An investigation into an optimal treatment protocol for self-myofascial release using a foam roller: A systematic review

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DECLARATION

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ABSTRACT

Background: Self-myofascial release can simply be defined as a self-massage technique using a device such as a foam roller or roller massager. Self-myofascial release is widely used by coaches and trainers on their athletes, despite not fully understanding the benefits or potential risks. **Purpose:** The purpose of this systematic review was to critically appraise the relevant, up to date literature and provide clarity for an optimal foam rolling (FR) intervention by answering questions regarding duration, pressure, FR density, cadence, long-term benefits and static stretching. **Methods:** Searches were conducted on five electronic databases, prior to February 2019. Included studies meet the following criteria: 1) Peer reviewed, academic journals, English language publications 2) Investigations that measure the effects of self-myofascial release (SMR) using a foam roller or roller massager on joint ROM in lower body muscles 3) Investigations that detail/compare various FR durations/densities/pressures or cadence using a control group, over a short or long period of time 4) Investigations that compare static stretching (SS) intervention in conjunction with a FR intervention. **Results:** A total of 27 articles met the inclusion criteria. A total of five studies concluded that self-myofascial release had no effect on improving flexibility and joint range of motion. Although the remaining 22 studies concluded self-myofascial release is beneficial for improving flexibility and joint ROM, considerable variation is noted between each studies foam rolling protocol. **Conclusion:** The review suggests that a self-myofascial release intervention using a high density foam roller or roller massager and the subject's bodyweight as applied pressure, for a duration of 3 sets of 30 seconds will improve flexibility and joint range of motion. The addition of a static stretching intervention to a foam rolling intervention was also found to be beneficial, however long term intervention were not found to be effective with flexibility and joint range of motion improvements lasting no longer than 30 minutes. It is important to note however, due to the limitations of this study, additional research is needed to confirm these findings.

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CHAPTER ONE: LITERATURE REVIEW

1.0 Introduction:

Self-myofascial release (SMR) can simply be defined as a self-massage technique using a device such as a foam roller or roller massager (Cheatham, Kolber, Cain, & Lee, 2015). Using a foam roller as a tool for SMR has become increasingly popular in the past decade (Healey, Hatfield, Blanpied, Dorfman, & Riebe, 2014). According to Barnes (1997), myofascial release can be described as a hands-on soft tissue technique that services a stretch into the restricted fascia (tough connective tissue). This technique is widely used by coaches and trainers on their athletes (Barnes, 1997), despite not fully understanding the benefits or potential risks.

However, it has been noted that foam rolling (FR) may have a positive impact on muscular function, performance and joint range of motion (Su, Chang, Wu, Guo, & Chu, 2017; Freiwald, Baumgart, Kuhnemann & Hoppe, 2016). Despite this, there is limited evidence to support an optimal SMR intervention protocol (Cheatham, Kolber, Cain, & Lee, 2015). This systematic review aims to critically appraise relative, up to date literature, and provide clarity for an optimal FR intervention.

1.1 Benefits of self-myofascial release:

The use of a SMR intervention using a foam roller or a roller massager, are frequently encouraged, despite not fully understanding the benefits or potential risks (Freiwald, Baumgart, Kühnemann, & Hoppe, 2016). Schleip and Muller (2013) suggest FR exercises are useful for general myofascial health and improving elastic recoil of fascial tissues. In relation to a more sports specific context, despite conflicting papers (Millar & Rocky, 2006; Mikesky, Bahamonde, Stanton, Alvey, & Fitton, 2002). Foam rolling has been suggested to benefit the following; athletic performance, aerobic capacity, flexibility, range of motion (ROM) and reduce the effect of delayed onset muscle soreness amongst others (Cheatham, Kolber, Cain, & Lee, 2015; Freiwald, Baumgart, Kühnemann, & Hoppe, 2016; Su, Chang, Wu, Guo & Chu, 2017).

Although FR protocols are commonly used in warm up strategies by trainer and coaches to enhance athletic performance, many studies report conflicting findings regarding the benefits of including a FR protocol in a warm up. Peacock, Krein, Silver, Sanders and Von Carlowitz, (2014) combined one set of 30 seconds FR along five

muscles in the lower extremities with an active warm up before preforming several performance tests (vertical jump, broad jump, predicted 1rm bench press and shuttle run) and reported an increase in performance measurements. Similarly, Malin et al. (2014) also found improvements in a 30-second cycling Wingate test after 3 sets of 30 FR protocol was applied to several muscle groups (gluteus maximus, quadriceps, hip flexors, hamstrings, gastrocnemius, adductors, iliotibial band) in the lower body.

Mikesky, Bahamonde, Stanton, Alvey, and Fitton, (2002) included a warm-up consisting of one set of two minutes using a roller massager on the hamstring before preforming a variety of performance tests including vertical jump, 20-yard dash and isokinetic knee extension at 90º and found no significant improvements. These finding are supported by MacDonald et al. (2013), MacDonald, Button, Drinkwater, and Behm, (2014), Sullivan, Silvey, Button and Behm, (2013) and Healey, Hatfield, Blanpied, Dorfman, and Riebe, (2014) who also found no improvements in athletic performance following a self-myofascial releases protocol. It should be noted that research lacks sufficient evidence to support a SMR protocol providing benifit for athletic performance (Freiwald, Baumgart, Kühnemann, & Hoppe, 2016).

Both MacDonald, Button, Drinkwater, and Behm, (2014) and Pearcey et al. (2015) reported two sets of 60 seconds FR reduced the symptoms of delayed onset muscles soreness after ten sets of ten back squats. Jay et al. (2014) also found positive results in reducing delayed onset muscles soreness using a roller massager for ten minutes. It is important to note findings from Vaughan and Mclaughlin (2014), found that three minutes of FR on the iliotibial band causes an increase in pressure pain threshold. Although FR has been shown to reduce the effects of delayed onset muscle soreness (DOMS), Freiwald, Baumgart, Kühnemann, and Hoppe, (2016) cautions the use of a foam roller and states there is little evidence to support the use of a foam roller to reduce the effects of DOMS as it may induce structural damage.

Peacock et al. (2014) investigated FR various lower body muscles (erecter spinae, gluteus maximus, piriformis, hamstring, gastrocnemius and soleus), and its influence of sit and reach scores and reported no increase in ROM. Similarly, Mikesky et al. (2002) studied the effects of one set of two minutes on an active straight leg raise test and also found no increase in hamstring flexibility. Sullivan et al. (2013), Jay et al. (2014) and Markovic (2015) however, found various FR durations (1 set of 5 seconds,

1 set of 10 seconds, 2 sets of 5 seconds, 2 sets of 10 seconds, 2 sets of 60 seconds, total foam roll for ten minutes) to improve hamstring flexibility. Plantor Flexor ROM has also been shown to improve after a FR intervention lasting three sets of thirty seconds (Halperin, Aboodarda, Button, Andersen, & Behm, 2014; Škarabot, Beardsley & Štirn, 2015), while FR of the quadriceps has been shown to improve knee extension ROM (Bradbury-Squires et al., 2015).

From the studies presented, it is evident that the benefits and risks of FR are still unclear; however, the majority of the research suggests that flexibility and ROM can be increased following a FR protocol, with an optimal FR protocol remaining unclear.

1.2 Duration of self-myofascial release:

While many studies have concluded that SMR benefits flexibility and joint ROM (Sullivan, Silvey, Button & Behm, 2013; Peacock et al., 2015; Bradbury-Squires et al., 2015; Bushell, Dawson, & Webster, 2015) the duration (sets and repetitions) of FR/roller massager interventions vary considerably, with sets ranging from one to five and repetitions ranging from five seconds to two minutes (Mohr, Long, & Goad, 2014; Grieve et al., 2015; Sullivan et al., 2013; Bradbury-Squires et al., 2015).

Authors such as Couture, Karlik, Glass and Hatzel, (2015), Mikesky, et al. (2002) and Peacock et al. (2014) all used various durations (four sets of thirty seconds, one set of 2 minutes and 2 sets of 1 minutes respectively) while investigating the effects SMR on the hamstring muscle and found no significant improvement in either hamstring flexibility or hip ROM. Similar to Mikesky et al. (2002), Miller and Rocky (2006), also found no improvement in hip flexor ROM with 32 sessions of three sets of one minute. However, Mohr, Long, and Goad, (2014) found that six sessions in two weeks of three sets of one minute was enough to improve hip flexor ROM. Junker and Stöggl, (2015) and Sullivan et al. (2013) also investigated the effects that three sets of thirty seconds and one or two sets of five or ten seconds had on hamstring flexibility during a battery of tests (electromyography was used to measure muscle activation during the maximum voluntary contraction) including a sit and reach test, which reported significant improvements. Finally, Peacock et al. (2015) concluded that one set of thirty seconds improved hamstring flexibility during an active straight leg raise test.

Improvements in knee joint ROM was noted when five sets of twenty- or sixty-seconds total (Bradbury-Squires et al., 2015) and three sets of one minute (MacDonald et al.,

2013) of FR the quadriceps were performed. Murray, Jones, Horobeanu, Tuner and Sproule (2016) noted minor improvement in hip flexor flexibility when durations of one set of one minute of FR was performed on the quadriceps. Studies have also shown that FR the planter flexor for a duration of one set of two minutes (Grieve et al., 2015) and three sets of thirty (Halperin et al., 2014) will increase ankle dorsiflexion ROM.

