involve alterations in those parts of the brain responsible for the pain experience, such as the anterior cingulate cortex, the amygdala, periaqueductal gray, and rostral ventromedial medulla. In whatever way they are affected, the analgesic effects that very likely arise following MFR and SMFR could potentially produce an increase in stretch tolerance immediately following the application of the therapy, which could account for acute changes in flexibility.

Although there has been substantial discussion of the potential mechanisms by which MFR and SMFR might exert their effects, the research has until very recently been limited in respect of the acute and chronic clinical effects of SMFR. Therefore, it was the purpose of this review to present the literature regarding the acute and chronic effects of SMFR.

Methods

PubMed and Google Scholar databases were searched during February 2015 for studies containing the words 'self-myofascial release', 'foam rolling' or 'roller massager'. The abstracts of articles referring to any of these key words were reviewed and the full texts were retrieved where it was apparent that the primary criteria were satisfied. Studies were included where a full text was available in English, where they explored the acute or chronic effects of any SMFR treatment in humans, where the effect of the intervention was compared either to a control condition that did not undergo treatment or to a baseline measurement. SMFR was here defined as any manual therapy treatment performed by an individual by themselves that involved a tool. Reference lists of the retrieved studies were reviewed and any further studies that were identified were then obtained.

[Table 1 about here]

The methodological quality of each study included in this review was assessed independently by both reviewers using the PEDro scale (2015) for measuring the study quality of experimental studies. The PEDro scale comprises a checklist of 11 criteria, of which only 10 criteria are scored (Table 1). The clear and unambiguous meeting of a criterion leads to 1 point being awarded. Consequently, a total of 10 points are available. Studies with PEDro scores of between 6 – 10 points were considered to be of high quality; studies with PEDro scores of between 4 – 5 points were considered to be of moderate quality; studies with PEDro

scores of between 0 – 3 points were considered to be of low quality. All disagreements regarding rating of PEDro scores was resolved by a consensus discussion between the reviewers.

Results

Study selection

The search strategy revealed 22 studies that met the inclusion criteria and were included in this review. Studies were divided into 6 categories: acute effects on flexibility (11 studies), acute effects on athletic performance (9 studies), acute effects on arterial stiffness and vascular endothelial function (1 study), acute effects on autonomic nervous system activity (2 studies), acute effects on delayed onset muscle soreness (3 studies), and chronic effects on flexibility (4 studies).

Study quality

[Table 2 about here]

The mean PEDro score for the studies included in the review was 5.91 ± 0.87 points (range: 4 – 8 points) (Table 2). According to the quality criteria set, the average quality of the studies included in this review is therefore moderate. Moreover, there was not a high degree of variation in quality between studies. No studies were able to satisfy the blinding criteria of subjects or therapists (PEDro scale questions 5 – 6) and very few studies reported satisfying the concealment of allocation (PEDro scale question 3) or blinding of assessors (PEDro scale question 7) criteria. The remaining six criteria were mostly always scored positively. Thus, although the mean PEDro score was <6 points, only two studies scored 4 points (Ebrahim & Elghany 2013; Bushell et al 2015) and only two studies scored 5 points (Roylance et al 2013; Chan et al 2015). The remainder of the included studies scored ≥ 6 points. The two lowest quality studies were chronic investigations of flexibility (Ebrahim & Elghany 2013; Bushell et al 2015). Given the difficulty of blinding subjects from the nature of the intervention performed, it is unsurprising that difficulty was experienced in the area. Only one trial attempted to mask the nature of the intervention from subjects (Mikesky et al 2002) and used a placebo intervention (mock electric stimulation). However, it was apparent from the descriptions provided that the real and placebo interventions were straightforward to distinguish from one another and, while the placebo effect might have been controlled for, blinding was not achieved. In contrast, concealment of allocation and blinding of assessors can evidently be achieved and future investigations should endeavor to comply with and report these methodological steps.

