Journal of Bodywork & Movement Therapies 24 (2020) 151–174

Contents lists available at ScienceDirect

Journal of Bodywork & Movement Therapies

journal homepage: www.elsevier.com/jbmt

Prevention and Rehabilitation

Effects of foam rolling on performance and recovery: A systematic review of the literature to guide practitioners on the use of foam rolling

Sharief Hendricks [a, c, *], Hayd'n Hill [a], Steve den Hollander [a], Wayne Lombard [a], Romy Parker [b]

[a] *University of Cape Town, Division of Exercise Science and Sports Medicine, Department of Human Biology, Faculty of Health Sciences, South Africa*
[b] *University of Cape Town, Pain Management Unit, Department of Anaesthesia and Perioperative Medicine, Faculty of Health Sciences, University of Cape Town, South Africa*
[c] *Institute for Sport, Physical Activity and Leisure, Leeds Beckett University, Leeds, United Kingdom*

A R T I C L E I N F O

Article history:
Received 30 October 2019
Accepted 30 October 2019

Keywords:
Foam rolling
Performance
Recovery
Flexibility

A B S T R A C T

Background: Foam Rolling (FR) is currently used by athletes at all levels. It is not known whether FR is more effective being used as a warm up to aid performance or more effectively used as a cool-down for recovery. Therefore, the purpose of this systematic review was to determine the effects of FR on performance and recovery.
Methods: A customized search strategy was conducted to search seven electronic databases: Google Scholar; Science Direct; Pubmed Central; Pubmed; ISI Web of Science; Medline and Scopus. The database search was limited to journals published in English between January 2006 and June 2019. Any study design, for example, cross-over, repeated measures, randomized-control trials, was considered, as long as one of the interventions was using a FR. Studies that tested FR combined with other techniques were also considered, as long as one of the conditions was FR only.
Results: A total of 49 articles met the inclusion criteria.
Conclusion: FR may reduce muscle stiffness and increase ROM and should be used in combination with dynamic stretching and active warm-up before a training session. Furthermore, the optimum dosage to achieve these flexibility benefits seems to be a total 90s–120s of FR. FR reduced DOMS and increased PPT, and therefore may optimize recovery from training. Future studies on the effects of FR should include true controls or sham groups, and consider the FR experience of the athlete.
Systematic Review Registration: PROSPERO – CRD42017064976.

1. Introduction

Foam rolling (FR) is a form of self-myofascial release (SMR) where an individual uses a tool to apply direct pressure to the targeted musculature (Freiwald et al., 2016; Healey et al., 2014). This technique is derived from myofascial release (MR), an umbrella term used for a wide range of manual therapy techniques where pressure is applied by a clinician to a muscle and fascia (Ajimsha et al., 2014; Barnes, 1997; McKenney et al., 2013). Two previous systematic reviews (Beardsley and Skarabot, 2015; Cheatham et al., 2015) suggested that SMR has a range of valuable effects for both athletes and the general population, including increasing flexibility, enhancing muscle recovery and enhancing pre- and post-exercise muscle performance (Beardsley and Skarabot, 2015; Cheatham et al., 2015). The authors of both previous reviews acknowledged that the research on the effects of SMR is still emerging and there is no current consensus on a FR protocol (Beardsley and Skarabot, 2015; Cheatham et al., 2015). With that said, it is worth noting that these two systematic reviews were not only on FR but included various other SMR tools.

FR has been advocated to increase performance (Healey et al., 2014; MacDonald et al., 2013; Peacock et al., 2015), improve

* Corresponding author. Division of Exercise Science and Sports Medicine, Department of Human Biology, Faculty of Health Sciences, the University of Cape Town and the Sports Science Institute of South Africa, Cape Town, PO Box 115, South Africa, 7725.
E-mail address: sharief.hendricks01@gmail.com (S. Hendricks).

https://doi.org/10.1016/j.jbmt.2019.10.019
1360-8592/

recovery (Kalen et al., 2017; Rey et al., 2017; Pearcey et al., 2015), increase flexibility (Boguszewski et al., 2017; Griefahn et al., 2017; Mohr et al., 2014), reduce delayed onset of muscle soreness (DOMS) and pain (Romero-Moraleda et al. 2017, 2019; Vaughan et al., 2014), affect arterial function (Murray et al., 2016), and modulate the autonomic nervous system (Kim et al., 2014). With that said, a review by Freiwald et al. (2016) suggested that FR should be used cautiously based on the available scientific evidence to enhance athletic performance and underlying mechanical and physiological mechanisms.

Foam Rolling has become one of the most popular SMR tools available, and is said to mimic the effects of MR (Curran et al., 2008; Peacock et al., 2014; Vaughan et al., 2014). It has rapidly gained popularity amongst elite and recreational athletes (Bushell et al., 2015), despite the FR research being in its infancy. To inform evidence-based practice, clarity is needed on when FR should be used, and what protocols should be prescribed to be effective. Therefore, the purpose of this systematic review was to determine the effects of FR on performance and recovery from post exercise induced muscle damage to guide practitioners on the use of FR.

2. Methods

2.1. Registration

In accordance with the Preferred Items for Reporting Systematic Reviews and Meta-analyses for Protocols (PRISMA-P) guidelines, this systematic review was registered with the International Prospective Register of Systematic Reviews (PROSPERO) and thus a registration/identification number acquired and entered into the protocol and systematic review (CRD42017064976). This allows for transparency of the systematic review process, to assist in minimizing bias, and to help reduce unnecessary duplication of reviews (Shamseer et al., 2015).

2.2. Information sources and search

A customized search strategy (Fig. 1) was conducted to search seven electronic databases: Google Scholar; Science Direct; Pubmed Central; Pubmed; ISI Web of Science; Medline and Scopus. The following eight search terms were utilized: “Foam Rolling”; “Myofascial Roller”; “Foam Rolling” OR “Myofascial Roller” AND “Self-Myofascial Release”; “Foam Rolling” OR “Myofascial Roller” AND “Myofascial Release”; “Foam Rolling” OR “Myofascial Roller” AND “Recovery”; “Foam Rolling” OR “Myofascial Roller” AND “DOMS” OR “EIMD”; “Foam Rolling” OR “Myofascial Roller” AND “Performance”; “Foam Rolling” OR “Myofascial Roller” AND “Flexibility”. The database search was limited to journals published in English between January 2006 and June 2019.

Reference lists of articles identified were hand searched to source additional articles. In addition, reference lists of previous systematic reviews or literature reviews identified were screened to identify further potential articles.

2.3. Eligibility criteria

A three-step method was followed to identify the studies that were reviewed. Databases were searched by two reviewers to identify potential titles and abstracts. The titles and abstracts were screened for eligibility by three reviewers independently (HH, SdH and SH) using the inclusion and exclusion criteria outlined in Table 1. The full text of all studies identified through screening were obtained after duplicates were removed. The full text of studies that included FR as an intervention were reviewed (Fig. 1).

Articles were included if they met the following criteria: published between January 2006 and June 2019, available full text in English and peer reviewed. Any study design, such as cross-over, repeated measures, randomized-control trials, was considered, as long as one of the interventions used a FR (Table 1). Studies that tested FR combined with other techniques were also considered, provided that one of the conditions was FR only. Literature reviews and systematic reviews were not included.

2.4. Data collection process

Data from the articles was extracted by two reviewers using a customized pre-set summary table to record the following items: sample demographics; study characteristics; type of foam roller; pressure instructions; foam rolling protocol; the outcome measure and data; findings and a methodological quality assessment using the Physiotherapy evidence database (PEDro) scale scores (Cheatham et al., 2015). The clinical trial quality was assessed using the PEDro scale and was categorized as either high quality, moderate quality, or low quality (Maher et al., 2003). The tool comprises a checklist of 11 criteria, of which only 10 criteria are scored (Table 2). Each of the 11 criteria leads to 1 point being awarded making the tool clear and unambiguous. For each criterion the study meets, 1 point was awarded. In this review, PEDro scores between 6 and 11 points were considered to be of high quality evidence; PEDro scores of between 4 and 5 points were considered to be of moderate quality; and PEDro scores between 0 and 3 were considered to be of poor quality (Maher et al., 2003; MacDonald et al., 2014). The PEDro scale does not evaluate clinical usefulness and can only be applied to experimental studies.

3. Results

3.1. Study selection

Selection of the studies started with 4039 titles identified through the database search. 3850 were excluded as shown in Fig. 1.

A total of 189 abstracts were obtained, and screened to obtain full text articles. Forty-six abstracts were excluded as they were non-peer reviewed articles, post graduate theses, conference abstracts and studies not utilizing foam rolling as an intervention. This left 91 articles that were screened for eligibility. A further 42 articles were excluded as the main focus was not on performance or recovery, or had low PEDro scores. Forty-nine articles were then available to utilize in this systematic review. The process of study selection and the number of studies excluded at each stage, with reasons for exclusion, is presented in Fig. 1. A summary of the included studies is presented in Table 4. Table 4.1 represents the performance studies and Table 4.2 represents the recovery studies.

3.2. Study characteristics

The 49 studies that were included in this review were then divided into categories involving performance (26 studies) and recovery (23 studies). Due to the inclusive nature of this study, under recovery, the studies were subdivided according to outcome. These subdivisions were: DOMS (5 studies), flexibility (8 studies), PPT (5 studies), and ‘other’ (5 studies).

3.3. Synthesis of results

3.3.1. Quality of studies

Overall, the scores fall in the category of high quality of evidence, according to the quality criteria of the PEDro scale meaning they could be included in this review. Nevertheless, the majority were in the lower half of the range (6–9 points out of 11). The most

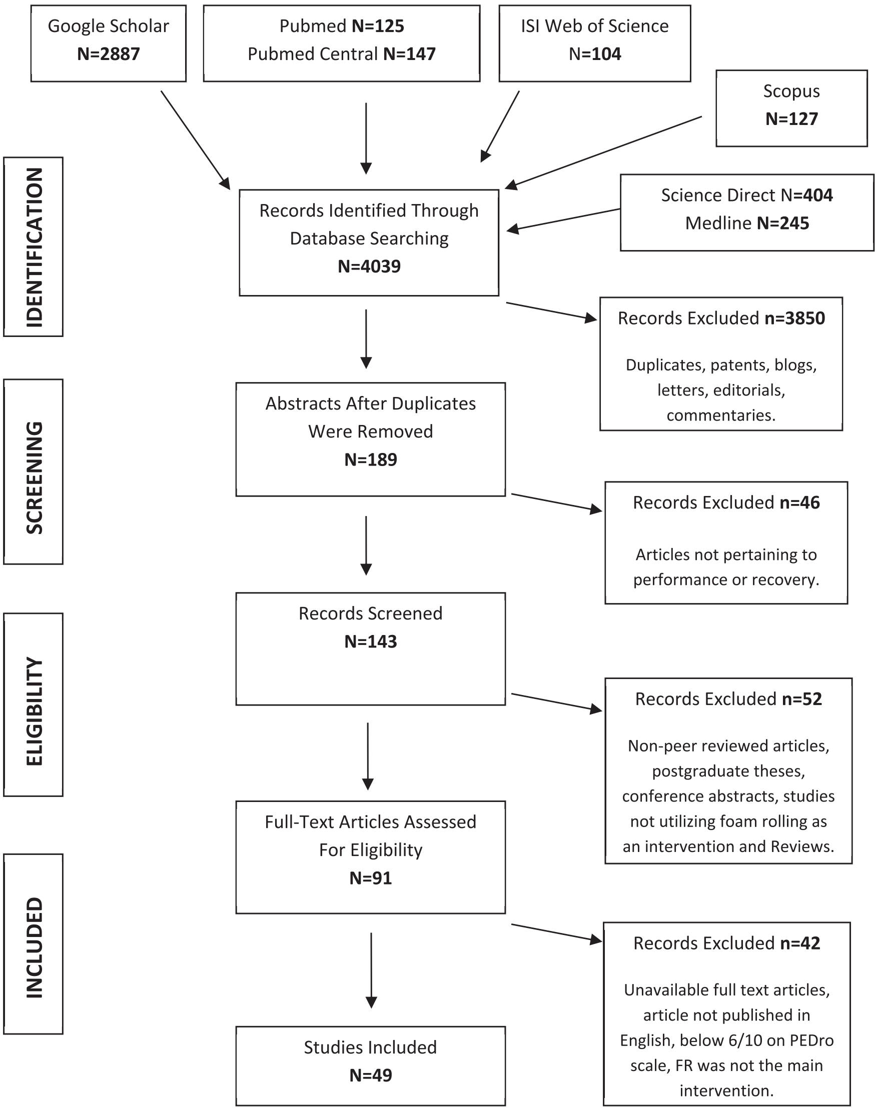

Fig. 1. Summary of data collection process.