It is important to consider the different variables within each study, which also have an effect on the on the results. Details of each study including duration, tool used, targeted muscle group and results identified are to be found in Appendix 1. The variety of durations used in these studies highlight the diversity among SMR intervention using a foam roller and have implications for optimal treatment times.

1.3 Varying cadence, pressure and foam roller density:

Cadence, foam roller density and pressure placed on the foam roller also vary considerably between studies (Bushell, Dawson & Webster, 2015; Bradbury-Squires et al., 2015; Mikesky, Bahamonde, Stanton, Alvey & Fitton, 2002; Sullivan, Silvey, Button, & Behm, 2013; Grieve et al., 2015; Škarabot, Beardsley, & Štirn, 2015) when investigating the effects SMR has on flexibility and joint ROM. Several studies did not report the cadence guildlines (Bushell, Alvey & Fitton, 2002; Peacock et al., 2015; Škarabot, Beardsley & Štirn, 2015; Mikesky et al., 2002; Grieve et al., 2015), however, within the studies which provide candence, (Mohr, Long & Goad, 2014; Macdonald et al., 2013; Bradbury-Squines et al., 2015; jay et al., 2014), guidelines vary considerably. Mohr, Long and Goad (2014) reported cadence of one roll inferior – one roll superior for one minute, similar to jay et al. (2014), while MacDonald et al. (2013) opted for a cadence of three/four strokes a minute. Cadence of 30 beats per minute (Bradbury – Squires et al., 2015), 50 bpm (Percray et al., 2015) and 120 bpm (Sullivan, Silvey, Button & Behm, 2013), back and forth were also noted.

Several of the studies detailed the pressure used during the SMR intervention (Bradbury-Squires et al., 2015; Sullivan, Silvey, Button & Behm, 2013; MacDonald, Button, Drinkwater & Behm, 2014; MacDonald et al., 2013), however many studied provided no information regarding pressure (Roylance et al., 2013; Peacock, Krein, Silver, Sanders and Von Carlowitz 2014). Both Sullivan et al. (2013) and Bradbury-Squires et al. (2015) used a custom made device to maintain the pressure of SMR at thirteen kilograms and 25% of the participants body weight respectively. Halperin,

Aboodarda, Button, Andersen, & Behm, (2014) instructed participants to apply pressure which was equal to 7/10 on a numerical pain rate scale. MacDonald et al. (2013), MacDonald, Button, Drinkwater and Behm (2014), Malin et al., (2013), noted that pressure was equivalent to each participants body weight.

Studies have reported using both high density foam roller (Healy et al., 2014; MacDonald et al., 2013; Škarabot, Beardsley & Štirn, 2015) and polyethylene foam roller (Bushell, Dawson, & Webster, 2015; Mohr, Long & Goad, 2014; Peacock et al., 2015), while Curran, Fiore and Crisco, (2008) notes that high density foam rollers may be more beneficial then commercial/lighter foam rollers.

These studies highlight the variety in FR interventions regarding cadence, pressure and foam roller density, and pose the questions surrounding the most beneficial cadence guidelines, pressure and foam roller density.

1.4 Short-term effects of self-myofascial release:

It is evident that the majority of studies which investigate the effects of FR of flexibility and ROM in the lower extremities focus on the acute effects of SMR (Macdonald et al., 2013; Sulliven et al., 2013; Halperin et al., 2014; Peacock et al., 2014; Grieve et al., 2015). Halperin et al, (2014), Škarabot, Beardsley, and Štirn (2015) and Grieve et al. (2015), investigated the acute effects FR had on plantar flexor flexibility using a roller massager, foam roller and tennis ball respectively. Both Halperin et al. (2014) and Škarabot, Beardsley, and Štirn, (2015) used the weight bearing lunge test and saw significant improvements, while Grieve et al. (2015) used the sit and reach test to measure plantar fascia flexibility and also saw acute improvements.

Mikesky et al. (2002) studied the acute effects a roller massager has on hamstring flexibility, with no improvements in an active straight leg reach noted, while Sullivan et al. (2013) noted immediate improvements in a sit and reach test after FR of various durations (1 set of 5 seconds; 2 sets of 5 seconds saw improvements of 4.3%; 1 set of 10 seconds; 2 sets of 10 seconds saw improvements of 4.3%) was performed on the hamstring muscle. Interestingly, Couture et al. (2015) also found no acute improvements in hamstring flexibility after 2 sets of 10 seconds and 4 sets of 30 seconds when compared to baseline values.

Macdonald et al. (2013) measured the effects of FR on knee extension ROM at two minute and ten minutes post FR intervention and noted improvements of 12.7% and 10.3 %. It is important to note the drop of 2.4% in knee extension ROM after eight minutes. Similarly, Bradbury-Squires et al., (2015) also noted significant ($P < .05$) improvements of 10% (after five sets of 20 seconds) and 16% (after 5 sets of 60 seconds) in knee extension ROM after FR the quadriceps.

Peacock et al. (2014) and Peacock et al. (2015) both examined the effects of one set of thirty seconds FR on various muscles in the lower body (erector spinae, multifidus, gluteal region, hamstring, calf, quadricep and hip flexors), however only Peacock et al. (2015) noted immediate improvements in sit and reach scores. Murray et al. (2016) studied the effects of FR the hip flexors and quadriceps for one set of sixty seconds on the flexibility of the quadricep and found no improvements after 5,10, 15 or 30 minutes post intervention. Su, Chang, Wu, Guo and Chu (2017) reported an increase in sit and reach scores immediately after FR quadriceps and hamstring for two sets of 30 seconds.

1.5 Long-term effects of self-myofascial release:

Although many of the research surrounding the effects of SMR on flexibility and joint ROM focus on the short-term effects, a few studies have examined the long-term effects of SMR on flexibility and joint ROM (Junker & Stöggl, 2015; Miller & Rockey, 2006; Bushell, Dawson, & Webster, 2015; Mohr, Long & Goad, 2014). Miller and Rockey (2006) investigated the long-term effect of FR on ROM in the hamstring muscle and proposed three sets of one minute, three days a week for a total of eight weeks, however no increase in hamstring ROM was noted. Similarly, Mohr, Long and Goad (2014) also investigated the effects FR for three sets of one minute had on hip flexion ROM, however the intervention was shorter (3 sessions for 2 weeks), with a total of only 6 session. Although significant improvements were noted in hip flexion ROM after the intervention, the additional static stretching (SS) intervention may have influenced these results.

Bushell, Dawson and Webster (2015) studied the long-term effect FR had on hip extension angles in a dynamic lung. The intervention included FR the hip-flexors and quadriceps for three sets of one minute per session, with a total of 7 sessions completed within three weeks, which resulted in an increase in hip extension ROM. Junker and

Stöggl (2015) investigated the long-term effect FR had on hamstring flexibility and also found improvements. The intervention used by Junker and Stöggl (2015) consisted of three sets of thirty seconds, three times a week for a total of 4 weeks. These studies generate questions regarding the duration of a FR protocol for improving flexibility and ROM and if a long term FR intervention will result in more improved results?

1.6 Self-myofascial release and static stretching:

Static stretching typically involves moving a limb to the limit of its ROM, either actively (without the assistance of an outside force) or passively (with outside force applied, e.g. wall), with the stretch usually being held for 15 to 30 seconds and repeated two – four times (Su et al., 2017). Previous studies suggest the benefits of SS include improving flexibility, ROM and reducing the risk of injuries. However, conflicting evidence has also found SS negatively effects performance and may not prevent injury (Su et al., 2017).

Despite these contradictory findings, a study by Mohr, Long, and Goad, (2014) combined a FR protocol with a SS protocol and examined the effect this has on hip ROM . Participants were instructed to roll the hamstring in the sagittal plane for one minute with a cadence of one second superior and one second inferior, which was repeated for three sets. Static stretching of the hamstring also consisted of three sets of 1 minute, with 30 seconds rest between sets. The authors found that a combination of FR and SS improved ROM in the hip more significantly then both FR and SS alone. Similarly, Škarabot, Beardsley and Štirn (2015) combined FR with SS and found significant improvements in ankle ROM compared to FR and SS alone. Roylence et al. (2013) investigated the effects of FR on the subject's erecter spinae, gluteus maximus, piriformis, hamstring, gastrocnemius and soleus. The subjects were instructed to independently roll the selected areas for a total of ten minutes, with no cadence reported in the study. No improvements were noted in the subjects sit and reach scores, when compared to baseline values. However, when SS was used in combination with FR, significant results were recorded. Fairall, Cabell, Boergers and Battaglia (2015) also found similar results, when examining shoulder joint ROM that FR and SS, and SS alone, yielded the best results.