Acute effects on flexibility

[Table 3 about here]

SMFR using a foam roller appears to lead to acute increases in flexibility in the majority of investigations (see Table 3). The average quality of the studies included in this section of the review was slightly higher than the average quality of the studies in the review overall (mean PEDro score = 6.18 ± 0.75 points; range: 5 – 8 points). Many of the investigations assessing the effects of SMFR on flexibility (Sullivan et al 2013; Jay et al 2014; Halperin et al 2014; Bradbury-Squires et al 2015) used the same type of commercially-available roller massager, manufactured by Theraband (The Hygenic Corporation, Akron, OH). This instrument is similar to a foam roller, insofar as it is a device involving dense foam wrapped around a solid plastic cylinder. However, it differs from a foam roller in that it has a central axle that is grasped by hand and applied to different parts of the body. The remaining studies (Roylance et al 2013; MacDonald et al 2013; Peacock et al 2014; Škarabot et al 2015) used foam rollers of varying kinds. It is not clear why Mikesky et al (2002), Roylance et al (2013) and Peacock et al (2014) alone failed to observe an acute increase in joint ROM following SMFR. The findings of Škarabot et al (2015) were unclear as there was a main effect of SMFR, although post hoc testing was unable to detect differences.

Differences in the type of tool used for SMFR might conceivably affect the effects observed, particularly as Curran et al (2008) reported that the type of SMFR tool affected the ability to apply pressure to the underlying tissue. The investigation performed by Mikesky et al (2002) was unique in its choice of tool and the lack of effect observed in this study may therefore have been a function of the tool used. Mikesky et al (2002) studied a device called The Stick (Relaxicizior Products Inc., Atlanta, Georgia). The only other study to explore an unusual device was performed by Grieve et al (2014), who investigated the effects of rolling a tennis ball underfoot. However, Grieve et al (2014) still observed an increase in flexibility despite using this unconventional tool. In addition to the choice of SMFR tool, Mikesky et al (2002) were one of the few investigations to use athletic subjects. Comparisons of the chronic effects of static stretching in trained and untrained subjects have reported greater effects in untrained individuals (Abdel-Aziem & Mohammad 2002) and this may therefore be a factor that could explain the lack of results reported by Mikesky et al (2002).

Differences in the instructions used for SMFR, leading to differences in pressure applied, might reasonably be expected to affect the change in flexibility observed. Instructions to subjects regarding the degree of pressure to be used in the application of SMFR have varied widely between study protocols. Interestingly, two of the investigators that reported no effect on flexibility (Roylance et al 2013; Peacock et al 2014) did not specify any particular requirements for the subjects regarding pressure. Regarding the other studies, one advised the use of a moderate pressure (Jay et al 2014), another advised that as much bodyweight as possible should be applied (MacDonald et al 2013), a third provided a force measurement on the basis of a pain scale (Halperin et al 2014), and two artificially limited force to a specific level by using a device (Sullivan et al 2013; Bradbury-Squires et al 2015). Since Roylance et al (2013) nor Peacock et al (2014) reported no effects, while Sullivan et al. (2013) reported an increase in ROM by 4.3% with a force of 13 kg and Bradbury-Squires et al (2015) reported increases in ROM of 10 – 16% with an average force of 21kg, it may be the case that higher pressures could lead to greater increases in joint ROM. However, given that different pressures have not yet been directly compared, this remains unclear.

The time course of the acute effects of SMFR on flexibility is unclear. This may be because of differences between study protocols, which can be observed in respect of many parameters, including the volume of SMFR conducted, the muscle group treated, the SMFR tool used, and the precise method of application, including the instructions provided to subjects in respect of the level of pressure to be applied (see Table 3). Alternatively, it may also reflect the problem of taking repeated measures of joint ROM, wherein a mobilizing effect is observed (Atha & Wheatley 1976). Only 4 studies have explored the time course of effects on flexibility of SMFR and all but one have reported effects lasting up to and including 10 minutes post-treatment. Halperin et al (2014), who tested the effects of 3 bouts of 30 seconds of SMFR with a roller massager on the plantar flexors with a pressure equivalent to a pain level of 7 out of 10, reported increases in joint ROM at 10 minutes post-intervention in addition to 1 minute post-intervention. MacDonald et al (2013), who tested the effects of 2 bouts of 1 minute of SMFR with a foam roller on the quadriceps where subjects applied as much of their body mass as possible onto the foam roller, reported increases at 10 minutes post-intervention in addition to 2 minutes post-intervention. Jay et al (2014), who tested the effects of an unspecified duration of SMFR the roller massager on the hamstrings using a moderate pressure, found that while flexibility was greater immediately post-intervention and at 10 minutes, the effects were lost at 30 and 60 minutes.