commonly neglected criteria those relating to blinding (PEDro scale questions 5–7). The majority of the studies failed to mention blinding of either the subjects or the testers/therapists, as well as whether the assessor were blinded or not. Very few studies reported satisfying the concealment of allocation (PEDro scale question 3). The remaining six criteria were positively scored for most of the included studies (Table 3). Table 2 shows the criteria for each category that had to be met to obtain a positive score, which in

Table 1
Inclusion and exclusion criteria used in the selection process.

Exclusion criteria applied by two authors to identify relevant articles.	Inclusion criteria used to select articles incorporated in the systematic review.
1. Conference proceedings, letters, editorials, blogs, commentaries, case reports, conference abstracts or non-peer reviewed articles. 2. Studies not utilizing foam rolling as an intervention. 3. Fail to obtain a minimum PEDro score of 6.	1. Date Range: January 2006–June 2019 2. Language: English 3. Journal Type: Peer reviewed journals 4. Any study design, for example, cross-over, repeated measures, randomized-control trials, was considered, as long as one of the interventions was using a FR. 5. Studies that tested FR combined with other techniques were also considered, as long as one of the conditions was FR only. 6. FR was utilized as a tool to enhance performance and/or recovery.

PEDro scale is a methodological quality assessment tool for randomized control trials.

Table 2
Physiotherapy evidence database (PEDro) scale scores.

1 Eligibility criteria were specified (no points awarded)
2 Subjects were randomly allocated to groups
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
10 The result of between-group 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 3
Pedro Score for each study.

Study Authors (Year)	1	2	3	4	5	6	7	7	8	9	10	Total
1. Aune et al. (2019)	1	1	0	1	0	0	1	1	1	1	1	**7**
2. Baumgart et al. (2019)	1	1	0	1	0	0	0	1	1	1	1	**6**
3. Behara and Jacobson (2017)	1	1	0	1	0	0	0	1	1	1	1	**6**
4. Boguszewski et al. (2017)	1	1	0	1	0	0	1	1	1	1	1	**7**
5. Cavanaugh et al. (2017)	1	1	0	1	0	0	0	1	1	1	1	**6**
6. Cheatham et al. (2017)	1	1	0	1	1	1	1	1	1	1	1	**9**
7. Cheatham and Kolber (2017)	1	0	0	1	1	0	0	1	1	1	1	**6**
8. Cheatham and Stull (2018a)	1	1	0	1	1	1	0	1	1	1	1	**8**
9. Cheatham and Stull (2018b)	1	1	0	1	1	1	0	1	1	1	1	**8**
10. Couture et al. (2015)	1	1	1	1	0	0	0	1	1	1	1	**7**
11. D'Amico and Paolone (2017)	1	1	0	1	0	0	0	1	1	1	1	**6**
12. Fleckenstein et al. (2017)	1	1	0	1	0	0	0	1	1	1	1	**6**
13. Griefahn et al. (2017)	1	1	1	0	1	1	1	1	1	1	1	**9**
14. Guillot et al. (2019)	1	1	0	0	1	1	0	1	1	1	1	**7**
15. Hall and Smith (2018)	1	1	1	1	0	0	0	1	1	1	1	**7**
16. Hansen et al. (2016)	1	1	0	1	1	0	0	1	1	1	0	**6**
17. Healey et al. (2014)	1	1	0	1	0	0	0	1	1	1	1	**6**
18 Hotfiel et al. (2017)	1	0	0	1	0	0	1	1	1	1	1	**6**
19. Jones et al. (2015)	1	1	0	1	0	0	0	1	1	1	1	**6**
20. Kalen et al. (2017)	0	1	0	1	0	0	0	1	1	1	1	**6**
21. Kelly and Beardsley (2016)	1	1	0	1	0	0	0	1	1	1	1	**6**
22. Killen et al. (2018)	1	1	0	1	0	0	0	1	1	1	1	**6**
23. Kim et al. (2014)	0	1	0	1	0	0	0	1	1	1	1	**6**
24. Lee et al. (2018)	1	1	0	1	0	0	0	1	1	1	1	**6**
25. MacDonald et al. (2013)	0	1	0	1	0	0	0	1	1	1	1	**6**
26. MacDonald et al. (2014)	0	1	0	1	0	0	0	1	1	1	1	**6**
27. Macgregor et al. (2018)	1	1	1	1	0	0	0	0	1	1	1	**6**
28. Mohr et al. (2014)	1	1	0	1	0	0	0	1	1	1	1	**6**
29. Monteiro and Neto (2016)	1	1	0	1	0	0	0	1	1	1	1	**6**
30. Monteiro et al. (2017a)	1	1	0	1	0	0	0	1	1	1	1	**6**
31. Monteiro et al. (2017b)	1	1	1	1	0	0	0	1	1	1	1	**7**
32. Monteiro et al. (2017c)	1	1	0	1	0	0	0	1	1	1	1	**6**
33. Monteiro et al. (2018)	1	1	0	1	0	0	1	1	1	1	1	**7**
34. Monteiro et al. (2019a)	1	1	0	1	0	0	1	1	1	1	1	**7**
35. Monteiro et al. (2019)	1	1	0	1	0	0	1	1	1	1	1	**7**
36. Morales-Artacho et al. (2017)	1	1	0	1	0	0	0	1	1	1	1	**6**
37. Murray et al. (2016)	1	1	1	0	1	0	0	1	1	1	1	**7**
38. Rey et al. (2017)	1	1	0	1	0	0	0	1	1	1	1	**6**
39. Richman et al. (2019)	1	1	1	1	0	0	0	1	1	1	1	**7**
40. Romero-Moraleda et al. (2017)	1	1	0	0	1	1	1	1	1	1	1	**8**
41. Romero-Moraleda et al. (2019)	1	1	0	1	0	0	1	1	1	1	1	**7**
42. Schroeder et al. (2017)	1	1	0	1	0	0	0	1	1	1	1	**6**
43. Skarabot et al. (2015)	1	1	1	1	1	0	0	1	1	1	1	**6**
44. Smith et al. (2018)	1	1	0	1	0	0	0	1	1	1	1	**6**
45. Su et al. (2017)	1	1	0	1	0	0	0	1	1	1	1	**6**
46. Wilke et al. (2018)	1	1	1	0	1	1	0	1	1	1	1	**8**
47. Wilke et al. (2019)	1	1	1	1	0	0	0	0	1	1	1	**6**
48. Williams and Selkow (2019)	1	1	0	1	0	0	1	1	1	1	1	**7**
49. Zorko et al. (2016)	1	1	0	1	1	0	0	1	1	1	1	**7**

each case is indicated as a "1". The mean PEDro score was 6.5, with a range from 6 to 9. Beyond summarising the quality of the studies, the data did not allow for statistical analyses as the outcome measures varied and data were represented differently throughout.

3.3.2. Performance

The research of FR on performance enhancement has increased since a previous review on SMR in 2015 (Cheatham et al., 2015). Twenty-six studies measured the effects of FR on performance (Table 4.1). According to the PEDro scale, the quality of evidence for these studies ranged from 6 to 9. There were variations in outcome measures, the FR tool and the protocol used, and the instructions given with regard to pressure applied. The most common type of FR used was a multi-level rigid roller which consists of a PVC pipe surrounded by foam. This was previously suggested to be the most effective FR type as greater pressure can be generated (Curran et al., 2008).

Most of the studies instructed the participants to apply as much pressure as possible while FR (Cavanaugh et al., 2017; MacDonald et al., 2013; Monteiro et al., 2017a, 2017b; 2017c; Schroeder et al., 2017), but instructions were commonly not mentioned (Behara and Jacobson, 2017; Healey et al., 2014; Jones et al., 2015; Monteiro and Neto, 2016; Morales-Artacho et al., 2017; Peacock et al., 2014, 2015) (Table 4.1). Performance FR protocols varied in terms of rolling direction, for example, unilateral (Behara and Jacobson 2017; Monteiro et al., 2017a; Killen et al. (2018)) vs. bilateral (Monteiro et al. 2017b, 2017c) and by frequency (for example, number of sets (Killen et al., 2018; Hall and Smith, 2018), duration (for example, length of rolling (Monteiro et al. (2017a) and tempo (for example, using a metronome (Lee et al., 2018; Macgregor et al., 2018). These variations appear to have influenced the results (Table 4.1). The studies reporting on FR applied for 30s and those who FR for more than 120s reported negative results for FR on performance (Cavanaugh et al., 2017; Healey et al., 2014; Jones et al., 2015; Sagiroglu et al. 0.2017).

Foam Rolling does not seem to impede performance but appears to be a performance enhancing tool due to its effects on flexibility prior to a bout of exercise when used in specific doses (Behara and Jacobson, 2017; MacDonald et al., 2013; Morales-Artacho et al., 2017; Su et al., 2017; Hall and Smith, 2018; Lee et al., 2018; Monteiro et al., 2019a) (Table 4.1). Based on the effects of FR on flexibility during a warm-up, studies suggest replacing SS with FR and using it combination with dynamic stretching (DS) (Su et al., 2017) and active warm-up routines (Martínez-cabrera and Núñez-sánchez, 2016; Morales-Artacho et al., 2017). FR as part of an active warm-up maintains muscle contractility (Behara and Jacobson, 2017; Hansen et al., 2016; Healey et al., 2014; Jones et al., 2015; Martínez-cabrera and Núñez-sánchez, 2016; Morales-Artacho et al., 2017; Su et al., 2017), muscle passive stiffness (Martínez-cabrera and Núñez-sánchez, 2016; Morales-Artacho et al., 2017) and reduces post-exercise fatigue (1.63 ± 1.79) on an overall soreness scale (Healey et al., 2014). Using FR as part of an active warm-up will be particularly useful for sports that require both flexibility and force production (MacDonald et al., 2013; Su et al., 2017).