Junker and Stöggl (2015) investigated the use of FR as a tool to improve hamstring flexibility. Participants were instructed to roll their hamstring for 30 – 40 seconds (10 rolls back and forth) and FR was subsequently compared to the contract-relax (PNF) stretch method for stretching the hamstrings. Although improvements were reported in both groups, no significant difference was noted when FR was compared to the conventional stretch. Pekünlü, Sağıroğlu, Kurt and Özsu (2016) and Killen, Zelizney and Xin Ye (2018) also suggest that FR serves no additional advantage over SS wanting to improve hamstring flexibility and hip ROM respectively, while Su et al. (2018) disagree. Su et al., (2018) examined the effects of FR, SS and dynamic stretching on quadricep and hamstring flexibility. Their study revealed FR to be more effective in increasing quadricep and hamstring flexibility then static and dynamic stretching. These studies pose the question; Does FR provide more significant results, in relation to flexibility and joint ROM, when partnered with SS.

1.7 Summary and Rationale:

The use of a foam roller/roller massager as a tool for SMR has become increasingly popular despite the diversity among FR protocol used in studies, and not having a full understanding of the benefits or potential risks associated with FR (Freiwald, Baumgart, Kühnemann, & Hoppe, 2016). Although the research suggests that FR improves flexibility and joint ROM (Sullivan et al., 2013, Jay et al., 2014 and Markovic 2015), it is evident that variation exists between the FR protocols used in each study. The duration of FR interventions varies considerably, with sets ranging from one to five and repetitions ranging from five seconds to two minutes (Mohr, Long, & Goad, 2014; Grieve et al., 2015; Sullivan et al., 2013; Bradbury-Squires et al., 2015). While many studies do not mention cadence guidelines or pressure (Bushell, Alvey & Fitton, 2002; Peacock et al., 2015; Škarabot, Beardsley & Štirn, 2015; Roylance et al., 2013), these two factors also vary considerably between studies. Cadence guidelines vary from 120 BPM (Sullivan et al., 2013) to three – four rolls a minute (MacDonald et al., 2013), while pressure placed on the foam roller vary from body weight (MacDonald et al., 2013) to a constant pressure of thirteen kilograms using a constant pressure apparatus (Sullivan et al., 2013). Although, Curran, Fiore and Crisco (2008), found high density foam rollers more beneficial then low density foam rollers, studies have also noted the use of polyethylene foam rollers (Bushell, Dawson & Webster, 2015; Mohr, Long, & Goad, 2014). Both the short term and long

term effects of SMR have been investigated (Macdonald et al., 2013; Sullivan et al., 2013; Halperin et al., 2014; Junker & Stöggl, 2015; Miller & Rockey, 2006; Bushell, Dawson, & Webster, 2015), with the research focusing mainly on the short term effects. Many studies have also investigated the effects of combining a SS protocol with a FR protocol (Roylance et al., 2013; Mohr, Long & Goad, 2014; Škarabot, Beardsley & Štirn, 2015). As these factors (duration, pressure, foam roll density, cadence, long term effects, short term effects and combining FR protocol with SS) vary considerably between studies, it is important, therefore, to review all the relevant literature surrounding FR to provide an optimal intervention by answering the following questions;

1.8 Research Questions:

- What are the optimal treatment times for a SMR intervention using a foam roller?
- What is the optimal pressure placed on a foam roller during a SMR intervention?
- What is the optimal foam roller density used for a SMR intervention?
- What is the optimal cadence prescribed for a SMR intervention using a foam roller?
- What are the long-term benefits, if any, of SMR when using a foam roller in relation to flexibility?
- When combined with FR, what effects, if any, will SS have on joint ROM? Will a combination of both FR and SS yield more optimal results when compared to FR alone?

CHAPTER TWO: METHODOLOGY

2.0 Conceptual Framework:

A systematic search strategy was conducted, in accordance with the Preferred Reporting Items for Systematic and Meta-Analyses (PRISMA) guidelines for reporting systematic reviews (Liberati et al., 2009). The PRISMA statement contains a 27-item checklist and, a four-phase flow diagram which can be seen in figure 1. The checklist includes items related to the title, abstract, introduction, methods, results, discussion and funding. The checklist was used to ensure the reporting of this systematic review was transparent, clear and complete, while reducing the risk of flawed reporting (Liberati et al., 2009). Study selection involved filtering articles through the four-phase flow diagram and applying the inclusion and exclusion criteria, which are defined below. The T.A.P (title, abstract, paper) method was also be followed. Firstly, a study was accepted or rejected based on its title. If the study is accepted, the abstract was then reviewed and either accepted or rejected. The final stage involved either the acceptance or rejection of the whole paper.

After the search strategy and study selection is complete, data extraction will begin. The PEDro (Physiotherapy Evidence Database) scale was applied here to validate the methodology of a study and appraise the literature quality (Moseley, Herbert, Sherrington & Maher, 2002).

2.1 Data Source and Data Collection:

Potential articles were retrieved from the following databases, prior to February 2019; PubMed, Science Direct, EBSCOhost, Academic Search Complete and Education Resources Information Centre (ERIC). A direct search of known journals was also conducted to identify other potential articles. As a systematic review depends on the quality of the selected studies (Liberati et al., 2009), only high-level studies will be included, such as randomised control trials, if possible. Therefore, studies which scored four or below were excluded from this review.

2.2 Search terms & Inclusion/Exclusion criteria:

The following terms were used to search the databases listed above, individually or as a combination of the following words; self-myofascial release, foam roller, roller massage, ROM, flexibility, acute effects, long-term effects, density, SS, durations,

hamstring, cadence. Exclusion terms will also be used and include the following; vibration rolling and injury. When searching these databases, Boolean operators (AND, OR, NOT) were used.

Studies were considered for inclusion, meet the following criteria: 1) Peer reviewed, academic journals, English language publications 2) Investigations that measure the effects of SMR using a foam roller or roller massager on joint ROM in lower body muscles 3) Investigations that detail/compare various FR durations/densities/pressures or cadence using a control group, over a short or long period of time 4) Investigations that compare SS intervention in conjunction with a FR intervention.

Studies were excluded if they were non-English publications or clinical trials. Specifically, trials that included SMR as an intervention but did not directly measure ROM in lower body muscles and case reports were not included.

2.3 Ethical Considerations:

Several ethical considerations should be noted when completing a systematic review. General publication ethics should be followed to ensure data extraction has been collected correctly and results are not skewed in a favoured direction, i.e. avoiding bias (Wager & Wiffen 2011). The PRISMA statement will be followed throughout the process of this systematic review (Liberati et al., 2009).

CHAPTER THREE: RESULTS

3.1 Results:

A total of 172 articles were identified from the search, after duplicates were removed and 141 articles were excluded as they did not meet the inclusion criteria. A total of 26 articles met the inclusion criteria, while the number of the studies rejected based on either title, abstract or paper is detailed in figure 1, which also provides reasons for exclusion of the articles.

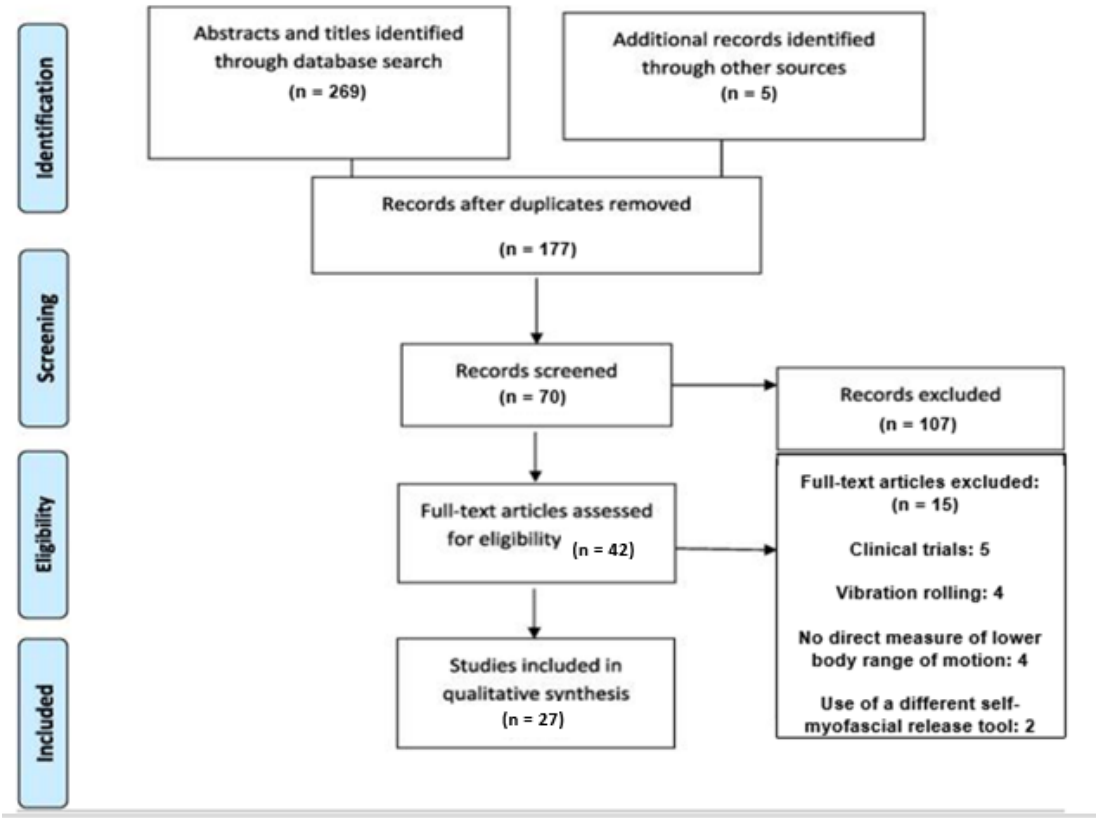

Figure 1: the PRSMA Statement: four-phase flow diagram (adapted from Liberati et al., 2009)

3.1.1 Data Extraction and Synthesis:

The following data was extracted from each study; subject demographics, intervention type, intervention parameters, muscles foam rolled and outcome, which can be found in Appendix 2. The PEDro (Physiotherapy Evidence Database) scale was used to assess the methodology of a study and appraise the literature quality (Moseley, Herbert, Sherrington & Maher, 2002). Table 1. outlines the Pedro score for each of the studies and appendix 3 provides a detailed description of each study. In the results

section the level of significance (p-value) is provided for each study to allow for comparison.