However, Škarabot et al (2015), who tested the effects of 3 bouts of 30 seconds of SMFR with a foam roller on the plantar flexors, reported that flexibility was only increased immediately post-intervention (by main effect only and not by post hoc testing) and not after 10 minutes.

The dose-response of the acute effects of SMFR on flexibility is also still unclear. Currently, only two investigations have directly assessed the acute effects of different volumes of SMFR on flexibility and while there is no strong evidence for a dose-response effect, non-significant trends observed make it difficult to discount the possibility completely. Sullivan et al (2013) compared the effects of four different volumes of SMFR with a roller-massager (either 5-second or 10-second durations and either 1 or 2 sets) on sit-and-reach performance. There was a significant increase in in all conditions but no significant difference between groups. There was a non-significant trend towards a dose-response effect with 10-seconds being slightly more effective than 5-seconds, irrespective of the number of sets. The extent to which these results were affected by the use of an artificially-limited and consistent force rather than a more conventional SMFR technique is unclear. Bradbury-Squires et al (2015) compared 5 bouts of either 20 or 60 seconds of SMFR on knee joint ROM. There a significant increase in in all conditions but no significant difference between groups. Again, a non-significant trend toward greater increases was observed with longer durations. Further research is needed to investigate whether a dose-response effect exists.

Precisely where the SMFR is applied may affect the resulting acute changes in flexibility but such effects may not always be predictable. Grieve et al (2014) surprisingly reported an increase in sit-and-reach performance following SMFR applied to the plantar fascia, which they suggested might relate to the continuity of fascia through the lower limb. In a related study, is noteworthy that Peacock et al (2015) compared SMFR using a foam roller when applied to the front and back of the body (inferior spine region, the gluteal region, hamstrings, rear calves, pectorals, and quadriceps) and when applied to the sides of the body (latissimus dorsi, obliques, side hip, iliotibial band, side calves, and adductors). The SMFR condition applied to the rear of the body produced greater changes in sit-and-reach flexibility than the other condition, most probably because it targeted the hamstrings directly. Whether these changes were greater than a control or than baseline, however, is unclear.

SMFR might exert additive effects to static stretching acutely (Škarabot et al 2015). Škarabot et al (2015) compared the effects of acute interventions comprising either SMFR using a foam roller, static stretching, or a combined protocol. Both SMFR and static stretching resulted in improvements in joint ROM and the combination of methods displayed an additive effect as it resulted in superior improvements to SMFR. This may imply that two mechanisms are in effect, with static stretching increasing flexibility by modifying sensation (Weppeler & Magnusson 2010) and SMFR being effective through a different neurophysiological mechanism. Alternatively, it may simply be the case that the two modalities are effective by similar mechanisms and that it was the higher overall treatment volume of the combined group that led to the superior results.

Acute effects on athletic performance

[Table 4 about here]

SMFR does not appear to impede athletic performance acutely or in the short-term (see Table 4). The average quality of the studies included in this section of the review was slightly higher than the average quality of the studies in the review overall (mean PEDro score = 6.11 ± 0.33 points; range: 6 – 7 points). Two of the investigations assessing the effects of SMFR on performance (Sullivan et al 2013; Halperin et al 2014) used the same type of commercially-available roller massager, manufactured by Theraband (The Hygenic Corporation, Akron, OH), one used a device called The Stick (Mikesky et al 2002) but the majority of studies (MacDonald et al 2013; Healy et al 2013; MacDonald et al 2014; Janot et al 2014; Peacock et al 2014) used foam rollers of varying kinds. In all cases except two (Janot et al 2014; Peacock et al 2014), there were no changes in performance measures following any of the SMFR protocols used.