Most of the studies reported no change in performance tests following FR (Behara and Jacobson, 2017; Hansen et al., 2016; Healey et al., 2014; Jones et al., 2015; MacDonald et al., 2013; Martínez-cabrera and Núñez-sánchez, 2016; Morales-Artacho et al., 2017; Su et al., 2017). It is not clear why two studies, both from Peacock and colleagues, reported increases in performance (Peacock et al., 2014, 2015). The reported increase in performance may be due to the general warm-up performed in both studies. Monteiro et al. (2017a) reported that FR increased the performance of FMS overhead deep squat scores. The increase in performance of this task was attributed to FR effects on flexibility (Monteiro et al., 2017a).

Table 4.1
Summary of studies on the effects of FR on performance.

Author	Aim	N	Subjects/ Population	Protocol	Outcome Measures	Findings
Aune et al. (2019)	To compare the acute and chronic effects of eccentric training and FR on the dorsiflexion ROM	23	Footballers (11 males, 12 females)	2 randomised experimental conditions: FR and ECC. Participants performed experiment daily for 28 days. Testing was at baseline, 30min post, 24 h post and 4 weeks post the first session. FR: 3 bouts of 60s across gastrocnemius distally, with 30s rest. Instruction: apply as much pressure as possible, at any tempo. Foam roller: SKLZ trainer roller. ECC: Single leg heel drops off 0.3m box. 3 sets of 15 with 30s rest between sets.	Dorsiflexion ROM assessed by a weight bearing inline lunge measured with an incline goniometer. Peak plantarflexion torque assessed by a MVC performed on a force plate. RSI assessed by a single leg vertical drop jump, off a 0.2m box onto a force plate.	Eccentric training more effective modality than FR for improving dorsiflexion ROM in elite footballers. No significant time-group effect for torque or RSI.
Baumgart et al. (2019)	To evaluate the biomechanical loads during different FR exercises and to investigate the acute effects on VJ height and tissue stiffness	20	Recreational male athletes	Crossover design with 3 randomised experimental conditions: FR, Cycling and a control. All interventions were performed over two weeks. Testing was done pre-, immediately post-, 15min post- and 30min post intervention. FR: 2 sets of 30s over anterior thigh proximally, calves distally. Foam roller: 30 cm high density foam. Cycling: 10min on stationary ergometer at 12–14 intensity (Borg scale). Control: 10min rest in supine.	Vertical ground reaction force using a force plate during FR. CMJ jump on a force plate. Vertical ground reaction forces sampled at 1000Hz and jump height was calculated using the impulse-momentum method. Muscular stiffness assessed using a myomechanographic device (MyontonPRO).	Jump height did not change after FR, but increased after cycling. Stiffness of the thigh decreased after FR but increased after cycling.
Behara and Jacobson (2017)	To examine the acute effects of deep tissue FR and DS on muscular strength, power, and flexibility in division 1 linemen	14	Well-trained NCAA Division 1 offensive lineman at Midwestern University	Cycle ergometer for 5min warm-up. Dependent variables were tested before and after a) no intervention b) deep tissue FR c) DS. The 2nd and 3rd sessions were exactly one week apart and the groups were randomly assigned to different groups. FR: rolling each extremity unilaterally (hamstrings, quadriceps, gluteus maximus, and gastrocnemius). 8min in total. DS: done on the same muscle groups co-ordinated to reflect the same time as FR. Total 8min. Instruction: Did not mention instructions with regard to pressure applied on FR. Foam roller: The Rumble Roller equipped with raised nodules.	VJ power (Watts) and velocity ($m \cdot s^1$) recorded with Tendo® Speed Analyzer Knee Isometric torque- quadriceps and hamstring – Biodex System 4 Pro ® dynamometer. Hip flexion ROM with Baseline® Bubble Inclinometer.	FR neither benefited or deterred maximal isometric strength or velocity. Appears to enhance ROM. May be an appropriate substitute for SS as a warm up due to SS potential interference with strength and power.
Cavanaugh et al. (2017)	FR of the quadriceps decreases biceps femoris activation	18	Recreationally active male (10) and female (8) adults	4 randomised experimental conditions separated by 24–48 h included rolling of the 1) Hamstrings, 2) quadriceps, 3) both muscle groups and 4) a control session. Warm up of 5-min of lower body cycling, highest of 3 VJs were recorded, followed by 3 standardised hurdle jump with single leg landing. Then 2 knee extension and knee flexion MVC's were performed in randomised order. 3 more hurdle jumps were performed post FR condition. FR: 4 sets of 45s with 15s rest in	Maximal voluntary contraction tested via EMG of the vastus lateralis, vastus medialis and biceps femoris which was monitored upon single leg landing from a hurdle jump. Perceived pain on VAS scale.	FR a muscle group may alter antagonist muscle activity. Changes in activation are likely a result of reciprocal inhibition due to increased agonist pain perception. Men and women respond similarly.

(continued on next page)

Table 4.1 (*continued*)

Author	Aim	N	Subjects/ Population	Protocol	Outcome Measures	Findings
				between at a cadence of 40bpm. Control: sit for 4 min. Instruction: Apply as much pressure as possible on the FR. Foam roller: closed cell expanded polypropylene pro foam roller.		
Guillot et al. (2019)	To compare short and long duration FR on ROM. To investigate the effectiveness of FR and elastic band training on ROM.	53	Male rugby players (30 in study 1, 23 in study 2)	Study 1: 3 randomised experimental conditions; FR for 20s, FR for 40s and control. Test-retest over 7 week period, with 15 intervention sessions. FR 20s: 7 back and forth movements (not exceeding 3s) on hip extensors, hip adductors, knee extensors, knee flexors and plantar flexors. FR 40s: 14 back and forth movements (not exceeding 3s) on hip extensors, hip adductors, knee extensors, knee flexors and plantar flexors. Foam Roller: 36 inch high density. Control: Cycling task at 50% of VO2max. Study 2: 2 Randomised conditions; Exercise based training and control. Test-retest over 5 week period with 24 intervention sessions. Exercise based training: Four 35s exercises targeting hip mobility. Control: Passive postural training of lower limbs.	Study 1: Hip abduction, knee flexion, knee extension, ROM assessed with a goniometer. Study 2: Hamstring and adductor ROM assessed through side split (seated), side split (supine), front split and S&R tests.	Study 1: FR improved all ROM scores (no difference between 20s and 40s FR groups) Study 2: Exercise based training improved S&R and side split stretch performances.
Hall and Smith (2018)	To compare the acute effect of a single bout of FR over the ITB compared to FR over the gluteal muscle group on hip adduction passive ROM	27	Healthy female (14) and male (12) adults	Crossover design with 3 randomised experimental conditions separated by 1 week: FR over ITB, FR over gluteal muscles, and control. Testing done pre and post intervention. Warm-up: 5 min cycle at 50 rpm. FR: 3 sets of 30s over targeted area with 30 s of rest, at a rate of 30s per minute. Foam roller: High-density ethylene vinyl acetate. Control group: Sat in chair for 3min.	Hip adduction ROM assessed through the modified Ober test.	A single bout of FR over a myofascial group increased ROM, whereas FR over the ITB did not.
Hansen et al. (2016)	To determine a dose-response relationship between FR and anaerobic power output in active college-aged males	19	Healthy and physically active male college students	Baseline Wingate test was done. Immediately following completion of the FR treatment, participants began a 3-min self-paced warm-up using 1 kg resistance on the flywheel. During warm-up, participant completed 3 sprints at 0:45, 1:30, and 2:30, each lasting 5s. The Wingate test was then conducted. Four different pre-exercise conditions were performed: Control, 30s, 60s, and 90s of FR. Participants completed 30s Wingate tests following each pre-exercise condition to assess anaerobic power. Each condition was completed on non-consecutive days. FR: Quadriceps, hamstrings, iliotibial band, hip adductors, gluteus maximus, hip flexors, gastrocnemius and soleus. Instruction: Participants applied self-selected pressure on the FR. Foam Roller: 92 × 15 cm high-density foam roller.	Wingate test on Monark 894E Peak Bike and Monark Anaerobic Test software version 3.3.0.0. Variables measured: peak power output, average power output, percent power drop, and minimum power output.	FR for increments of 30, 60, or 90s did not significantly alter the anaerobic power output in healthy, active college age males. FR should be avoided as a pre-exercise warm-up where the aim is to increase the body's performance during exercise.

Table 4.1 (*continued*)

Author	Aim	N	Subjects/ Population	Protocol	Outcome Measures	Findings
Healey et al. (2014)	To determine whether the use of FR before athletic tests can enhance performance	26	Healthy recreationally active college students (13 male and 13 female)	1 day familiarization and 2 days experimentation. Testing sessions separated by 5 days. A dynamic warm-up was done at the beginning of both testing sessions. Half the subjects performed FR in the first trial, and the other half performed planking in the first trial. The groups changed over to either planking or FR in the second trial, depending on what they had done in the first trial. Participants completed 4 athletic tests post-intervention. Dynamic warm up: walking lunges (5 each leg), walking knee to chest (5 each leg), side squats (5 each leg), walking butt kicks (5 each leg), frankensteins (5 each leg), and penny pickers (5 each leg). Planking: 5x30s. Same amount of time as FR protocol FR: 30s on each muscle: quadriceps, hamstrings, calves, latissimus dorsi, and the rhomboids. Instruction: No pressure specified. Foam Roller: non-uniform cylinder consisting of a hollow polyvinyl chloride inner core.	Likert scale. Isometric force assessed via isometric squat. Lower body power assessed through the VJ test (height and power). Pro agility assessed using the 5-10-5 yard shuttle run.	No significant difference between planking and FR for all 4 athletic tests. Post- exercise fatigue after FR was significantly less than the planking counterparts. FR had no effect on performance.
Jones et al. (2015)	To determine the effects of FR on VJ performance	20	Recreationally trained male kinesiology students.	Participants underwent 3 days of testing separated by at least 24 h. Day 1- Dynamic warm-up, baseline testing and familiarization. Day 2 & 3- Dynamic warm-up, FR protocol or control protocol followed by testing. Day 2 and 3 were separated by 48 h. Warm-up: High knee pulls, Frankenstein's, and forward gate swings for 20 m each. Control: Performed same movements as FR group, but using a rolling skateboard that replaced the foam roller. Both groups rolled back and forward to the beat of a metronome set to 40 beats per min. Switch direction at each beep, resulting in 10 reps. FR: 30s bout for each muscle group: gastrocnemii, quadriceps, hamstrings, glutei, in that order. Both sides were rolled simultaneously. Instruction: No mention of pressure applied. Foam Roller: 36 inch high-density foam roller.	VJ height on a force plate using a vanes device. Jump height, impulse and relative ground reaction force were measured.	30s bouts of lower body FR do not improve VJ performance.
Killen et al. (2018)	To examine the acute effects of unilateral hamstrings SS and self-administered FR on the contralateral hip flexion passive ROM and strength performance.	23	Healthy adults (13 males, 10 females)	Crossover design with 2 randomised interventions; SS and FR. Testing done pre- and post- intervention. Participants were familiarized will the protocol. SS: 10 sets of 30s passive stretches on dominant hamstring, 30s rest between stretches.	Contralateral hip flexion passive ROM assessed through a SLR test with an inclinometer. Isometric knee flexion strength assessed through a tension load cell. Amplitude of EMG through surface EMG placed on biceps femoris and semitendinosus muscles.	Both interventions significantly increased the contralateral hip flexion passive ROM. There was no significant interactions with strength or EMG amplitude.