Table 1: PEDro scores for included studies

Authors	1	2	3	4	5	6	7	8	9	10	11	Total Score
Halperin et al (2014)	Y	N	N	Y	Y	N	N	Y	Y	Y	Y	7
Monteiro et al (2017)	N	Y	N	Y	N	N	Y	N	Y	Y	Y	6
Miller et al (2006)	Y	Y	N	Y	N	N	N	N	Y	Y	Y	6
Aune et al (2019)	Y	Y	N	Y	N	N	N	N	Y	Y	Y	6
Bradbury-Squires et al (2015)	Y	N	N	Y	N	N	N	Y	Y	Y	Y	6
Su et al (2017)	Y	Y	N	Y	N	N	N	N	Y	Y	Y	6
De Souza et al (2019)	N	Y	N	Y	N	N	N	N	Y	Y	Y	5
Smith et al (2018)	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	7
Behara et al (2017)	Y	Y	N	Y	N	N	N	N	Y	Y	Y	6
MacDonald et al (2013)	Y	N	N	Y	N	N	N	Y	Y	Y	Y	6
Peacock et al (2015)	Y	N	N	Y	N	N	N	Y	Y	Y	Y	6
Skarabot et al (2015)	Y	Y	N	Y	N	N	Y	Y	Y	Y	Y	8
Killen et al (2018)	N	Y	N	Y	N	N	N	N	Y	Y	Y	5
Roylance et al (2013)	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	7
Morton et al (2016)	N	Y	N	Y	N	N	N	Y	N	Y	Y	5
Kelly et al (2016)	Y	Y	N	Y	N	N	N	N	Y	Y	Y	6
Couture et al (2015)	Y	N	N	Y	N	N	N	N	Y	Y	Y	5
Hall and Smith (2018)	Y	Y	N	Y	N	N	N	N	Y	Y	Y	6
Junker et al (2015)	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	7
Grieve et al (2015)	Y	Y	N	Y	N	N	Y	Y	Y	Y	Y	8
Monteiro et al (2018)	Y	Y	N	Y	N	N	Y	Y	Y	Y	Y	8
Richman et al (2018)	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	7
Mohr et al (2014)	Y	Y	N	Y	Y	N	N	Y	Y	Y	Y	8
Hodgson et al (2018)	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	7
Sullivan et al (2013)	Y	N	N	Y	N	N	N	Y	Y	Y	Y	6
Cheatham et al (2018)	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	7
Murray et al (2016)	Y	Y	N	Y	N	N	Y	N	Y	Y	Y	7

3.1.2 Study Characteristics:

A total of 562 subjects participated in the 27 studies, all of whom had no major injuries that would have excluded them from any testing. Due to the diversity among the 27 studies, Appendix 3 provides a more detailed account of each study. The studies were grouped and analysed according to the six research questions. However, due to the large number of studies, further categorisation was needed, therefor subgroups were assigned based on the muscles foam rolled in each of the studies.

3.2 Variables/Concepts:

Table 2. shows a list of concept definitions which will be explored in this systematic review.

Table 2:List of concepts and their definitions

Concept	Definition
Self-myofascial release	self-massage technique using a device such as a foam roller or roller massage (Cheatham, Kolber, Cain, & Lee, 2015)
Total duration	Foam rolling sets multiplied by foam rolling time (seconds)
Foam rolling density	High density (form roller) and low density (soft roller)
Cadence	The tempo at which a subject foam rolls, e.g. 5 roll (up and back) in 30 seconds
Foam roll pressure	The pressure/force placed on the foam roller
Acute effects	Foam rolling lasting between 5 seconds and up to 20 minutes
Chronic effects	Foam rolling lasting up until 8 weeks (long term effects)

3.3 Duration of self-myofascial release:

All 27 studies selected for this review stated the duration of SMR used, which is presented in table 3, while also detailing muscles foam rolled and the results of each paper. The most common duration used was 3 sets of 30 seconds (Halperin, Aboodarda, Button, Andersen & Behm, 2014; Su et al. 2018; Smith, Pridgeon & Hall, 2018; Skarabot, Bearddsky & Stirn, 2015; Kelly & Beardsky, 2016; Hall & Smith, 2018; Junker & Stoggl, 2015; Hodgson, Lima, Low & Behm, 2018), however, these studies all foam rolled different muscles, apart from Skarabot, Bearddsky and Stirn (2014) and Halperin, Aboodarda, Button, Andersen and Behm (2014), who both foam rolled the plater flexor. All seven papers using the duration 3 sets of 30 seconds saw improvements, however Hodgson, Lima, Low and Behm (2018) used 4 sets of 30 seconds and found no acute increase in hip flexion ROM.

Five studies compared different FR durations (Bradbury-Squires et al. 2015; Monteiro, Cavanaugh, Frost & da Silva, 2017; Couture, Karlik, Glass & Hatzel, 2015; Sullivan et al. 2013; de Souza et al. 2019), however, all studies used different variations. Monteiro, Cavanaugh, Frost and da Silva Novaes, (2017) compared two different durations (60 seconds; 120 seconds) and 2 different SMR instruments (foam roller;

roller massager) and found that the foam roller and a higher duration better improved hip ROM. Both Couture et al. (2015) and Sullivan et al. (2013) compared different SMR durations (4 sets of 30 seconds, 2 sets of 10 seconds; 1 set of 5 seconds, 1 set of 10 seconds, 2 sets of 5 seconds, 2 sets of 10 seconds respectively) on the hamstring muscles, however only Sullivan et al. (2013) found a positive results concluding that particularly longer durations improve hamstring flexibility. Both de Souza et al. (2019) and Bradbury-Squires et al. (2015) targeted the quadriceps, while de Souza et al. (2019) also FR the calf muscles. Bradbury-Squires et al. (2015) found that both durations (5 sets of 20 seconds, 5 sets of 60 seconds) increased knee joint ROM, while de Souza et al. (2019) found that the shorter duration (2 set of 10 second) resulted in an acute increase in hip ROM, while no improvements were found in the longer duration (2 sets of 20 seconds).

Aune et al. (2019), Mohr, Long and Goad, (2014) and Miller and Rockey, (2006) all used a duration of 3 sets of 60 second and targeted hamstring muscles, while Aune et al. (2019) targeted plater flexor. Aune et al. (2019) and Miller and Rockey, (2006) found no improvements after four week and eight-week intervention respectively, however Aune et al. (2019) found an acute increase in dorsiflexion ROM (30 minutes). Mohr, Long and Goad, (2014) found an acute increase in hip flexion ROM after applying a duration of 3 sets of 60 seconds, however FR was combined with SS. MacDonald et al. (2013) used a duration of 2 sets of 60 seconds targeting the quadriceps and found it was successful at acutely increasing knee joint ROM while Murray et al., (2016) found no improvement in hip flexor and quadricep flexibility after applying a duration of 1 set of 60 seconds.

Cheatham and Stull (2018), Monteiro, Vigotsky, da Silva Noves and Skarabot (2018), and Grieve et al. (2015) opted for a duration of 1 set of 120 seconds with all studies finding acute increases in ROM. Monteiro et al. (2018) compared two self- myofascial release instruments (foam roller, roller massager), with both instruments improving hip ROM, with improvements lasting up to 30 minutes. Cheatham and Stull. (2018) and Grieve et al. (2015) found the duration increased knee flexion ROM and hamstring and lumber spine flexibility respectively.

Killen et al. (2018) applied the longest duration (10 sets of 30 seconds) of self-myofascial release, however found that SS was significantly better at improving hip

ROM then FR. Similarly, Morton, Oikawa, Phillips, Devries and Mitcheel, (2016) also compared SS to SS with FR using a duration of 4 sets of 45 seconds and found no significant difference. Richman, Tyo and Nicks (2018), Behara and Jacobson (2017) and Roylance et al. (2013) all applied a similar technique for the duration of self-myofascial. Richman et al. (2018) foam rolled 6 muscle (hip flexors and quadriceps, adductors, tensor fasciae latae and gluteus, hamstrings, plantarflexors, and dorsiflexors) for 30 seconds, while Behara and Jacobson (2017) foam rolled 4 muscles (left & right hamstrings, left & right quadriceps, left & right gluteus maximus, and left and right gastrocnemius) for 60 seconds each with both studies increasing ROM. Roylance et al. (2013) also foam rolled 4 muscle groups (lower back, hamstrings, calves, glutes) and also found acute improvements in joint ROM.