It is unclear why Janot et al (2014) alone found adverse effects on performance following a bout of SMFR nor why Peacock et al (2014) alone found improvements. In respect of the adverse effects reported by Janot et al (2014) is possible that there are differences in the effects of SMFR on short-duration, anaerobic activities in comparison with those requiring maximal force production. Previous studies investigating the effects of static stretching on the Wingate test have been conflicting, with some finding reductions in Wingate test performance (Franco et al 2012), others finding some beneficial effects (O'Connor et al 2006) and others finding no effects (Kingsley et al 2013). The lack of a reduction in performance following the static stretching

condition may have been because of the short durations of the stretches used in this study (30 seconds), as reviewers have reported that short-duration stretches of <30 seconds (Behm & Chaouachi 2011), <45 seconds (Šimić et al 2012), or <60 seconds (Kay & Blazevich 2012), may not be detrimental to short-term muscular performance. However, the mechanism by which static stretching could increase muscular performance is unclear. Generally, it is thought that short-term muscular performance is negatively affected by way of an adverse effect on either neuromuscular activation or on the length-tension relationship of the muscle (Behm & Chaouachi 2011). It is possible that static stretching might lead to a beneficial effect during a Wingate cycling test through reduced muscular stiffness and increased compliance (Behm & Chaouachi 2011). It is interesting that Bradbury-Squires et al (2015) reported that SMFR application appears to improve movement efficiency, as indicated by lower levels of neural drive. Lower EMG activity of the vastus lateralis muscle after SMFR, compared to a control, was reported during a bodyweight lunge. EMG activity was particularly reduced during the push-off phase, which led the authors to speculate that the mechanism could be a more efficient, prolonged stretch-shortening cycle.

Acute effects on arterial stiffness and vascular endothelial function

SMFR with a foam roller has been found to lead to acutely improved arterial function, as measured by brachial-ankle pulse wave velocity, and improved vascular endothelial function, as measured by plasma nitric oxide concentrations, although the literature is very limited (Okamoto et al 2014). Okamoto et al (2014) proposed that an improvement in arterial stiffness might have arisen from reductions in smooth muscle tension (which contains collagen) because of increases in its pliability following the application of pressure. They also suggested that the pressure applied by the foam roller might trigger the release of plasma nitric oxide concentrations, as such pressure could increase flow velocity in the veins and thereby elevate shear stress on the walls of the vasculature, which is a stimulus for nitric oxide production. This vasodilatory effect might also lead to the observed reduction in arterial stiffness. In a related study that did not use SMFR, Queré et al (2009) took vascular measurements of arterial stiffness in normotensive and hypertensive patients after two types of massage and reported improvements, which they also ascribed to the actions of plasma nitric oxide following from elevated shear stress on the walls of the vasculature.

Acute effects on autonomic nervous system activity

There are some early indications that SMFR may modulate the activity of the autonomic nervous system beneficially for the purposes of recovery. Kim et al (2014) compared the effects on serum cortisol concentrations in 24 healthy, young females of a single 30-minute session of foam rolling to passive rest, after a 30-minute walk on a treadmill in high heels, designed to induce physical stress. Both SMFR and passive rest resulted in reduction of serum cortisol but there were no significant differences between conditions. The reduction in both cases may have been affected by the diurnal variations in cortisol levels, as measurements were taken at peak hours during the day, so the drop may have been expected regardless of treatment. However, there was a trend reported for lower cortisol levels after SMFR, which the authors attributed to increased parasympathetic activation. Similar findings have been reported after massage, involving heightened parasympathetic activity, reduced heart rate, reduced blood pressure, increased endorphin levels, and increased heart rate variability (Weerapong et al 2005). However, further research is required to explore whether such an effect exists in respect of SMFR. Chan et al (2015) retrospectively assessed the effects on measures of heart rate variability in patients with myofascial pain dysfunction syndrome of self-massage with a baseball on the neck and upper back muscles over a 2-week period. They reported that high frequency percentage increased while low frequency percentage decreased, which they interpreted as an increase in parasympathetic nervous system activity and a decrease in sympathetic nervous system activity.