(*continued on next page*)

Table 4.1 (*continued*)

Author	Aim	N	Subjects/ Population	Protocol	Outcome Measures	Findings
				FR: 10 sets of 30s rolls, with 30s rest. Cadence of 1s proximally and 1s distally over dominant hamstring muscle. Foam roller: FitPlus premium high density 6x12 inch.		
Lee et al. (2018)	To determine the immediate effects of VR, non-vibration FR, and SS during warm-up on flexibility, proprioception, isokinetic muscle strength, and dynamic balance.	30	Male college students	Crossover design with 3 randomised interventions separated by 48 h; VR, FR and SS. Testing was done and pre- and post- each intervention. VR & FR: 3 sets of 30s over quadriceps and hamstrings at 40bpm using a metronome. Instructions: As much weight as possible on the foam roller. Vibrating roller: motor surrounded by an expanded polypropylene foam outer shell. Foam roller: Vibrating roller with motor turned off. SS: 3 sets of 30s stretches of quadriceps and hamstrings.	Knee flexion ROM assessed passively through Ely's test using a goniometer. Knee extension ROM assessed passively through the popliteal angle hamstring test using a goniometer. Knee joint proprioception and muscle strength assessed with a Biodex isokinetic dynamometer. Dynamic balance in one-leg stance assessed using the Y balance test.	VR significantly increased ROM, isokinetic peak torque and balance, without hampering joint proprioception. VR significantly more effective than SS in increasing quadriceps muscle strength and balance.
MacDonald et al. (2013)	To determine the effect of SMR via FR application on knee extensor force and activation and knee joint ROM.	11	Healthy, recreationally resistance-trained, male students	Participants took part in 4 sessions separated by 24–48hr. 2 sessions. 1 FR session and 1 control session where ROM was tested pre-, 2min post and 10min post intervention, and 1 FR session and 1 control session where force was measured pre-, 2min post and 10min post intervention. Warm up: 5min Monark cycle ergometer. Control: received no SMR. FR: quadriceps for 2 × 1min bouts with 30s interval. Instruction: place as much of their body mass as possible onto the foam roller. Foam Roller: Hollow PVC pipe surrounded by neoprene foam.	Knee joint ROM assessed using a modified kneeling lunge. Knee extensor force and activation assessed with an extension table and a high-wire attached to the ankle to measure MVC, rate of force development and muscle activation.	An acute bout of slow undulating FR of the quadriceps increases ROM, but had no significant impact on knee extensor force or activation.
Macgregor et al. (2018)	To determine the effect of FR for three days on muscular efficiency and ROM	16	Healthy, active males	Crossover design with 2 randomised crossover experimental conditions; FR and control. There were three testing sessions on three consecutive days, with seven days separating the conditions. Testing was done pre-, immediately post, 15min-post and 30min-post intervention. FR: 2min over quadriceps, Rate of movement controlled by metronome at a rate of 1 roll per s. Foam roller: Hollow PVC pipe surrounded by thin layer of neoprene. Control: 2min rest with dominant leg upon the foam roller to maintain knee joint angle at 60.	Mechanical and contractile properties of vastus lateralis and rectus femoris assed using TMG. Knee flexion ROM assessed in a modified kneeling lunge position. MVC of the knee extensors assessed using an isokinetic dynamometer. Surface EMG over vastus lateralis during a submaximal isometric contraction.	Following FR, MVC was elevated compared to rest and surface EMG amplitude was transiently reduced during a submaximal contraction.
Monteiro et al. (2017a)	To determine the acute effects of different SMR volumes on the FMS overhead deep squat performance	20	Recreationally active, resistance-trained females	2 experimental protocols, separated by 2–3 months. Experiment 1: 4 visits separated by 96hr. Anthropometric data collected on visit one, baseline testing on visit 2&3 and FR and retest on visit 4. FR: over both lateral thighs unilaterally for 4 single sets of 30s, 60s, 90s, 120s per side with	FMS overhead deep squat score.	SMR appears to be an effective modality for inducing acute improvements in the performance of the FMS overhead deep squat in all conditions tested.

Table 4.1 (*continued*)

Author	Aim	N	Subjects/ Population	Protocol	Outcome Measures	Findings
				15min rest between sets. Experiment 2: 4 visits separated by 96hr. Anthropometric data collected on visit one, baseline testing on visit 2. Randomly assigned SMR and FR interventions and retest on visit 3&4. FR over lateral side of the trunk or SMR over plantar surface of the foot using a tennis ball for 4 single sets of 30s, 60s, 90s, 120s per side with 60min rest between sets. Instruction: Exert as much pressure as possible. Foam Roller: The Grid Foam Roll.		
Monteiro et al. (2017b)	To determine if there is change in maximum repetition performance after different antagonist FR volumes in the inter-set rest period.	25	Recreationally active females	10 RM testing and retesting using the knee extension machine. Warm-up 2 sets of 15 reps at 50% of normal training load. Experimental protocol: Knee extensions to concentric failure with pre-determined 10 RM load. 4min rest between each consecutive set. Both the order of visits (PR and FR) and different FR volumes (FR60 and FR120) were randomized in a randomized, counterbalanced fashion. For both conditions, three sets were performed with 4 min of rest between each set. There was a 10min break between FR protocols to avoid fatigue. FR: FR of hamstrings performed bilaterally in a seated position. FR60 (60s) and FR90 (90s) Instruction: exert as much pressure as possible Foam Roller: The Grid foam roller.	6 sets of 10 RM Knee extensions to concentric failure.	The results suggest that more inter-set FR applied to the antagonist muscle group is detrimental to the ability to continually produce force. Decreases in maximum repetition performance has implications for FR prescription and implementation, in both rehabilitation and athletic populations.
Monteiro et al. (2017c)	To determine the acute effects of different FR volumes in the inter-set rest period on maximum repetition performance	25	Recreationally active females	6 visits. Participants underwent knee extension 10 RM test and retest procedure for the first two visits. All 48 h between each visit. Four sets of knee extensions with 10 reps to concentric failure was completed on four different occasions. Between each set, a 4 min rest interval was implemented in which participants either passively rested or performed FR for different durations. FR: performed bilaterally in prone over the quadriceps for either 60s, 90s or 120s. Instruction: apply as much pressure as possible Foam Roller: The Grid foam roller.	Number of knee extensions reps completed.	FR seems to be detrimental to a person's ability to continually produce force, and should not be applied to the agonist muscle groups between sets of knee extensions.
Monteiro and Neto (2016)	To determine the effect of different FR volumes on knee extension fatigue	25	Recreationally active females	3 sets of knee extensions with a pre-determined 10 RM load to concentric failure. A control and FR condition was performed during the interest period. After that, fatigue index was calculated. FR: consisted FR to the anterior thigh bilaterally. FR was performed during the interest period for 60s, 90s, and 120s.	10 RM testing Fatigue index (%)	The FR fatigue index declined (less fatigue resistant) compared to the control condition. FR for more than 90s could be detrimental to the ability to continually produce force.

(continued on next page)

Table 4.1 (*continued*)

Author	Aim	N	Subjects/ Population	Protocol	Outcome Measures	Findings
				Each interest Rolling was done on different occasions. As well as a visit for control, which consisted of a 4min passive rest. Instructions: No mention with regard to pressure applied. Foam roller: The Grid Foam Roller.		
Monteiro et al. (2018)	To investigate short-term changes in passive hip flexion and extension after FR and roller massage durations of 60 and 120s	10	Recreationally active men	Crossover design with 4 randomised experimental conditions; 60s of FR, 120s FR, 60s rolling massage, and 120s rolling massage. 4 visits over a 9 day period, with pre- and post-intervention testing. FR: over hamstrings, between ischial tuberosity and popliteal fossa in fluid, dynamic motions, for 60 or 120 s. Foam roller: hard inner core enclosed in a layer of ethylene vinyl acetate foam. Roller massage: Rolling SM stick up and down posterior aspect of thigh for 60 or 120s.	Hip flexion and extension ROM assessed passively with a goniometer	Significant differences in hip extension and flexion ROM between FR and roller massage.
Monteiro et al. (2019a)	To investigate the acute effects of FR and rolling massage of anterior thigh on hip ROM	18	Recreationally active, resistance trained males	Crossover design with 2 randomised experimental conditions; FR and rolling massage. 2 visits over 4 day period, with pre- and post-intervention testing at 0, 10, 20 and 30min post intervention. FR: one set of 120s, over anterior thigh, between acetabulum and quadriceps tendon in fluid, dynamic motions. Instructions: Support body weight on foam roller. Foam roller: hard inner core enclosed in a layer of ethylene vinyl acetate foam. Roller massage: Rolling SM stick up and down anterior aspect of thigh for 120s.	Hip flexion and extension ROM assessed passively with a goniometer.	Hip flexion and extension ROM increased following both interventions, and remained increased 30min post intervention. FR was statistically superior in improving hip flexion and extension ROM.
Monteiro et al. (2019)	To investigate the effects of different SM volumes and modalities on passive hip ROM	25	Recreationally active, resistance trained males	Subjects performed 4 experimental conditions in a randomized order, separated by at least 48hr; FR or roller massage for 60 or 120s. FR: One set of either 60 or 120s, over anterior thigh, between acetabulum and quadriceps tendon in fluid, dynamic motions. Instructions: Self-paced, support body weight on foam roller, and to maintain pressure at 8 out of 10 on the pain level scale. Foam roller: hard inner core enclosed in a layer of ethylene vinyl acetate foam. Roller massage: Rolling SM stick up and down anterior aspect of thigh for 60 or 120s. Maintain pressure at 8 out of 10 on the pain level scale.	Hip flexion and extension ROM assessed passively with a goniometer.	Both FR and rolling massage increased hip ROM but larger volumes (120s) and FR produced the greatest increases.
Morales-Artacho et al. (2017)	To compare the effects of a cycling warm-up and a FR warm-up on hamstring stiffness	14	Physically active (recreationally active) males.	4 separate testing sessions. Each session included a warm-up condition: Control, Cycling, FR, or Cycling & FR. Conducted in random order 3 days apart. Start of each session participant lay in relaxed lying position for 30min.	5 min incremental cycling test for maximal aerobic power output. Passive Hip flexion ROM measured with dynamometer. Shear modulus measured with an ultrasound scanner as an index of stiffness.	Combined warm-up elicited no superior effects on muscle stiffness compared with cycling alone. Showing the key role in active warm-up in reducing muscle stiffness. Performing passive tasks (FR) at

Table 4.1 (*continued*)