Table 3: details the durations, muscles foam rolled and results of each paper

Author:	**Duration:**	**Muscles Targeted:**	**Methods:**	**Improvement (p value)**	**Other:**
Halperin et al. (2014)	3 sets of 30 seconds	Planter Flexor	Weight bearing Lunge (Ankle ROM)	Yes ($p < 0.005$)	SS
Su et al. (2017)	3 sets of 30 seconds	Quadricep and Hamstring Flexibility (knee flexion/ Extension	Modified T-test Sit and Reach test	Yes ($p < 0.001$)	SS
Smith et al. (2018)	3 sets of 30 seconds	Glutes, hamstring, Quadriceps, calf	Sit and reach test	Yes ($p < 0.003$)	
Skarabot et al. (2015)	3 sets of 30 seconds	Planter Flexor	Weight bearing Lunge (Ankle ROM)	Yes ($p < 0.05$)	SS
Kelly et al. (2016)	3 sets of 30 seconds	Calf muscle (of dominate leg)	Weight bearing Lunge (Ankle ROM)	Yes ($p < 0.05$)	
Hall et al. (2018)	3 sets of 30 seconds	IT band, Gluteal muscles (hip adduction)	Modifed Ober test ((hip adduction ROM)	Yes ($p < 0.001$)	
Junker et al. (2015)	3 sets of 30 seconds	Hamstring flexibility	Stand and reach test	Yes ($p < 0.001$)	Long term
Hodgson et al. (2018)	4 sets of 30 seconds	Quadriceps and hamstring muscles (of dominate leg)	Straight leg raise (hip flexion ROM)	No ($p < 0.1$)	Long term
Bradbury-Squires et al. (2015)	5 sets of 20 seconds; 5 sets of 60 seconds	Quadricep muscles (knee joint ROM)	Passive knee extension test	Yes ($p < 0.5$)	
Monteiro et al. (2017)	FR 60/120 seconds; RM 60/120 seconds	Anterior part of thigh (hamstring) Hip ROM (passive hip flexion/ extension)	Manual Goiometer	Yes ($p < 0.001$)	
Couture et al. (2015)	4 sets of 30 seconds; 2 sets of 10 seconds	Hamstring	Passive knee extension test	No ($p < 0.986$)	
Sullivan et al. (2013)	1 set of 5 seconds; 1 set of 10 seconds; 2 sets of 5 seconds; 2 sets of 10 seconds;	Hamstring	Sit and reach test	Yes ($p < 0.0001$)	
De Souza et al. (2019)	2 sets of 10 seconds; 2 sets of 20 seconds	Quadriceps and calf	Passive extended leg elevation test (Hip flexion ROM) Weight	Yes ($p < 0.001$)	

			bearing Lunge (Ankle ROM)		
Miller et al. (2006)	3 sets of 60 seconds	Hamstring muscle Group	Flexometer (Active knee extension)	No ($p < 0.05$)	Long term
Aune et al. (2019)	3 sets of 60 seconds	Planter flexor	Weight bearing Lunge (Ankle ROM)	Yes ($p < 0.001$)	Long term
Mohr et al. (2014)	3 sets of 60 seconds	Hamstring muscle group	Bubble inclinometer	Yes ($p < 0.001$)	SS
MacDonald et al. (2013)	2 sets of 60 seconds	Quadricep	Modified kneeling lunge (knee joint ROM)	Yes ($p < 0.001$)	
Murray et al. (2016)	1 set of 60 seconds	Anterior part of thigh (hamstring)	Angle at force standard endpoint (Hip flexor and quadricep flexibility)	No ($p < 0.2$)	
Monteiro et al. (2018)	1 set of 120 seconds	Anterior part of thigh (hamstring)	Manual goniometer (passive hip flexion and extension)	Yes ($d = 2.2/2.0$) d = Cohen's d	
Grieve et al. (2015)	1 set of 120 seconds	Planter Flexor (hamstring and lumber spine flexibility)	Sit and reach test	Yes ($p < 0.03$)	
Cheatham et al. (2018)	1 set of 120 seconds	Quadricep	Passive knee flexion ROM	Yes ($p < 0.78$)	
Peacock et al. (2015)	1 set of 30 seconds		Sit and reach test	Yes ($p < 0.05$)	
Killen et al. (2018)	10 sets of 30 seconds	Hamstrings (Hip flexion passive ROM)	Straight leg raise test	No ($p = 0.03$)	SS
Morton et al. (2016)	4 sets of 45 seconds	Quadriceps (knee extension)	Biodex dynamometer	Yes ($p < 0.38$)	Long term SS
Richman et al. (2018)	FR 6 muscles for 30 seconds		Sit and reach test	No ($p < 0.07$)	
Roylance et al. (2013)	FR 4 muscle groups for a total of 10 minutes	Hamstring (Hip flexor passive ROM)	Sit and reach test	Yes (p value not stated)	SS
Behara et al. (2017)	FR each muscle for 1 minute		Hip ROM	Yes ($p < 0.0001$)	

3.4 Varying cadence, pressure and foam roller density:

3.4.1 Optimal Cadence:

Guidelines regarding cadence were mentioned in all studied except for the following; Monteiro et al. (2018), Richman et al. (2018), Behara and Jacobson (2017), Monteiro et al (2017), Morton et al. (2016), Grieve et al. (2015), Peacock et al. (2015), Skarabot et al. (2015), Roylance et al. (2013) and Miller and Rockey (2006), while Aune et al. (2019) stated that cadence was not controlled. The information provided in the 17 studies was very varied. Hodgson et al. (2018), Bradbury-Squires et al. (2015), Couture et al. (2015) and Sullivan et al. (2013) opted to use bpm as a method of controlling cadence, although none of the studies used the same bpm. Sullivan et al. (2013) used a beat of 120 bpm, Hodgson et al. (2018) used 60 bpm, Couture et al. (2015) used 40 bpm and Bradbury-Squires et al. (2015) opted for 30 bpm. Both Hall and Smith (2018), and Smith, Pridgeon and Hall, (2018) used 30 rolls per minute while

Killen et al. (2018), Halperin et al (2014) Mohr, Long and Goad, (2014) selected more specific instructions, dedicating one second to every roll (one second to travel the length of the muscle). De Souza et al. (2019) and Murray et al. (2016) also used the same approach dedicating two seconds to every roll, while Kelly and Beardsky (2016), instructed participants to spend 3 seconds FR down the muscle and 1 second FR up the muscles. Su et al. (2017) instructed participants to roll back and forward twice during a 30 second period, while Junker and Stoggl (2015) instructed participants to roll back and forth ten times in a 30 second period. Macdonald et al. (2013) opted for a cadence of 3 to 4 foam rolls a minute while Cheatham and Stull (2018) instructed participants to foam roll 1 inch every second and was the only study to use this method.

3.4.2 Optimal Pressures:

Pressure guidelines were mentioned in all studies except for the following; Cheatham and Stull (2018), Hodgson et al. (2018), Smith et al. (2018), Behara and Jacobson (2017), Couture et al. (2015) and Hall and Smith (2015). The majority of studies had their participants applying their bodyweight as prescribed pressure (Aune et al., 2019; Killen, Zelizney &Ye, 2018; Monteireo et al., 2018; de Souza et al., 2019; Monteireo et al., 2017; Sue et al., 2017; Kelly & Beardsky, 2016; Murray, Jones, Horobeanu, Tuner & Sproule, 2016; Peacock et al.,2015; Roylance et al., 2013; Miller & Rockey 2006), with Morton et al. (2016) instructing participants to apply as much as their bodyweight as possible onto the foam roller. The remaining 8 studies provided a more detailed account of the pressure applied during the FR interventions.

Junker and Stoggl (2015), Halperin et al. (2014) and Mohr, Long and Goad, (2014) based the pressure used in their respective studies on the pain threshold scale, with Junker and Stoggl (2015) implementing a comfortable pressure, while Mohr, Long and Goad, (2014) and Halperin et al. (2014) both opted to use perceived pain of 7/10 on a numeric pain rate scale with Mohr, Long and Goad, (2014) using a visual analogue scale for guidance. Both Bradbury-Squires et al. (2015) and Sullivan et al. (2013) used a constant pressure apparatus to monitor and control the applied pressure, applying a standard pressure of 25% of body weight and a constant pressure of 13kg respectively. Richman et al. (2018) and Couture et al. (2015) opted to use minimum body weight which participant did not find too painful, while Skarabot et al. (2015) instructed participants to cross opposite leg over the leg being foam rolled to allow for more pressure to be applied.