Acute effects on DOMS

[Table 5 about here]

SMFR appears to alleviate the sensation of DOMS acutely (see Table 5). The average quality of the studies included in this section of the review was slightly higher than the average quality of the studies in the review overall (mean PEDro score = 6.67 ± 1.15 points; range: 6 – 8 points). To date, three studies have explored the acute effects of SMFR on DOMS, of which two used a foam roller (MacDonald et al 2014; Pearcey et al 2014) and one used a roller massager (Jay et al 2014) but all three found beneficial effects. These effects of SMFR on DOMS have been reported in both trained (MacDonald et al 2014; Pearcey et al 2014) and untrained (Jay et al 2014) populations, and using a range of different outcome measures, including pressure pain threshold (PPT) (Pearcey et al 2014; Jay et al 2014), self-reported pain using a visual analogue scale (VAS) (Jay et al 2014), and self-reported pain using the BS-11 Numerical Rating Scale (MacDonald et al 2014). These findings indicate that

SMFR can reduce DOMS in a diverse range of populations, using various tools, and when measured using different outcome measures.

Although a discussion of pain and the mechanisms by which SMFR might affect pain is beyond the scope of this review (see further Bialosky et al 2009; Butler & Moseley 2013), it is interesting to note the findings of Gibson et al (2009) who explored the nociceptive response to hypertonic sodium solution applied at both fascial and deep muscle levels after unilateral eccentric exercise. Eccentric exercise was used as it has been found to cause more DOMS than other muscle actions (Schoenfeld 2012). The researchers found that fascial injection of the eccentrically-exercised leg caused significantly more pain than muscular injections of either leg or fascial injections of the non-exercised leg. It was therefore proposed that fascia might play a key role in the experience of DOMS.

Chronic effects on flexibility

[Table 6 about here]

There are conflicting reports regarding whether SMFR using a foam roller over a long-term period leads to improved flexibility (see Table 6). This may be a function of the lower average quality of the studies included in this section of the review compared with the average quality of the studies in the review overall (mean PEDro score = 5.00 ± 1.15 points; range: 4 – 6 points). The lower average quality of studies in this section was caused by the inclusion of two lowest quality studies in the review (points (Ebrahim & Elghany 2013; Bushell et al 2015)). All investigations made use of the foam roller and all but one study (Bushell et al 2015) explored the effects of SMFR on the same muscle group (the hamstrings) with little difference between studies in respect of the instructions provided. Therefore, the reasons for the conflicting nature of the results may lie rather in the heterogeneity of the intervention durations or in the nature of the subject populations. Indeed, the three studies of fairly short duration (Mohr et al 2014; Ebrahim & Elghany 2013; Bushell et al 2015) found a beneficial effect of SMFR while the study reporting on an intervention of longer duration (Miller & Rockey 2006) did not. Additionally, all but one of the studies involved subjects with restricted hip flexion ROM, either because of unspecified reasons not relating to previous injury (Mohr et al 2014; Miller & Rockey 2006) or because of previous hamstring strain injury (Ebrahim & Elghany 2013). It is noteworthy that in the investigation by Miller & Rockey (2006) that although there was no significant difference in the improvement

in flexibility between the SMFR condition and the control, both SMFR and control groups displayed large numerical increases in flexibility, which is suggestive of a natural resolution to existing restricted ROM. Also, the males in the SMFR condition displayed increases in ROM, while the males in the control condition did not display any changes. On the other hand, the females displayed changes in ROM irrespective of the protocol. It therefore seems difficult to draw inferences from this trial regarding the chronic effects of SMFR on flexibility in healthy subjects without flexibility restrictions at baseline.

SMFR might exert additive effects to static stretching when performed over a long-term period (Mohr et al 2014), in a similar way to that observed in acute trials (Škarabot et al 2015). Mohr et al (2014) compared the effects of chronic interventions comprising either SMFR using a foam roller, static stretching, or a combined protocol. Both SMFR and static stretching resulted in similar positive changes in ROM and the combination of methods displayed an additive effect as it resulted in superior improvements to both SMFR and static stretching. As noted with the acute effects of SMFR, this may imply that two mechanisms are in effect in each case.