Author	Aim	N	Subjects/ Population	Protocol	Outcome Measures	Findings
				Testing done Pre-, 5min post- and 30min post-condition. Control: 15min period in a lying position on a padded bench. Cycling protocol- 5min cycling at 40%, 5 min at 60% of maximum power followed by 5 × 6s all out sprints every minute for 6 min. FR: back and forth movements on the posterior thigh. 60s bilateral set, and ten 1-min unilateral alternative sets (5 per leg) on hamstring muscles with 30s rest between sets. Metronome controlled at 27 bpm. Cycling & FR protocol: first cycling warm up protocol followed by FR protocol, separated by 2min rest. Total duration was a 30min warm-up. Instruction: No instruction given with regard to pressure applied. Foam Roller: The Grid foam roller	Muscle contractility via surface EMG.	the start of a warm-up routine (before active tasks) may help maximise reductions in muscle stiffness. Evidence is not conclusive.
Richman et al. (2019)	To determine the effect of a 6-min of FR in addition to a general warm-up and DS session, on explosive athletic performance in female volleyball and basketball players	14	Female volleyball and basketball players	Cross-over design with 2 randomised experimental conditions; FR and light walking, separated by 7 days. Participants were familiarized with the procedures before the trial. Light walking for 5 min warm-up. S&R was tested pre-, immediately post and 5min post-interventions. 5min of DS followed post- intervention S&R tests. Other outcome measures were assessed 5min post intervention. FR: 30s per leg over hip flexors and quadriceps, adductors, tensor fasciae latae and gluteus, hamstrings, plantar flexors, and dorsiflexors, for a total of 6min. Instructions: perform movements in controlled, deliberate manner, using steady pressure not overly painful. Foam roller: 12.7 cm diameter, consisting of 5 mm thick hollow plastic core covered with 12 mm layer of dense foam. Light walking: 6min of light walking.	Flexibility assessed with S&R test. Lower body power was assessed through the SJ, CMJ, and a 30 cm drop jump tests underneath the Vertec. Agility was assessed through the T-test. 10 yds acceleration was assessed with timing gates.	There was a significantly greater improvement in S&R, SJ and CMJ after FR compared to light walking.
Schroeder et al. (2017)	To investigate the acute effects of FR, stretching, and weight training on contractile properties of the bicep femoris.	12	Healthy adults (6 males, 6 females)	Cross-over design with 3 experimental conditions; FR, weight training and stretching. Testing was done directly before and within 5min post-intervention. Weight training: 3 sets of lunges, deadlifts and hip thrusts at a load of 8–12 reps to failure, separated by 1min rests. Stretching: 3 sets of straight legs bend-overs, sitting upper body and hip twists, standing unilateral back and hamstring stretches. 1min permanent tension intervals with 1min rest periods. FR: Unilateral hamstring roll-outs, unilateral buttock roll-outs and bilateral lower back roll-outs. 3 sets of 60 s at a cadence of 2 s per roll-out, with 1 min rest	Muscle displacement and contraction time of the bicep femoris assessed using TMG.	Muscle tone increased after strength training, but there were no relevant changes after stretching or FR.

(*continued on next page*)

Table 4.1 (*continued*)

Author	Aim	N	Subjects/ Population	Protocol	Outcome Measures	Findings
				periods. Foam roller: Black-roll™		
Smith et al. (2018)	To evaluate the time course of the effects of DS and FR on VJ height and ROM	29	Healthy students (8 male, 21 female)	Participants completed 4 different sessions (control, FR, DS and FR & DS) in a randomised order. There were 5–7 days between sessions. After a 5 min warm-up (cycle ergometer) and baseline assessments, participants completed the intervention sessions. Testing was repeated every 5 min for 20 min after the intervention session. Control: Rest for 22 min. DS: Rest for 7 min. 4 reps of butt-kicks, high-knees, leg raises and toe-walks over a 20m distance, for 15min. FR: Rest for 15 min. FR over gluteals, hamstrings, quadriceps, and calf muscles.3 sets of 30 s with 30 s rest between sets, at a rate of 30 rolls per min using a metronome. FR & DS: FR protocol followed by DS protocol. Foam roller: High-density ethylene vinyl acetate foam roller.	Flexibility assessed with S&R test. Lower body power assessed through a VJ on a force plate. Jump height was determined using the flight-time method.	FR had no effect on jump height, but did acutely increase ROM, although its effect was quickly dissipated.
Su et al. (2017)	To compare the acute effects of FR, SS, and DS during warm-ups on muscular flexibility and strength in young adults	30	15 male and 15 female college students	3 test sessions in randomised order with 48–72hrs between sessions. At each session, 5 min light aerobic cycling, pre-test measures, another 5min of light aerobic cycling followed by FR, SS, or DS. Post-test measures 5 min after intervention. FR: 2 × 30s on anterior thigh bilaterally, then 2 × 30s on posterior thigh. Repeat 3 times (Roughly 6 min duration). SS: Stretch to mild discomfort. Bilateral quadriceps and hamstrings stretched 3 × 30s each (Roughly 6 min duration). DS: 2 controlled movements, forward lunge and front kick through active range. Each movement performed for 1 min, in which 15 reps on each leg were completed. Both performed 3 times for a total of 6min. Instructions: place as much body weight as possible. Foam Roller: PVC pipe with EVO foam surrounding.	Isokinetic peak torque of knee extensor and flexor using a Biodex isokinetic dynamometer. Flexibility of quadriceps measured by Thomas test Flexibility of hamstring by S&R test.	FR is more effective than SS and dynamic stretching in acutely increasing flexibility of the quadriceps and hamstrings, and may be recommended as part of a warm-up to enhance performance.
Williams and Selkow (2019)	To investigate if FR of the plantar surface of the foot in addition to the hamstring group was more effective at improving flexibility of the hamstrings when compared to either intervention alone	15	Collegiate students (5 males, 10 females)	Participants received each intervention separated by at least 96 h in a randomized order: FR over hamstring, SMR over plantar surface of foot, and a combination of both. Testing done pre and post-intervention. FR: Two min on both legs over posterior aspect of thigh, at a cadence of 60bpm. Instructions: Apply as much pressure as possible, pushing into discomfort but not pain. Foam roller: Perform Better Elite molded. SMR: 2 min over the medial arch of sole, at a cadence of 90bpm,	Flexibility assessed with S&R test.	There was an overall improvement in flexibility, but no significant differences were found between interventions.

Table 4.1 (*continued*)

Author	Aim	N	Subjects/ Population	Protocol	Outcome Measures	Findings
				with a lacrosse ball. Instructions: Apply as much pressure as possible, pushing into discomfort but not pain. Combination: Two min of FR and 2 min of rolling lacrosse ball on plantar surface of foot.		

FR- Foam Rolling; **SS-** Static Stretching**; ROM-** Range of Motion; **SMR-** Self Myofascial Release; **RM-** Repetition Maximum; **SJ-** Squat Jump; **CMJ-** Countermovement Jump; **VJ-** Vertical Jump; **reps-** Repetitions; **min-** Minutes; **s-** Seconds; **hr-** Hour; **m-** Meters; **n-** Number; **SLR-** Straight Leg Raise; **TMG-** Tensomyography; **FMS-** Functional Movement Screen; **S&R-** Sit-and-Reach; **EMG-** Electromyography; **ECC-** Eccentric Exercise; **MVC-** Maximal Voluntary Contraction; **RSI-** Relative Strength Index; **DS-** Dynamic Stretching; **VAS-** Visual Analog Scale; **VO_2 max-** Maximal Oxygen Consumption; **VR-** Vibration Foam Rolling; **bpm-** Beats per Minute.

Several studies did not support FR for performance enhancement (Monteiro and Neto, 2016; Monteiro et al., 2017b, 2017c; Morales-Artacho et al., 2017; Schroeder et al., 2017). It was found that FR did not enhance performance due to a decrease in muscle activation of the biceps femoris when the quadriceps were exclusively rolled (Cavanaugh et al., 2017) suggesting FR has an antagonistic effect. Three studies conclude, both objectively and subjectively, that inter-set FR should be avoided as it may affect the individual's ability to continually produce force (Monteiro and Neto, 2016; Monteiro et al., 2017b; Morales-Artacho et al., 2017).

It is important to note that in this review we are focusing on FR used as a warm-up to enhance performance. While the above studies seem to suggest that FR does not enhance performance, these findings are important for practitioners as they appear to present the first indications of risks associated with FR.

3.4. Recovery

3.4.1. Exercise induced muscle damage (EIMD) and delayed onset of muscle soreness (DOMS)

Five studies looked at the effect of FR on recovery from EIMD and DOMS and the results suggest that FR seems to enhance recovery from EIMD and DOMS (MacDonald et al., 2014; Rey et al., 2017; Romero-Moraleda et al. 2017, 2019; Zorko et al., 2016) (Table 4.2). Four of the studies support FR for enhancing recovery from EIMD and DOMS (MacDonald et al., 2014; Rey et al., 2017; Romero-Moraleda et al., 2017, 2019) while Zorko et al., 2016 found that FR was just as effective as passive rest in enhancing short term recovery (Zorko et al., 2016). According to the PEDro scale, the quality of evidence for these studies ranged from 6 to 8.

On one occasion, FR was reported to decrease muscle soreness (>75% likelihood) while improving vertical jump height, muscle activation, and passive and dynamic ROM (MacDonald et al., 2014). The authors also found that FR negatively affected evoked contractile properties of the muscle (MacDonald et al., 2014). In another study, FR had a large effect on the recovery of agility, TQR and perceived muscle soreness, compared to the passive recovery group (Rey et al., 2017). Only one study did not support the use of FR in enhancing recovery with results showing that both FR and passive rest promoted small recoveries on all main outcome variables (effect size = 0.2–0.6). In this study, FR appears to be as equally effective as passive rest for short-term recovery of muscle contractile function – improvements for FR ranged from 5.5%–16.2% and for passive rest from 4.7%–8.3% (Zorko et al., 2016).

3.4.2. Flexibility

Flexibility was a common component evaluated throughout the eligible studies, with eight of the 49 studies focusing only on flexibility measures (Boguszewski et al., 2017; Couture et al., 2015; Griefahn et al., 2017; Kelly and Beardsley, 2016; Mohr et al., 2014; Murray et al., 2016; Skarabot et al., 2015 Wilke et al., 2019) (Table 4.2). Flexibility in these studies was measured as part of recovery from a bout of exercise, which may assist in reducing the risk of injury. Studies on flexibility as part of recovery ranged from 6 to 9 on the PEDro scale (mean 6.75). The most commonly used FR was the Grid foam roller (Kelly and Beardsley, 2016; Murray et al., 2016; Škarabot et al., 2015) and in most of the studies the participants were advised to exert as much pressure as possible (Kelly and Beardsley, 2016; Mohr et al., 2014; Murray et al., 2016; Škarabot et al., 2015), while respecting pain (Griefahn et al., 2017).

Six of the eight studies found positive results for FR improving flexibility. FR seemed to enhance hip flexion ROM (Mohr et al., 2014; Murray et al., 2016), knee flexion ROM (Murray et al., 2016), as well as ankle dorsi-flexion ROM (Kelly and Beardsley, 2016; Škarabot et al., 2015). These studies were however limited to single joint ROM testing. One study found that FR did not only improve DF ROM on the ipsilateral limb for 20min (0.51cm/3.97%) but also in the contralateral limb for at least 10min (0.25cm/1.97%), indicating that FR has a crossover effect (Kelly and Beardsley, 2016). It was also shown that the effects of FR only lasted 10min, even when combined with SS (Škarabot et al., 2015). One study resulted in increased hamstring flexibility and had comparable results with proprioceptive neuromuscular facilitation (PNF) stretching, though it was also shown that FR did not have an effect on muscle contractility or temperature (Murray et al., 2016). Also, FR had an enhanced effect when combined with SS and/or postural alignment exercises (Mohr et al., 2014; Škarabot et al., 2015).