3.4.3 Foam roller and roller massager Densities:

Out of the 27 studies included in this systematic review, 19 studies used a foam roller, as the main tool for self-myofascial release, while 5 studies used a roller massager, 2 studies used both a foam roller and roller massager and 1 study (Grieve et al., 2015) used a tennis ball. The grid foam roller was used in 4 studies (Cheatham & Stull, 2018; Skarabot et al., 2015; Murray et al., 2016; Kelly & Beardsky, 2016), while Richman et al. (2018) used a commercial roller similar to the grind foam roller. Four studies (Smith et al., 2018; Kelly & Beardsky, 2016; Hall & Smith, 2018; Mohr, Long and Goad) referred to the use of a foam roller with an outer layer of ethylene vinyl acetate foam, which along with the grind foam roller are high density. Three studies revealed the use of a 6 inch x 12 inch high density foam rollers while two study (Roylance et al., 2013; Miller & Rockey, 2006) reported using a 45 inch x 15 inch and 6 inch x 36 inch high density foam roller, respectively. Three studies (Su et al., 2017; Morton et al., 2016; MacDonald et al., 2013) reported using foam rollers they constructed themselves, while Behar et al. (2017) and Aune et al. (2019) opted for the rumble roller and sklz trainer roller, respectively. Junker and Stoggl (2015) reports using a foam roller, however the make and dimensions of the tool used is unclear.

Roller massagers were used in five of the studies that qualified for this analysis, with three (Hodgson et al., 2018; Halperin et al., 2014; Sullivan et al., 2013) of those five using theraband roller as the main tool for self-myofascial release. De Souza et al (2019) reported using a 90 cm x 15 cm high-density roller massager, while Bradbury-Squres et al. (2017) used a common massage stick. Both Monteiro et al. (2017) and Monteiro et al. (2018) required the use of both a foam roller and roller massager to complete their respective studies, while Grieve et al (2015) used a tennis ball as a tool for self-myofascial release. Cheatham and Stull (2018) was the only study, which qualified for this review, to compare the immediate effects of variety of foam roller densities (soft, medium and hard) and found that all three foam roller densities produced similar increases in passive knee flexion ROM.

3.5 Long-term effects of self-myofascial release:

The majority of the studies which qualified for this analysis investigated the acute effects of self-myofascial release, with a total of five studies examining the long-term effects. Out of the remaining studies, Junker and Stoggl (2015) intervention was the only one to yield positive results. Junker and Stoggl (2015) determined that 4 weeks

(3 sets of 30-40 seconds each leg, 3 times a week) was effective at improving hamstring flexibility (p=0.004) via stand and reach test, with no changes noted in the control group. Morton et al. (2016) and Hodgson et al. (2018) also investigated the effects of a 4-week SMR intervention on hamstring flexibility. Morton et al. (2016) examined whether 4 sets of 60 seconds FR, twice daily for 4 weeks would better improve knee extension ROM, however it was combined with SS. An increase in ROM motion over time ($p < 0.001$) was found, however similar results were noted in the SS group. Hodgson et al. (2018) investigated the effects of FR 6 times a week for 4 weeks and 3 times a week for four weeks (each intervention used 4 sets of FR for 30 seconds) targeting the quadriceps and hamstrings. The straight leg raise, and kneeling lunge position were used to measure hamstring and quadricep ROM respectively, with both interventions resulting in a decrease in ROM.

Miller and Rockey (2016) also investigated the effects of a FR on hamstring flexibility, however opted for a 8-week long (3 sets of 60 seconds, 3 days a week) intervention, where hamstring flexibility was measured using a flexometer. The intervention revealed no significant differences ($p < 0.05$) between the treatment group and the control group, concluding that an 8-week FR intervention is an ineffective technique for increasing hamstring flexibility. Aune et al. (2019) investigated the effective of a 4-week (3 sets of 60 seconds) FR intervention on dorsiflexion ROM, targeting the gastrocnemius muscle. Range of motion measurements were taking using a weight bearing inline lunge test which were taken 30 minutes, 24 hours and 4 weeks after the first FR session was complete. Only acute improvements (up to 30 minutes post rolling) were noted ($p < 0.001$) and the 4-week intervention did not show significant improvement in chronic ROM.

3.6 Self-myofascial release and static stretching:

A total of six studies examined the effects of FR and SS. Two studies (Killen et al., 2018; Mohr, Long and Goad, 2014) examined the acute effects of FR and SS on hip flexion ROM. Both studies focused the FR of the hamstrings to improve ROM, however Killen et al. (2018) opted for ten sets of 30 seconds of either self-administered foam roller or SS (straight leg raise) while Mohr, Long and Goad, (2014) compared 3 sets of 1 minute of FR, SS (PNF) and a combination of both. Killen et al (2018) noted that both interventions showed significant increases in hip flexion, however the SS intervention yielded more significant results (p=0.026) compared to the FR group.

Mohr, Long and Goad, (2014) found that a combination of SS and FR resulted in a significant increase ($p=0.001$) in hip flexion ROM when compared to SS ($p=0.04$) and FR alone ($p=0.006$). Similar to Mohr, Long and Goad, (2014), Skarabot et al (2015) also concluded that FR, SS and a combination of both resulted in acute increase in ankle dorsiflexion ROM, while combining SS with FR yielded more beneficial results ($p < 0.05$) then FR alone.

Morton et al (2016) investigated whether a combination of FR and SS would better improve knee extension ROM compared to SS alone over four weeks. Subjects were instructed to complete two sessions daily for 4 weeks, which consisted of 4 sets x 60 seconds FR of the hamstring and 4 sets x 45 seconds hamstring static stretch in the combination group, while subjects in the SS group only completed the SS. The results of the intervention showed a significant increase ($p < 0.001$) in ROM overtime, however combining FR with SS didn't enhance the effects of SS. Su et al. (2017) examined the acute effects of FR and SS, separately as methods of improving knee flexion, which was assessed using a sit and reach test, as did Morton et al (2016). However, Su et al (2017) reported an increase in sit and reach scores ($p < 0.001$) immediately after FR quadriceps and hamstring for two sets of 30 seconds.

Roylance et al (2013) also used the sit and reach test as an assessment measure to examine the acute effects of a combination of FR and SS for joint ROM. The intervention included a total of ten minutes FR and SS the following four muscles groups; lower and upper back, glutes, hamstring and calves. The investigation showed a statically significant increase in sit and reach scores when FR, and SS are combined. Halperin et al. (2014) compared SS to FR and found similar acute improvements in both interventions lasting up to ten minutes.

CHAPTER FOUR: DISCUSSION

The purpose of this systematic review was to critically appraise the relevant, up to date literature and provide clarity for an optimal FR intervention by answering questions regarding duration, pressure, FR density, cadence, long-term benefits and SS. Despite the large number of studies regarding SMR, limited number of studies have investigated the effect SMR has on flexibility and joint ROM, with no study reporting an optimal protocol to enhance flexibility and joint ROM. The current published research suggests that flexibility and joint ROM can be enhanced using a high-density foam roller or roller massager for a duration of 3 sets of 30 seconds, however these improvements are acute and may only last up to 10 minutes. Out of the 27 studies analyzed in this review, six (Hodgson et al. 2018; Killen et al. 2018; Richman, Tyo and Nicks, 2018; Murray et al. 2016; Couture et al. 2015; Miller & Rockey, 2006) papers demonstrated no improvements in flexibility or joint ROM. The following discussion will analyze and conclude each research question separately.

4.1 Duration of self-myofascial release:

The main finding regarding duration from this systematic review is that the durations used in these studies vary considerably, with many not stating a rational for the durations used. The research presented in this review suggests that a SMR intervention of numerous durations will offer acute improvements to ankle joint ROM, knee joint ROM, Hip adduction/flexion ROM, sit and reach scores and stand and reach scores with the use of a foam roller or roller massager and durations being noted between 1 set of 5 seconds to 3 sets of 1 minute. These findings are in accordance with previous research (Cheatham & Stull, 2015) which concluded that both FR and roller massagers may offer acute benefits in flexibility and joint ROM when durations between 2 to 5 sets of 5 seconds to 2 minutes. The most common duration was 3 sets of 30 secs, which saw positive results in seven studies, however Hodgson et al. (2018) study contradicts this majority as Hodgson et al. (2018) added an extra set and found no improvements in hip ROM. A possible reason for no improvements being noted in the study is that acute testing was not completed, as it was a long duration study, only pre and post testing was complete. Despite this, it may be suggested that longer durations do not necessarily equate to greater improvements, which is supported by other studies

within the review such as Killen et al. (2018) study which found that 10 sets of 30 seconds had no benefit on hip ROM. It is important to note that Killen et al. (2018) study lacks significant scientific rigor as it fails to mention the source of the subjects, how many subjects completed testing and scoring a five on the Pedro scale. Many studies within this review also suggest a dosage based response, with other studies contradicting their findings, for example, Sullivan et al. (2013) showed an increase in ROM particularly in longer durations, however 2 sets of 10 seconds were the longest duration investigated in the study, while de Souza et al. (2019) et al. suggested 2 sets of 10 seconds was sufficient at increasing ankle ROM as it showed greater improvements then 2 sets of 20 seconds. As well as suggesting a dosage based response, these studies also support the possibility of longer durations not having a greater effect on flexibility and ROM, however further research is needed.