Discussion

This review assessed the acute and chronic effects of SMFR in six categories: acute effects on flexibility, acute effects on athletic performance, acute effects on arterial stiffness and vascular endothelial function, acute effects on autonomic nervous system activity, acute effects on delayed onset muscle soreness (DOMS), and chronic effects on flexibility. Eleven studies were identified that reported the acute effects of SMFR on flexibility, 9 studies were found that reported the acute effects of SMFR on athletic performance, 1 study reported the acute effects of SMFR on arterial stiffness and vascular endothelial function, 2 studies reported the acute effects of SMFR on autonomic nervous system activity, 3 studies reported on the acute effects of SMFR on DOMS, and 4 studies reported on the chronic effects of SMFR on flexibility.

In terms of the acute effects of SMFR on flexibility, the majority of investigations found that SMFR does lead to increased joint ROM. This may make SMFR a viable alternative to static stretching prior to exercise, training or competition that requires increased flexibility. In addition, it has been reported that the time-course of effects appears to be limited to around 10 minutes. While the dose-response of effects on flexibility is unclear, most studies have found meaningful improvements with around 1 – 2 minutes of treatment. Precisely where SMFR

is applied may affect the resulting acute changes in flexibility but such effects may not always be predictable and the reasons for this are unknown.

In terms of the acute effects of SMFR on athletic performance, the majority of investigations found that SMFR does not impede athletic performance across a wide range of different force and power production outcome measures. Coupled with the ability to increase flexibility, this may make SMFR attractive to athletes who are looking for short-term improvements in flexibility that do not cause performance decrements as static stretching is known to do (Kay & Blazevich 2012). The difference in acute effects on athletic performance between SMFR and static stretching may indicate that their effects are mediated by different mechanisms.

In terms of the acute effects of SMFR on DOMS, the majority of investigations have reported that SMFR reduces DOMS, which may also make SMFR attractive to athletes looking for methods to enhance recovery from training or competition. Whether these beneficial effects of SMFR on DOMS are related to the potential effects on improved arterial function, improved vascular endothelial function, and increased parasympathetic nervous system activity acutely, are unclear.

In terms of chronic effects of SMFR on flexibility, the literature was conflicting, although this may be a function of the study quality rather than the treatment effects per se. There were several features of the literature in this area that made interpretation difficult, including a poorer quality of studies, a lack of detail regarding the protocols used, the nature of the populations, and the very short duration of most of the protocols (1 – 2 weeks).

Conclusion

SMFR appears to have a range of potentially valuable effects for both athletes and the general population, including increasing flexibility and enhancing recovery. Specifically, SMFR seems to lead to increased joint ROM acutely and does not impede athletic performance acutely. SMFR therefore seems suitable for use by athletes or the general population prior to exercise, training sessions or competition. SMFR seems to alleviate DOMS acutely and may therefore be suitable for use by athletes or the general population for enhancing recovery from exercise, training sessions or competition. There is also limited evidence that SMFR may lead to improved arterial function, improved vascular endothelial function, and increased parasympathetic nervous system

activity acutely, which may also be useful in recovery. Finally, there is some evidence that long-term SMFR may lead to improved flexibility, although not all chronic studies confirm these results.

ACCEPTED MANUSCRIPT

ACKNOWLEDGEMENTS

There were no conflicts of interest

No acknowledgements were considered appropriate

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TABLES

PEDro criteria	
1	Eligibility criteria were specified
2	Subjects were randomly allocated to groups (in a crossover study, subjects were randomly allocated an order in which treatments were received)
3	Allocation was concealed
4	The groups were similar at baseline regarding the most important prognostic indicators
5	There was blinding of all subjects
6	There was blinding of all therapists who administered the therapy
7	There was blinding of all assessors who measured at least one key outcome
8	Measures of at least one key outcome were obtained from more than 85% of the subjects initially allocated to groups
9	All subjects for whom outcome measures were available received the treatment or control condition as allocated or, where this was not the case, data for at least one key outcome was analysed by "intention to treat"
10	The results of between-group statistical comparisons are reported for at least one key outcome
11	The study provides both point measures and measures of variability for at least one key outcome

Table 1: PEDro rating criteria (PEDro, 2015)