It is not clear as to why the two studies which found no improvement in flexibility did so (Couture et al., 2015; Griefahn et al., 2017). One study reported that FR for 2min was not adequate to induce improvements in knee joint flexibility (Couture et al., 2015). The other study found improvements in thoracolumbar mobility, but it did not improve lumbar flexion ROM (Griefahn et al., 2017). The studies did not provide sufficient information as to the protocol used to explore the mechanisms which might have contributed to the lack of effect.

3.4.3. Pressure Pain Threshold (PPT)

Five studies focused on the measurement of PPT (Cheatham et al., 2017; Cheatham and Kolber, 2017; Cheatham and Stull 2018a, 2018b; Wilke et al., 2018). The mean PEDro score was 7.8 and the range from 6 to 9 points. FR had an immediate effect on significantly increasing the PPT (Cheatham et al., 2017; Cheatham and Kolber, 2017; Cheatham and Stull, 2018a, 2018b). Cheatham and Stull (2018a) showed that FR with active joint motion has a greater effect on passive joint ROM and PPT than rolling without motion, while Wilke et al., 2018 showed that static compression of the MTrP was effective in reducing latent MTrP sensitivity.The instructional strategies used in the application of the FR did not affect the results with all strategies showing similar change in knee

Table 4.2
Summary of studies on the effects of FR on recovery.

Author	Aim	N	Subjects/ Population	Protocol	Outcome Measures	Findings
Boguszewski et al. (2017) **Flexibility**	To determine the effect of FR on the functional limitations of musculoskeletal system	37	Healthy and physically active females	2 randomised experimental conditions, FR and control. FR group performed FR after physical exercise for twice a week, for two months. Control did not undergo any exercise or treatment after exercise. Testing done pre- and post-condition. FR: 8 exercises rolling the anterior, posterior, medial and lateral thigh, the calf, back, posterior arm and shoulder. 20min of FR. Instructions: Focus more on sorer muscle groups and massage slowly.	Mobility assessed by the FMS, core strength and endurance assessed by the Core Muscle Strength and Stability Test. ROM assessed by the S&R test.	FR may minimize the functional limitations of the musculoskeletal system. FR may help maintain core stability.
Cheatham et al. (2017) **PPT**	A comparison of Video-Guided, Live Instructed, and Self-guided FR interventions on knee joint ROM and PPT: A randomised control trial.	45	45 healthy adults	All participants underwent pre-test measures, followed by the instruction and rolling intervention, then immediate post-test measures. Video guided group rolled from patella to the pelvis four times at a cadence of 1 inch per s, followed by 4 knee bends to 90°. Live instructed group was the same routine as video guided. Self-guided the plank position and roller position was shown, then participants performed their preferred method of FR. FR: 3 protocols, as above, on left quadriceps. Instructions: no pressure instructions specified. Foam Roller: GRID foam roller.	Passive knee flexion measured by baseline inclinometer for knee ROM in prone lying PPT measured by JTECH algometer.	All intervention groups showed gains in ROM and PPT, indicating no difference attributable to instructional strategy.
Cheatham and Kolber (2017) **PPT**	Does SMR with FR change PPT of ipsilateral lower extremity antagonist and contralateral muscle groups? An exploratory study	21	21 healthy adults	All participants underwent pre-test measures, followed by the intervention, then immediate post-test measures. FR: instructional video was used to standardise the FR of the left quadriceps muscle group. Instruction was to roll between 2 zones of the quadriceps 4 times at 1inch per s. Then the participants were instructed to stop at the one of the zones and perform 4 knee bends to 90°. The sequence was repeated for 2 min. Instructions: instructed to apply as much weight as tolerable. Foam Roller: GRID Foam Roller.	Wireless JTECH algometer to measure PPT.	Acute increase in PPT occurs after a 2 min FR intervention with a rigid foam roller.
Cheatham and Stull (2018a) **PPT**	To compare the effects of a FR session to the left quadriceps with active joint motion and without joint motion on passive knee flexion ROM and PPT	30	Healthy adults (19 males, 11 females)	2 randomised experimental conditions: FR with active joint motion and FR with non-joint motion. Testing done pre- and post-intervention. FR with active joint motion: Rolling of quadriceps with 4 active knee bends in upper and lower zones of quadriceps. Instructions: instructional video, cadence of 1inch per second for 2 min. FR with non-joint motion: Rolling of quadricep. Instructions: Keep knee straight, own cadence for 2 min. Foam roller: Rigid solid plastic cylinder with medium density, multilevel foam outer covering.	Knee flexion ROM assessed passively with an inclinometer. PPT of the quadricep assessed in a relaxed standing with an algometer (Jtech), with a graded force of 50–60 kPa/s until the subject verbally reported the presence of pain.	FR with active joint motion has a greater effect on passive joint ROM and PPT than rolling without motion.

Table 4.2 (*continued*)

Author	Aim	N	Subjects/ Population	Protocol	Outcome Measures	Findings
Cheatham and Stull (2018b) **PPT**	To compare the immediate effects of three different density type foam rollers on passive knee flexion ROM and PPT of the quadriceps musculature	36	Recreational adults (26 males, 10 females)	3 randomised experimental conditions; Soft density FR, Medium density FR, Hard density FR. Testing done pre- and post-intervention. FR: Instructional video guided session. Foam rollers: soft density - solid EVA foam medium density - hard, hollow core wrapped in moderately firm EVA foam hard density - hard, hollow core wrapped in very firm EVA foam.	Knee flexion ROM assessed passively with an inclinometer. PPT of the quadricep assessed in a relaxed standing with an algometer (Jtech), with a graded force of 50–60 kPa/s until the subject verbally reported the presence of pain.	All three foam rollers produced similar post-intervention effects on knee ROM and PPT.
Couture et al. (2015) **Flexibility**	The effect of FR duration on Hamstring ROM	33	College aged men (14) and women (19).	Day 1- orientation, health history questionnaire, 5min warm-up, baseline hamstring ROM measured. Baseline measures used as a control. Day 2 and 3–5min cycle and assigned FR duration. Short FR- 2 sets of 10s, Long FR- 4 sets of 30s. 2–4 min rest then ROM measurements commenced. Instructions: No instructions with regard to pressure exerted, but pressure exerted was measured. Foam Roller: Commercial Foam Roller.	Passive knee extension test in prone lying and hip flexed to 90°. Measured with goniometer. Pressure exerted – digital scale.	Self-Administered FR for a total up to 2 min is not adequate to induce. improvements in knee joint flexibility.
D'Amico and Paolone (2017) **Other**	To examine the impact of FR on recovery between two 800m runs	16	Trained males	Crossover design with 2 randomised experimental conditions; FR and control. 1 familiarization session and 2 testing sessions, separated by 72 h. Testing pre and post-sessions. Participants completed two 800m runs on a treadmill, separated by 30 min rest of either FR or passive rest. Speed of each run was maximal. FR: six 5s slow passes over gluteal muscles, hip flexors, quadriceps, iliotibial bands, adductors and calves, from origin to insertion. Foam roller: Premium EVA 12″ x 6″ round roller.	Blood lactate concentration assessed by an AccuSport lactate analyser. VO_2 max assessed by open circuit spirometry system. Stride length, 800m run time and hip extension assessed retrospectively on Dartfish™.	No significant differences were found between conditions.
Fleckenstein et al. (2017) **Other**	To compare the effects of a single bout of preventative or regenerative FR on exercise-induced neuromuscular exhaustion	45	Healthy adults (23 males, 22 females)	3 randomised experimental conditions; FR of lower limb muscles prior to induction of fatigue, FR after induction of fatigue, no-treatment control. Testing at baseline, after completion of the fatigue protocol, and 5min post fatigue. Neuromuscular fatigue protocol: 3 CMJs, 20s bout of step-ups on a 40 cm box at a frequency if 220 beats per min, three bodyweight squats and a pro agility shuffle repeated until subjects were no longer able to attain 90% of maximal jump height in two consecutive rounds. FR: 30 s on each muscle - knee extensors, hamstrings, adductors, calf muscles and ITB. Instruction: Speed at 60bpm (metronome) and at a subjective pain intensity of seven on a 10 mm visual analogue scale.	MIVF of knee extensors assessed by m3 diagnos + at 60° knee flexion. Self-perceived muscular exhaustion of lower limb assessed with VAS. Reactive strength index calculated by vertical jump height divided by ground reaction time.	Preventative and regenerative FR resulted in a decreased loss in MIVF compared to control 5min after exhaustion. Regenerative rather than preventative FR seems sufficient to prevent further fatigue.

(continued on next page)

Table 4.2 (*continued*)

Author	Aim	N	Subjects/ Population	Protocol	Outcome Measures	Findings
				Control: seated for 5min. Foam roller: 30 × 15 cm compressed foam with hollow core.		
Griefahn et al. (2017) **Flexibility**	To determine if exercises with FR have a short-term impact on the thoracolumbar fascia	38	Healthy athletic adults (13 males, 25 females)	3 treatment groups: Control group, placebo group and a foam roll group. Measurements were executed before the intervention and exactly 10 min after the treatment. Control: no treatment received. Waited for the same treatment duration as the other groups. FR: gluteus maximus, erector spinae of lumbar and thoracic spine, and the latissimus dorsi were rolled out for 30s. This was repeated 3 times on each muscle group. Placebo group: the same areas were rolled out with no pain stimulus, also for a total time of 1min and 30s. The examination and treatment strategy was exactly the same as the FR group. Instructions: use body weight while respecting pain.	Mobility of thoracolumbar fascia determined using a sonographic measurement. Lumbar flexion assessed with modified Schober test. Pain tolerance measured by using the Baseline Dolorimeter 12–1442 algometry.	FR exercises significantly improves the mobility of the thoracolumbar fascia in a healthy young population, but did not improve Lumbar flexion ROM.
Hotfiel et al. (2017) **Other**	To determine the acute effects of lateral thigh FR on arterial tissue perfusion determined by spectral Doppler and power Doppler ultrasound	21	Healthy medical and sports students (12 males, 9 females)	Baseline Doppler examinations were done under resting conditions. Then participants were re-examined directly after (1min) and 30 min after prescribed FR intervention. FR: 3 sets of 45s of FR on the lateral thigh. 20s rest between each set. Instructions: instructed to place as much pressure as tolerable on the foam roller. Foam Roller: customized foam roller with a polypropylene centre.	Arterial tissue perfusion determined by spectral Doppler and power Doppler ultrasound, represented peak flow (Vmax), time average velocity maximum (TAMx), time average velocity mean (TAMn), and resisted index (RI).	Local blood flow increases significantly after FR of the lateral thigh. These changes could still be detected at 30min post intervention.
Kalen et al. (2017) **Other**	To compare the effectiveness of active recovery in the form of running or FR on clearing blood lactate compared to sitting after a water rescue	12	Lifeguards	Crossover design with 3 randomised experimental conditions; Running, FR and passive. Outcome measures assessed at baseline, post water rescue and post intervention. Water rescue: 10m run into sea, 100m swim to victim, 100 two of victim to shore, extracting victim to dry sand. Passive: remain seated for 25min. Running: 4min remove wetsuit and walk, 16min run at 60% VO2max, 5min walk. FR: Quadriceps, ITB, hamstrings, adductors and gluteus. Distally and then proximally, repeated for 1 min on each muscle, for total time of 20 min. Instructions: pain scale level of 7. Foam roller: High density 19 x 15 cm.	Blood lactate concentration assessed by LactateScout analysed. Total time of water rescue recorded. RPE assessed with CR-10 scale.	Post recovery lactate levels were significantly lower for FR and running compared with resting. No differences between FR and running.
Kelly and Beardsley (2016) **Flexibility**	To determine the specific and cross-over effects of FR on ankle dorsiflexion ROM	26	16 male and 10 female recreationally active university students.	Warm-up of 10 double-leg heel raises to the floor. Baseline dorsiflexion ROM for both ipsilateral and contralateral legs at 0, 5, 10, 15, and 20 min following the control protocol or the FR protocol. Control: 2 min long sitting rest	Wall lunge test/weight bearing lunge test (cm).	FR improves ankle DF ROM for at least 20min in the ipsilateral limb and 10 min in the contralateral limb, indicating that FR produces a cross-over effect into the contralateral limb.