4.2 Varying cadence, pressure and foam roller density:

4.2.1 Optimal Cadence:

The main finding regarding cadence from this systematic review is that cadence varies considerably between studies, making it difficult to conclude an optimal cadence. The most commonly used method of prescribing cadence was the use of a metronome, which was used by four studies (Hodgson et al., 2018; Bradbury-Squires et al., 2015; Couture et al., 2015; Sullivan et al., 2013), however each study used a different BPM. This method may be the most convenient for athletes to follow, however additional research is needed to conclude an optimal BPM, preferably a study which compares different BPM/cadences.

4.2.2 Optimal Pressures:

The research suggests that the participants bodyweight is sufficient to use as a prescribed pressure during a SMR intervention, however it is important to consider the variance noted between each study, making it difficult to compare each study, therefore it is important to note that the use of participants bodyweight may just be the most common pressure prescribed and not the most optimal. Previous research by Grabow et al. (2018) suggests that completing a SMR intervention at different pain thresholds (4/10, 6/10, 8/10) does not result in significant differences in ROM. This may support the convenience and effectiveness of using an athlete's bodyweight as a prescribed pressure. The studies by Bradbury-Squires et al. (2015) and Sullivan et al.

(2013) contradict the majority of findings by applying 25% of body weight and a constant pressure of 13kg respectively, both showing improvements in joint ROM. Although more research is needed to investigate if additional pressure can enhance ROM and flexibility, Skarabot et al's. (2015) method of crossing their opposite leg over the leg the leg being foam rolled allowing for additional pressure, which may be the most convenient method for athletes.

4.2.3 Foam roller and roller massager Densities:

The research suggests that the use of a high density foam roller during a SMR intervention, yields more optimal results, with the foam roller being more commonly used then the roller massager. However, this does not suggest that a foam roller is a more optimal choice of tool for a SMR intervention, because the roller massager was not investigated as often as the foam roller and only two studies compared the two self-myofascial release tools (Monteiro et al., 2017; Monteiro et al., 2018). Cheatham and Stull (2018) study contradicts the main finding of this review regarding foam roller density, stating that different foam roller densities have no effect on ROM with soft, medium and hard foam rollers all increasing ROM.

4.3 Long-term effects of self-myofascial release:

Overall, the research presented in this systematic review implies that there are no long-term benefits of SMR when using a foam roller or roller massager to improve flexibility and joint ROM. The majority of the studies which qualified for this review investigated the acute effects of self-myofascial on flexibility and joint ROM, which resulted in improvements, however the majority of these studies failed to specify when exactly testing was done post intervention and how long these improvements lasted. The minority of studies which detailed how long these positive results lasted, suggest that the effects of SMR on flexibility and joint ROM may only last up to 10 minutes (Kelly & Beardsky, 2016; Skarabot et al. 2015; MacDonald et al. 2013) with improvements lasting no longer then 30 minutes (Aune et al. 2019; Monteiro, Vigotsky, da Silva Noves & Skarabot, 2018). It is important to note that these reported findings may of varied if the majority of studies which reported only pre and post testing details, clarified the specific time post intervention and recorded how long the improvements lasted, as Smith et al. (2018) investigated how long improvements would last and report improvements only lasting five minutes. These findings are in

accordance with Cheatham et al. (2015) findings which stated that both a foam roller and roller massager may offer short term benefits for increasing flexibility and joint ROM.

Of the studies which investigated the long-term effects of SMR only one study (Junker & Stoggl, 2015) found repeated FR over a long period of time to be beneficial. Junker and Stoggl (2015) randomised control trial had the largest number of participants (47) out of the studies analysed in this review, scored a seven on the Pedro scale and the findings are in accordance with previous research such as Bushell, Dawson and Webster (2015). Despite this, this study contradicts the majority of findings regarding long term benefits of self-myofascial release. Morton et al. (2016) also found that repetitive FR over a long period of time improved knee ROM, however it was combined with SS which may have influenced the results. Mohr, Long and Goad (2014) found similar results which may suggest a possible benefit for long term SMR to yield positive results when combined with SS, however, future research is needed. Aune et al. (2019), Hodgson et al. (2018) and Miller and Rockey (2006), concluded that a long term SMR intervention had no benefit on improving dorsiflexion ROM, active knee extension and hip flexion rom respectively. It is important to note that each of these studies had a small sample size (23 participants) and Aune et al. (2019) method of testing is questionable as the use of a flexometer is noted, which did not arise in any other study reviewed. However, Aune et al. (2019) was the only study to test the acute effects of SMR, indicating acute improvements lasting up to 30 minutes and returning to baseline within 24 hours. Further study is needed due to the lack of scientific rigor noted in these studies; however, it would be beneficial to include this method of testing in future studies as it would allow an accurate estimation of the length of improvements.

4.4 Self-myofascial release and static stretching:

The research suggests that combining a FR and SS intervention yields more optimal results compared to FR and SS alone. Four studies (Morton, Oikawa, Phillips, Devries and Mitcheel, 2016; Skarabot et al. 2015; Mohr, Long and Goad, 2014; Roylance et al. 2013) concluded that when combined with SS, FR produces more beneficial results, however only Mohr, Long and Goad, (2014) and Skarabot et al. (2013) findings are reliable regarding scientific rigor (with both scoring 8/11 on the Pedro scale). Morton et al's (2016) study concluded that a combination of FR and SS increase ROM

however no significant difference was noted between the three groups (FR, SS, SS and FR). Roylance et al. (2013) study also needs to be highlighted, as although it is in accordance with the majority of findings suggesting that a combination of FR and SS significantly increases joint ROM, however the p-value was not stated.

The research also suggests that FR is more beneficial then SS alone, however this is only supported by two studies (Su et al. 2017; Halperin et al. 2014) which have a combined total of 24 participants, suggesting additional research is needed. Killen et al's. (2018) study challenges these findings as it suggests that SS is more beneficial then FR alone, however Killen et al. (2018) opted for 10 sets of 30 seconds, again suggesting that a longer duration of FR does not equate to greater improvements as Su el al. (2017) and Halperin et al. (2014) opted for 3 sets of 30 seconds, which may also be applied to FR and SS combined, however more research is needed.

4.5 Limitations:

There are specific limitations regarding this review which need to be discussed. Firstly, the variation noted between each study, made it difficult to compare, as each study differed from the next in some way. Secondly, due to the variation between each of the studies it was difficult to conclude which protocol was more effective as there was often more than one variable different between the studies, making it difficult to compare. Participant numbers were low in a number of studies and many studies failed to report whether subjects were male or female. Due to a limited number of research databases available through the institutes e-Library, the standard of the studies included where of a low quality. Ideally, every relevant database would have been searched to ensure a more comprehensive review. Finally, a meta-analysis was not conducted, which would have evaluated each study in a statistical nature.

4.6 Conclusion and Practical Application:

Upon analysing the research, it becomes evident that a SMR intervention may be beneficial as part of a warm up, due to the acute effects noted, lasting no longer then 30 minutes. It should be noted that a long tern intervention is not effective. The characteristics of an optimal SMR intervention to improve flexibility and joint ROM using a FR or RM are as follows:

- Duration: 3 sets of 30 seconds

- Foam roller density: high density foam roller
- Pressure: participants bodyweight (cross opposite leg over the leg being foam rolled allowing for additional pressure)
- Cadence: unknown
- Static Stretching: it is beneficial to add a SS intervention to a SMR intervention to yield more optimal results

It is important to note however, due to the limitations of this study, additional research is needed to confirm these findings.

CHAPTER FIVE: BIBLIOGRAPHY

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CHAPTER SIX: APPENDICES

Appendix 1: Synopsis of existing research highlighting the various durations, tools used, targeted muscle group and results.

Authors	Duration	Tool	Muscle Groups	Result and Improvements noted
Bradbury-squires et al., (2015)	5 sets of 20 sec 5 sets of 60 sec	Roller Massager	Quadriceps	5 sets of 20 sec improved by 10% 5 sets of 60 sec improved by 16%
Bushell et al., (2015)	7 session (total) 3 sets 1 min	Polyethylene Foam Roller	Hip extension range of motion quadricep	Yes
Couture et al., (2015)	2 sets of 10 sec 4 sets of 30 sec	Commercial Foam Roller	Hamstring Hamstring flexibility	No improvements noted
Grieve et al., (2015)	1 set of 2 min	Tennis ball	Plantar flexor	Yes
Halperin et al., (2014)	3 sets of 30 sec	Roller Massager	Plantar Flexor	Improvements of 4 %
Junker et al., (2015)	3 sets of 30 seconds	Foam Roller	Hamstring Sit and reach	Yes
MacDonald et al., (2013)	2 sets 1 min	High Density Foam Roller	Quadriceps	Improvements of 12.7% noted
Millar and Rocky, (2006)	8 weeks4 times a week 3 sets of 1 minute	Foam Roller	Hamstring Hip flexion ROM	No
Mohr et al., (2014)	6 sessions in 2 weeks 3 sets of 1 minute	Polyethylene Foam Roller	Hamstring Hip flexion ROM	Yes
Mikesky et al., (2002)	1 set of 2 mins	Roller Massager	Hamstring Hip range of motion	No improvements
Murray et al., (2016)	1 set 60 sec	Foam Roller	Quads hip flexors	No