Study author	1	2	3	4	5	6	7	8	9	10	11	Total
Bradbury-Squires et al 2015	0	1	0	1	0	0	0	1	1	1	1	6
Bushell et al 2015	1	0	0	0	0	0	0	1	1	1	1	4
Chan et al 2015	1	0	0	1	0	0	0	1	1	1	1	5
Ebrahim & Elghany 2013	1	0	0	0	0	0	0	1	1	1	1	4
Grieve et al 2014	1	1	1	0	0	0	1	1	1	1	1	7
Halperin et al 2014	1	1	0	1	0	0	0	1	1	1	1	6
Healey et al 2013	0	1	0	1	0	0	0	1	1	1	1	6
Janot et al 2014	1	1	0	1	0	0	1	1	1	1	1	7
Jay et al 2014	1	1	1	1	0	0	1	1	1	1	1	8
Kim et al 2014	0	1	0	1	0	0	0	1	1	1	1	6
MacDonald et al 2013	0	1	0	1	0	0	0	1	1	1	1	6
MacDonald et al 2014	0	1	0	1	0	0	0	1	1	1	1	6
Mikesky et al 2002	0	1	0	0	0	0	1	1	1	1	1	6
Miller & Rockey 2006	1	1	0	1	0	0	0	1	1	1	1	6
Mohr et al 2014	1	1	0	1	0	0	0	1	1	1	1	6
Okamoto et al 2014	0	1	0	1	0	0	0	1	1	1	1	6
Peacock et al 2014	0	1	0	1	0	0	0	1	1	1	1	6
Peacock et al 2015	0	1	0	1	0	0	0	1	1	1	1	6
Pearcey et al 2014	0	1	0	1	0	0	0	1	1	1	1	6
Roylance et al 2013	1	1	0	1	0	0	0	1	1	0	1	5
Sullivan et al 2013	1	1	0	1	0	0	0	1	1	1	1	6
Škarabot et al 2015	1	1	0	1	0	0	0	1	1	1	1	6

Table 2: PEDro score of methodological quality for included studies

Study author	Protocol	SMFR tool	Muscle group treated	Pressure of SMFR, including instructions to subjects	Flexibility measurement	Increase in ROM?
Mikesky et al 2002	1 bout of 2 minutes	The Stick	Hamstrings	Pressure not specified. Subjects were told "to concentrate on the test they were about to perform while they administered self-massage"	Active straight-leg raise	No
MacDonald et al 2013	2 bouts of 1 minute	Foam roller	Quadriceps	"...told to place as much of their body mass as possible onto the foam roller..."	Knee extension ROM	Yes
Sullivan et al 2013	1 or 2 bouts of 5 or 10 seconds	Roller massager	Hamstrings	Force application was maintained constant at 13kg by using a custom-made device to perform the SMFR.	Sit-and-reach test	Yes
Roylance et al 2013	2 minutes (estimated)	Foam roller	Various	Pressure not specified.	Sit-and-reach test	No
Jay et al 2014	Not specified	Roller massager	Hamstrings	The subjects were instructed to apply a moderate pressure.	Sit-and-reach test	Yes
Halperin et al 2014	3 bouts of 30 seconds	Roller massager	Plantar flexors	"...instructed to apply pressure equivalent to a pain level of 7 out of 10."	Weight-bearing lunge test	Yes
Bradbury-Squires et al. 2014	5 bouts of 20 or 60 seconds	Roller massager	Quadriceps	Constant application at 25% of body mass by using a custom-made device to perform the SMFR.	Knee extension ROM	Yes
Peacock et al 2014	1 bout of 30 seconds	Foam roller	Various	Pressure not specified.	Sit-and-reach test	No
Grieve et al 2014	2 minutes	Tennis ball	Plantar fascia	"...instructed to apply as much pressure as they could, pushing into discomfort but not pain..."	Sit-and-reach test	Yes
Peacock et al 2015	Unclear	Foam roller	Various	Pressure not specified.	Sit-and-reach test	Yes
Škarabot et al 2015	3 bouts of 30 seconds	Foam roller	Plantar flexors	"...instructed to apply as much pressure as they could, pushing into discomfort but not pain..."	Weight-bearing lunge test	Yes