Table 4.2 (*continued*)

Author	Aim	N	Subjects/ Population	Protocol	Outcome Measures	Findings
				position. FR: 3 sets of 30s FR of the plantar flexors on the dominant leg. 10s rest between sets. Total time of 2 min 1st set focus on lateral aspect, 2nd set focus on middle aspect, 3rd set focus on medial aspect of the calf. Instructions: place as much force as possible through the foam roller. Foam Roller: The Grid Foam Roller.		
Kim et al. (2014) **Other**	To examine the effect of SMR induced with FR on the reduction of stress by measuring the serum concentration of cortisol	24	Healthy females in their 20's	Walk 30 min on treadmill, 10 ml blood was collected after the 30 min walk, and blood collected from the subjects after 30 min of the SMR program or after the 30 min of rest. Control: rested for 30min lying down FR: entire spine, 6min; the cervix, 6min; the thorax, 6min; the quadriceps, 3 min; the hamstring, 3min; the tensor fascia latae, 3min; and the calf muscle, 3 min. During the 30 min SMR program, pressure was applied on a single spot for 30s using the subject's body weight in order to stimulate the corresponding muscle over a period of 3–6 min as a means of alleviating muscle tension in the spine and areas around the 4 limbs. Instructions: no pressure instructions mentioned.	Serum cortisol levels	SMR induced with a FR did not significantly affect the reduction of stress.
MacDonald et al. (2014) **DOMS**	To understand the effectiveness of FR as a recovery tool after exercise.	20	Physically active resistance-trained male participants volunteered.	5 testing sessions. Orientation: Subject forms, 1RM squat. Pre-test: Perceived pain, test measurements. Post-test: Post-0-hrs: Perceived pain, test measurements, FR. This was repeated post-24-hr, post-48-hr, and post-72-hr. Each session was separated by 24hr. Except session 1 & 2 separated by 96hr. DOMS inducing protocol: 10 x 10 back squats, 60% the participants 1 RM. Control: participated in all the above, but were just tested at the given hours and did not FR. FR: targeted 5 different muscle groups of the anterior, posterior, lateral, medial aspect of the thigh with the glutes included. 60s per muscle group on one side, 60s per muscle group on the other side. Using small undulating movements. Instructions: not mentioned. Foam Roller: custom-made foam roller that was constructed of a polyvinyl chloride pipe (10.16-cm outer diameter and 0.5-cm thickness) surrounded by neoprene foam (1-cm)	Thigh girth (cm). BS-11 Numerical Rating Scale (Muscle soreness and FR-Pain). Modified kneeling lunge and passive knee flexion, Passive SLR and active SLR (ROM). Peak twitch force. Isometric knee extension at 90°. VJ height.	FR decreased muscle soreness while improving VJ height, muscle activation, and passive and dynamic ROM. FR negatively affected several evoked contractile properties of the muscle.
Mohr et al. (2014) **Flexibility**	To determine if FR before SS produces a significant change in passive hip-flexion ROM	40	Healthy subjects with less than 90 degrees of passive hip flexion	Participants took part in 6 sessions (separated by 48 h each) where passive hip flexion was measured before and immediately after the four	Passive SLR ROM measured with a baseline bubble inclinometer.	Results support the use of a FR combined with SS protocol. However, there was an increase in ROM across all treatment groups.

(continued on next page)

Table 4.2 (*continued*)

Author	Aim	N	Subjects/ Population	Protocol	Outcome Measures	Findings
				interventions: SS, FR and SS, FR, or control (rest). SS: held for 1 min and rest for 30s (x3). FR: from ischial tuberosity to popliteus fossa (1s down and 1s up) 3 × 1 min reps with a 30s break in between. Instructions: allow as much pressure as possible. Foam Roller: Cando EVA foam roller.		
Murray et al. (2016) **Flexibility**	To establish if a single bout of foam rolling affects flexibility, skeletal muscle contractility and reflected temperature	12	Male adolescent squash players from an elite sports school	2 Randomized experimental conditions; FR and control. Testing done on 2 separate sessions separated by 7–12 days. One session was FR, other was a control. Tests were done at 0, 5, 10, 15 and 30 min post intervention. Control: Prone lying for same duration as FR protocol. FR: over the anterior thigh, speed controlled by metronome (2s per pass) and force controlled by FR on force plate (600 Hz). Duration of 60s resulted in 30 full rolls, 15 in each direction. Instruction: place their body weight on the roller (600 Hz). Foam Roller: The Grid foam roller.	Thermography imaging for superficial thermal responses Passive ROM of hip and knee via 'angle at force standardised endpoint' which is a video based method. TMG assessment for muscle contractility.	Single 60s bout of FR to the quadriceps induces small significant change in flexibility. Muscle contractility and temperature remain unchanged.
Rey et al. (2017) **DOMS**	To examine the effectiveness of FR performed immediately after a training session on TQR, perceived muscle soreness, jump performance, agility, sprint, and flexibility 24 h after training.	18	Professional soccer players	During first session, baseline measurements were collected and players performed a standardized soccer training session. After training players were assigned to either the FR group or the passive recovery group. Post intervention testing was conducted after 24hrs. FR: 5 different exercises over quadriceps, hamstrings, adductors, gluteal and gastrocnemius. Instructions: Move proximally and distally, with as much body weight on the FR as tolerable, at a cadence of 50bpm. Each exercise on both right and left legs for two 45s bouts with 15s rest between bouts for a total time of 20 min. Passive recovery: Sit on a bench for 20 min.	CMJ on a mobile contact time. Jump height assessed based on flight time. 5 and 10m sprint tests assessed with timing gates. Agility assessed with T-test. Flexibility assessed through the S&R test. General perception of recovery was assessed through the TQR scale. Muscle soreness was assessed by VAS when palpating the belly and distal region of relaxed knee extensors and flexors.	FR had a large effect on the recovery of agility, TQR and perceived muscle soreness, compared to the passive recovery group.
Romero-Moraleda et al. (2017) **DOMS**	To compare the immediate effects of a neurodynamic mobilization treatment or FR treatment after DOMS	32	Healthy adults (21 males, 11 females)	Participants performed 100 drop jumps (5 sets of 20 repetitions, separated by 2min rests) from a 0.5m box to induce muscle soreness. 48 h after participants randomly assigned to FR or neurodynamic mobilization group. Testing was done prior to drop jumps, as well as pre- and post-interventions. FR: down quadriceps using short kneading-like motions until at patellae, and then up in one fluid motion. Motion repeated for 5 sets of 1min, with 30 s rest. Foam roller: Uniform	DOMS assessed through NPRS. MVC and muscle peak activation of the quadriceps assessed with surface-EMG placed on the vastus-medialis, vastus lateralis, and rectus femoris muscles. Leg strength assessed with a Tecsymp Tkk5002 leg dynamometer.	Both interventions reduced NPRS scores after treatment. Only FR significantly improved quadricep strength.

Table 4.2 (*continued*)

Author	Aim	N	Subjects/ Population	Protocol	Outcome Measures	Findings
				polystyrene foam cylinder. Neurodynamic mobilization: Slump knee-bend technique repeated on both sides for 1min for a total of 5 sets, with 30s rest between sets. Cadence for both interventions was 3:4 using a metronome.		
Romero-Moraleda et al. (2019) **DOMS**	To compare the effects between non-vibration FR and VR on VAS, PPT, oxygen saturation, CMJ and hip and knee ROM after eliciting muscle damage through eccentric acute exercise.	38	Healthy adults (32 male, 6 female)	Participants performed 10 sets of 10 squats in a flywheel device. 48 h after participants randomly assigned to non-vibrating or vibrating FR groups. Testing done prior to exercise inducing muscle damage, as well as pre- and post-interventions. FR: (Same procedure for both groups). Down quadriceps using short kneading-like motions until at patellae, and then up to initial position in one fluid motion. Motion repeated for 5 sets of 1min, with 30 s rest. Non-vibrating foam roller: 15 cm diameter uniform polystyrene foam cylinder. Vibrating foam roller: Hyperice foam roller with vibration at 18Hz.	DOMS with VAS in 4 conditions: passive, isometric quadriceps contraction, dynamic squat, quadricep stretch. PPT with digital pressure algometer at three points of the quadriceps. Muscle oxygen saturation assessed at rest, during squats and immediately after. CMJ on infrared Optojump photoelectric cells. Passive and active knee ROM.	Both interventions were effective in improving PPT, oxygen saturation, CMJ, and knee joint ROM. VR achieved greater short term benefits in pain perception.
Skarabot et al. (2015) **Flexibility**	Comparing the effects of SMR with SS on ankle ROM in adolescent athletes	11	Resistance trained adolescent swimmers (5 females, 6 males)	Within subject randomised design. Each participant attended 3 separate visits (24h apart). On each visit, pre-test was done, participant's performed either SS, FR, or FR & SS, post-test done at 10min, 15min and 20min post intervention. SS: Single plantarflexion stretch, 3 sets of 30s. 15s rest in between. Standing with leg on edge of bench. FR: 3 × 30s with 15s rest between sets. Seated position with one leg straight and relaxed, other leg crossed over the other rolling the full length of gastrocnemius. FR and SS combined both protocols. Instructions: to exert as much pressure on the foam roller as possible. Foam Roller: The Grid Foam Roller	Passive ankle dorsiflexion ROM tested using wall lunge.	FR, SS and FR & SS all lead to acute increases in flexibility and FR & SS appears to have an additive effect in comparison to FR alone. All three-intervention benefits lasted less than 10 min.
Wilke et al. (2018) **PPT**	To examine whether a single bout of FR is effective in reducing MTrP.	50	Healthy adults (21 males, 29 females)	All participants were screened for latent MTrP and randomly allocated into three groups; static compression of MtRP, FR over MtRP or placebo laser acupuncture over MTrP. Testing done pre and immediately post intervention. Static compression of MtRP: Compress trigger point by means of a foam roller without further movement for 90s, at a targeted discomfort of 6–7 on the pain scale. FR: 5 strokes back and forth per minute over insertion and origin of gastrocnemius for 90s.	PPT of the most sensitive MTrP was measured with a handheld mechanical pressure algometer.	Only static compression of the MTrP was effective in reducing latent MTrP sensitivity.