Peacock et al., (2014)	1 set 30 sec	Polyethylene Foam Roller	Hamstring	No
Peacock et al., (2015)	1 set 30 sec	Polyethylene Foam Roller	Hamstring ASLR	Yes
Skarabot et al., (2015)	3 sets of 30 sec	High Density Foam Roller	Plantar Flexors Ankle dorsiflexion	Yes
Su et al., (2017)	2 sets of 30 sec	Foam Roller	Quads and Hamstrings Sit and reach	Yes
Sullivan et al., (2013)	1 set 5 sec 1 set 10 sec 2 set 5 sec 2 set 10 sec	Roller Massager	Hamstring Sit and reach	Yes improvements noted of 4.3%(5sec) and 2.3% (10 sec)

Appendix 2: Study characteristics

Autor's	Demographics	Intervention type	Targeted Muscles	Parameters	Improvements
Halperin et al (2014)	12 Male 2 Female	Randomised cross over design	Planter Flexor muscles (ankle ROM)	Weight bearing lunge	Yes
Monteiro et al (2017)	10 Male	Randomised cross-over within subject design	Hip ROM (passive hip Flexion and Extension ROM	Manual Goniometer	Yes
Miller et al (2006)	23 Subjects	Parallel group randomized controlled trail	hamstring muscle group (active Knee extension)	Flexometer	No
Aune et al (2019)	23 Subjects	Randomised trail, with pre-test, post-test design	Planter Flexor muscles (dorsiflexion ROM)	Weight bearing inline lunge	No (only acute)
Bradbury-Squires et al (2015)	10 Male	A repeated measure pre-test, post-test design	Knee joint ROM (quad muscles)	knee-extension and kneeflexion maximal voluntary isometric contractions	Yes
Su et al (2017)	30 Subjects	Crossover study	Knee flexion and extension (quad and hamstring flexibility)	modified Thomas test (flexibility of quads), sit and reach test(lower back and hamstring flexibility)	Yes
de Souza et al (2019)	14 Male	Cross-sectional study with a	Ankle dorsiflexion ROM and Hip flexion ROM	Weight bearing lunge,	Yes

		within-subject crossover design	(posterior thigh and calf muscles	passive extended leg elevation lunge test	
Smith et al (2018)	21 Female 8 Male	repeated-measures design	gluteals, hamstrings, quadriceps, and calf muscles	Sit and reach test	Yes
Behara et al (2017)	14 Subjects	randomized crossover design	hamstrings, quadriceps gluteus maximus, gastrocnemius	Hip range of motion	Yes
MacDonald et al (2013)	11 Male	within-subject design	Quadriceps (knee joint ROM)	modified kneeling lunge	Yes
Peacock et al (2015)	16 Male	counterbalanced, crossover, within-subjects design	erector spinae, multifidus, gluteus maximus, gluteus medius, gluteus minimus, semitendinosus, semimembranosus, biceps femoris, gastrocnemius, soleus, pectoralis major, pectoralis minor, rectus femoris, vastus lateralis, and vastus medialis	Sit and reach test	Yes
Skarabot et al (2015)	5 Female 6 Male	randomized within-subject design	Plantarflexor (dorsiflexion ROM)	Weight-bearing lunge test	Yes

Killen et al (2018)	13 Male 10 Female	within-subjects randomized crossover design	Hip flexion passive ROM (hamstring)	Straight leg raise test	No
Roylance et al (2013)	27 Subjects	randomized crossover design	lumbar spinal flexion, hip flexion, knee extension, and ankle dorsiflexion)	Sit and reach test	Yes
Kelly et al (2016)	26 Subjects	randomized controlled between-subjects design	calf muscles (ankle dorsiflexion ROM)	Weight bearing lunge	Yes
Morton et al (2016)	20 Subjects	randomised trail with pre-test, post-test design	Hamstrings	Biodex dynamometer (hamstring tightness)	Yes
Couture et al (2015)	19 Female 14 Male	pre/post-test design	Hamstring	Passive knee extension test	No
Hall et al (2018)	14 Female 12 Male	randomized within-subject design	IT band, Gluteal muscle group (hip adduction passive ROM)	Modified Ober test	Yes
Junker et al (2015)	47 Male	randomised controlled trial	hamstring flexibility	Stand and reach test	Yes
Grieve et al (2015)	33 Subjects	pilot single blind randomised control trial	Plantarflexor	Sit and reach test	Yes
Monteiro et al (2018)	18 Male	single-blinded, randomized, crossover, within-subject design	Anterior of the thigh (hamstring)	manual goniometer (passive hip flexion and extension)	Yes
Richman et al (2018)	14 Female	randomized crossover design	hip flexors and quadriceps,	Sit and reach test	No

			adductors, tensor fasciae latae and gluteus, hamstrings, plantarflexors, and dorsiflexors		
Mohr et al (2014)	40 Subjects	Controlled laboratory study	hamstring muscle group (Hip flexion ROM)	Bubble inclinometer	Yes
Hodgson et al (2018)	23 Subjects	Randomized controlled intervention study	quadriceps and hamstrings (Knee extension and Flexion)	Kneeling lunge position	No
Sullivan et al (2013)	10 Females 7 Males	pre/post-test design	hamstring muscle group	Sit and reach test	Yes
Murray et al (2016)	123 Males	randomized crossover study	anterior part of thigh (hamstring)	angle at force standardized endpoint (quadriceps and hip flexors)	No
Cheatham et al (2018)	10 Females 26 Males	Pre-test, post-test randomized controlled trial	Quadriceps	baseline digital inclinometer (knee flexion ROM)	Yes

Appendix 3: Study description

Autor	Duration	FR Density	Cadence	Pressure	Other	Improvements
Halperin et al (2014)	3 sets of 30 seconds		Not mentioned	7/10 on a numeric pain rate scale	SS	Yes
Monteiro et al (2017)	60 seconds 120 seconds		Not mentioned	Bodyweight		Yes
Miller et al (2006)	3 sets of 1 minute		Not mentioned	Bodyweight	Long term	No
Aune et al (2019)	3 sets of 1 minute		Not controlled	Bodyweight	Long term	No (only acute)
Bradbury-Squires et al (2015)	5 sets of 20 seconds/ 5 sets of 60 seconds		30 BPM	Pressure apparatus applied a standard pressure (25% of bodyweight)		Yes
Su et al (2017)	3 sets of 30 seconds		Move back and forth twice for 30 seconds	Bodyweight	SS	Yes
De Souza et al (2019)	2 x 10 seconds/ 2 x 20 seconds		4 seconds per foam roll (2 seconds up, 2 seconds down)	Bodyweight		Yes
Smith et al (2018)	3 sets of 30 seconds		30 foam rolls per minute	Not mentioned		Yes
Behara et al (2017)	1 minute on each muscle; hamstrings, quadriceps gluteus maximus, gastrocnemius		Not mentioned	Not mentioned		Yes
MacDonald et al (2013)	2 sets of 1 minute		3-4 rolls per minute			Yes
Peacock et al (2015)	1 set of 30 seconds		Not mentioned	Bodyweight		Yes
Skarabot et al (2015)	3 sets of 30 seconds		Not mentioned	One leg crossed over other to	SS	Yes

			allow for more pressure		
Killen et al (2018)	10 sets of 30 seconds	1 second up, 1 second down	Bodyweight	SS	No
Roylance et al (2013)	4 muscle groups for a total of 10 minutes	Not mentioned	Bodyweight	SS	Yes
Kelly et al (2016)	3 sets of 30 seconds	3 seconds down, 1 second up	Bodyweight		Yes
Morton et al (2016)	4 sets of 45 seconds	Not mentioned	Bodyweight (as much as possible)	Long term SS	Yes
Couture et al (2015)	4 sets of 30 seconds/ 2 sets of 10 seconds	40 BPM	Opposite leg used as a stabilizer (minimum weight on foam roller)		No
Hall et al (2018)	3 sets of 30 seconds	30 foam rolls per minute	Not mentioned		Yes
Junker et al (2015)	3 sets of 30/40 seconds	10 foam rolls in 30/40 seconds	Comfortable pressure, based on pain threshold	Long term	Yes
Grieve et al (2015)	1 set of 2 minutes	Not mentioned	Not mentioned		Yes
Monteiro et al (2018)	1 set of 2 minutes	Not mentioned	Bodyweight		Yes
Richman et al (2018)	30 seconds per muscle (6 muscles)	Not mentioned	Steady pressure, which subjects felt, but was not to painful		No
Mohr et al (2014)	3 sets of 1 minute	1 second up, 1 second down	Perceived pain of 7/10 on a visual analogue scale	SS	Yes
Hodgson et al (2018)	4 sets of 30 seconds	60 BPM	Not mentioned	Long term	No
Sullivan et al (2013)	1 set of 5 seconds/1 set of 10 seconds/2	120 BPM	Constant pressure apparatus, set at a		Yes

	sets of 5 seconds/2 sets of 10 seconds		constant pressure of 13kg	
Murray et al (2016)	1 set of 60 seconds	2 seconds per pass	Bodyweight	No
Cheatham et al (2018)	1 set of 2 minutes	1 inch per second	Not mentioned	Yes