Table 3: Acute effects of SMFR on flexibility

Study author	Protocol	SMFR tool	Muscle group treated	Pressure of SMFR, including instructions to subjects	Performance measurement	Change?
Mikesky et al 2002	1 bout of 2 minutes	The Stick	Hamstrings	Pressure not specified. Subjects were told "to concentrate on the test they were about to perform while they administered self-massage"	Vertical jump, flying-start 20-yard dash, and isokinetic knee extension at 90 degrees	No
MacDonald et al 2013	2 bouts of 1 minute	Foam roller	Quadriceps	"...told to place as much of their body mass as possible onto the foam roller..."	MVIC knee extension at a 90 degree knee angle and rate of force development	No
MacDonald et al 2014	2 bouts of 1 minute	Foam roller	Hamstrings	"...told to place their bodyweight on the foam roller..."	MVIC knee extension torque at a knee angle of 90 degrees and counter-movement vertical jump performance	No
Sullivan et al 2013	1 or 2 bouts of 5 or 10 seconds	Roller massager	Hamstrings	Force application was maintained constant at 13kg by using a custom-made device to perform the SMFR.	MVIC knee flexion torque	No
Janot et al 2014	3 bouts of 30 seconds per muscle group	Foam roller	Various	No specific instructions given to subjects but it was noted that the pressure provided was specific to the bodyweight of the individual.	30-second cycling Wingate test	Yes, decrease
Healey et al 2013	30 seconds per muscle group	Foam roller	Various	No specific instructions regarding pressure were provided.	Isometric Smith machine quarter squat, counter-movement jump, and 5-10-5 yard shuttle run	No
Halperin et al 2014	3 bouts of 30 seconds	Roller massager	Plantar flexors	"...instructed to apply pressure equivalent to a pain level of 7 out of 10."	MVIC plantar flexion torque	No
Peacock et al 2014	1 bout of 30 seconds	Foam roller	Various	Pressure not specified.	Vertical jump; standing long jump; predicted 1RM bench press; 37m sprint; 18.3m pro-agility test	Yes, increase
Peacock et al 2015	Unclear	Foam roller	Various	Pressure not specified.	Vertical jump; standing long jump; predicted 1RM bench press; 18.3m pro-agility test	No

Table 4: Acute and short-term effects of SMFR on force production or athletic performance

Study author	Protocol	SMFR tool	Subject population	DOMS-inducing protocol	Measurement	Reduction in symptoms?
MacDonald et al 2014	2 bouts of 60-seconds per exercise	Foam roller	Physically active, males with resistance-training experience	10 sets of 10 repetitions of back squats with 60% of one-repetition maximum (1RM) with 2 minutes of rest between each	BS-11 Numerical Rating Scale of pain at 0, 24, 48 and 72 hours	Yes
Pearcey et al 2014	2 bouts of 60-seconds per exercise	Foam roller	Healthy young males with resistance-training experience	10 sets of 10 repetitions of back squats with 60% of one-repetition maximum (1RM) with 2 minutes of rest between each	PPT at 24, 48, and 72 hours	Yes
Jay et al 2014	10 minutes	Roller massager	Healthy young males	10 sets of 10 repetitions of stiff-legged deadlifts with a kettlebell	VAS for pain and PPT at 48 hours	Yes

Table 5: Acute effects of SMFR on DOMS

Study author	Duration	Protocol	SMFR tool	Muscle group treated	Pressure of SMFR, including instructions to subjects	Flexibility measurement	Increase in joint ROM?
Miller & Rockey 2006	8 weeks (24 sessions)	3 bouts of 1 minute	Foam roller	Hamstrings	No specific instructions provided.	Hip flexion ROM	No
Mohr et al 2014	2 weeks(6 sessions)	3 bouts of 1 minute	Foam roller	Hamstrings	“instructed to support their body weight with their arms extended but to allow as much pressure between the hamstring muscle group and the foam roller.”	Hip flexion ROM	Yes
Ebrahim & Elghany 2013	3 weeks (12 sessions)	Unclear	Foam roller	Hamstrings	No specific instructions provided.	Unclear	Yes
Bushell et al 2015	1 week	3 bouts of 1 minute	Foam roller	Hip flexors and quadriceps	No specific instructions provided.	Dynamic lunge position	Yes

Table 6: Chronic effects of SMFR on flexibility