(*continued on next page*)

Table 4.2 (*continued*)

Author	Aim	N	Subjects/ Population	Protocol	Outcome Measures	Findings
				Placebo laser acupuncture: Applied in the prone position using the Laserneedle System, with the device switched off. Foam roller: Blackroll™		
Wilke et al. (2019) **Flexibility**	To investigate the effect of FR velocity on ROM and tissue stiffness	17	Physically active adults (7 males, 10 females)	Cross-over design with 3 randomized experimental conditions; Fast-FR, slow-FR and control. One week washout period between intervention sessions. Testing was done pre, immediately post, 5min post and 10min post intervention. FR: Four sets of 45s with 30s rests over anterior thigh, at a pressure of 6–7 on the pain scale. Velocity was determining by a metronome. The Fast-FR group the cadence was 1s per stroke (60bpm) and the slow-FR group was 10s per stroke (6bpm). Foam roller: Polypropylene foam roller. Control: Seated for 5min.	Compressive tissue stiffness assessed with a semi-electronic tissue compliance meter. Knee flexion ROM assessed with an ultrasonic 3D movement analysis system.	FR of the anterior thigh decreases myofascial stiffness regardless of the velocity.
Zorko et al. (2016) **DOMS**	The acute effect of SM on the short-term recovery of muscle contractile function	10	Recreationally active college students (9 males, 1 female)	2 visits, 48 h between visits. 3 sets of 15 reps on knee extension machine at 70% of 1 RM was done at each session (fatigue protocol). Either FR (intervention) or passive rest (control) followed this. Standardised warm-up: 6min stepping routine, knee extensions then intervention or control. FR: Plank position, small kneading motions, then more fluid motions, then maintain pressure on tender area of the quadriceps. Lasting 90s. Passive rest was done in prone for 90s. Instructions: no instruction with regards to pressure. Foam Roller: Grid Foam Roller.	MVC of vastus lateralis Direct muscle stimulation through electrodes and biphasic electrical current.	Both FR and passive rest promoted small recoveries on all main outcome variables. FR appears to be equally effective as passive rest for short term recovery of muscle contractile function.

FR- Foam Rolling; **SS-** Static stretching**; ROM-** Range of Motion; **SMR-** Self Myofascial Release; **RM-** Repetition Maximum; **SJ-** Squat Jump; **CMJ-** Countermovement Jump. **VJ-** Vertical Jump; **reps-** Repetitions; **s-** Seconds; **hr-** Hours; **min-** Minutes; **n-** Number; **m-** Metres **SLR-** Straight Leg Raise; **ITB-** Ilio-tibial Band; **PPT-** Pressure Pain Threshold. **ml-** Millilitres; **DOMS-** Delayed Onset of Muscle Soreness; **S&R-** Sit-and-Reach; **TMG-** Tensomyography; **VO_2 max-** Maximal Oxygen Consumption; **MIVF-** Maximum Isometric Voluntary Force; **MVS-** Maximal Voluntary Contraction; **VAS-** Visual Analog Scale**; NPRS-** Numerical Pain Rating Scale; **TQR-** Total Quality Recovery; **MTrP-** Myofascial Trigger Points; **bpm-** Beats Per Minute; **VR-** Vibration Foam Ro.

ROM (4.9 ± 1.8°) and significant changes in PPT (145.3 ± 77.4 kPa) (Cheatham et al., 2017).

3.4.4. Other

Five studies fall into the category of “other” under the recovery section (Hotfiel et al., 2017; D'Amico and Paolone, 2017; Fleckenstein et al., 2017; Kalen et al., 2017; Kim et al., 2014). All of the studies scored a 6 on the PEDro scale, placing the studies at the low end of the methodological quality rating.

One study showed that SMR induced with a foam roller did not affect the reduction of stress (Kim et al., 2014). In this study the participants performed a 30-min walk on a treadmill to induce physical stress. Both FR and walking reduced cortisol serum levels but there were no significant differences between the strategies (Kim et al., 2014). In another study, Hotfiel et al., 2017 found that local blood flow increases significantly after foam rolling of the lateral thigh, with a baseline Vmax (peak flow) of 7.2 ± 2.6 cm s^1 increasing immediately after the intervention to 12.5 ± 5.0 cm s^1 (Hotfiel et al., 2017). However, this study did not compare FR with any other strategy. Using lifeguards, Kalen et al., 2017 compared the effectiveness of active recovery in the form of running or FR on clearing blood lactate compared to sitting after a water rescue. The authors found that post recovery lactate levels were significantly lower for FR and running compared with resting (no differences between FR and running) (Kalen et al., 2017).

4. Discussion

4.1. Performance

The majority of the studies found that FR did not improve athletic performance, but at the same time, FR did not impede various force and power outcome measures. Due to the increases shown in flexibility with no decrease in physical performance (Behara and

Jacobson, 2017; MacDonald et al., 2013; Morales-Artacho et al., 2017; Su et al., 2017; Hall and Smith, 2018; Lee et al., 2018; Monteiro et al., 2019a), FR appears to be a good tool to use for or during a warm up to increase flexibility but it is advised to be used in combination with DS (Su et al., 2017) and active warm-up (Martínez-cabrera and Núñez-sánchez, 2016; Morales-Artacho et al., 2017). This is encouraging as various studies have implicated massage and SS as impeding performance (Barnes, 1997; Behara and Jacobson, 2017; Healey et al., 2014; Healey et al., 2014). It appears that combining DS with FR will enhance performance (Su et al., 2017), while Behara and Jacobson (2017) suggested that FR be a substitute for SS. Dynamic stretching has been found to improve athletic test performance on its own (Jones et al., 2015). Therefore, It seems reasonable to suggest that FR be used in combination with DS and an active warm-up to attenuate passive muscle stiffness and increase flexibility before a training session (Martínez-cabrera and Núñez-sánchez, 2016; Morales-Artacho et al., 2017; Peacock et al., 2014; Su et al., 2017).

Foam Rolling appears to enhance performance when flexibility is part of the performance measure. Cavanaugh et al. (2017) showed a negative effect of FR and reported a decrease in muscle activation of the biceps femoris and concluded that FR does not enhance performance (Cavanaugh et al., 2017). In this case, the quadriceps were rolled alone, with the authors' suggesting a possible antagonistic effect due to reciprocal inhibition when rolling the quadriceps muscle group. On three separate occasions, Monteiro et al. (2018, 2017b, 2017c) found that using FR in between sets when doing resistance training seemed to be detrimental to the ability to continually produce force. In other words, the timing of FR use can be detrimental, depending on the type of activity (Monteiro and Neto, 2016; Monteiro et al., 2017b, 2017c). Su et al. (2017) recommend that FR should be utilized to enhance performance in activities or sports that require flexibility, correlating with the findings of the performance studies displaying increases in flexibility (Behara and Jacobson, 2017; MacDonald et al., 2013; Morales-Artacho et al., 2017; Peacock et al., 2014, 2015; Schroeder et al., 2017; Su et al., 2017).

The dosage of FR in terms of time(s) appears to be critical for effect. Monteiro et al. (2017a) reported that the improvement in FMS scores were only present in the group that rolled for more than 90s, suggesting that this may be a threshold to achieve desired results. Another study showed that FR for 30s did not improve the vertical jump (Jones et al., 2015), while Healey et al. (2014), who also rolled for 30s on each muscle, showed no effect on performance. Hansen et al. (2016) found that FR for less than 90s, had no effect on anaerobic power. Performing FR for more than 90s however, produced enhanced ROM (Behara and Jacobson, 2017; Su et al., 2017). MacDonald et al. (2013) was one of the only studies that rolled for less than 90s and still found flexibility improvements but no enhancement on knee extensor force (MacDonald et al., 2013). It appears that the protocol of 60s–90s of FR may coincide with the benefits seen with short duration massages (MacDonald et al., 2014; MacDonald et al., 2013). Given the above evidence, it seems 60s–90s of FR on a muscle group may be effective, but more evidence points to rolling for 90s as the threshold to obtain benefits.

Theories have been proposed to explain the mechanisms through which FR may achieve the neurophysiological and the mechanical effect (Schleip, 2003; Simmonds et al., 2012; Stecco et al., 2008; Kelly and Beardsley, 2016). The results neither confirm or deny either effect, and may indicate that both mechanisms may not work independently. However, more research is needed on this topic. It is believed that FR may act by reducing neural inhibition, as seen by the increase in vertical jump scores (MacDonald et al., 2014) and the increase in PPT (Vaughan et al., 2014). This may be an example of the mechanical effect. However, studies that reported antagonistic effects when FR (Cavanaugh et al., 2017; Monteiro et al., 2017b), support neurophysiological effects.

Further to the antagonistic effects of FR (Cavanaugh et al., 2017; Monteiro et al. 2017b, 2017c), cross-over effects were found in a study by Kelly and Beardsley (2016) who reported improvements in contralateral limb flexibility for up to 10 min (Kelly and Beardsley, 2016). An SMR study by Aboodarda et al. (2015) showed heavy roller massage and manual massage over tender spots in plantar flexors increased the PPT of the ipsilateral and contralateral calf. These effects lasted up to 15 min and suggest global effects of SMR and the neural response that may be due to the mechanical stress or modulation of the central nervous system (Aboodarda et al., 2015). These global effects can be further supported by Grieve et al. (2015) finding that SMR to the bilateral plantar surfaces using a tennis ball increased hamstring and lumbar flexibility (Grieve et al., 2015). It is difficult to determine if these results could be directly related to the mechanical theory or the neurophysiological theory. There has not been any FR research directly measuring or determining the mechanisms through which FR operates. If the mechanisms could be determined, it may help practitioners understand when FR can be optimally used.

4.2. *Exercise induced muscle damage (EIMD) and delayed onset of muscle soreness (DOMS)*

Foam Rolling seems beneficial for recovery from DOMS and its physical performance decrements. Five studies reported on outcomes in this category. Four of the studies support FR for enhancing recovery from EIMD and DOMS (MacDonald et al., 2014; Rey et al., 2017; Romero-Moraleda et al., 2017, 2019) while Zorko et al., 2016 found that FR was just as effective as passive rest in enhancing short term recovery (Zorko et al., 2016).

Four of the five studies dealing with DOMS, showed that FR reduces DOMS and thus helps recovery from EIMD (MacDonald et al., 2014; Rey et al., 2017; Romero-Moraleda et al., 2017, 2019). These studies suggest FR may be a useful tool to enhance recovery from training or from competition through reducing decrements associated with DOMS. Overall, it seemed that FR was improving physical performance post a DOMS-inducing protocol, but it should be noted that these were improvements in physical performance back to baseline. This suggests that FR may be beneficial for athletes to recover and return to their normal performance faster.

Zorko et al. (2016) reported that FR was just as effective as passive rest in enhancing short-term recovery (Zorko et al., 2016), though it should be noted that DOMS can have its main effects between 24 and 72 h post EIMD activity. This result may reflect the methods used. Zorko et al. (2016) measured short-term recovery of contractile muscle function, and not an array of athletic or flexibility measurements i.e. the tests were not functional and had no pain measurement. Also, the timing of the post-intervention testing seems to be a critical factor with the monitoring of recovery.

Whether these beneficial effects of SMR 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. It is believed that the pain and stiffness related to DOMS may be related to an inflammatory response of the connective tissue and therefore FR may influence these inflammatory responses through one of the above mechanisms (MacDonald et al., 2014). The neural inhibition mechanisms were considered by Pearcey et al. (2015) who hypothesized that a reduction in DOMS had a neural impact with improved movement and fiber recruitment patterns. With that said, these mechanisms remain unclear.

4.3. Flexibility

Flexibility was the most common measure throughout all the included studies. The majority of the studies found that SMR through FR does lead to an acute increase in ROM. Eight of the 49 studies focused only on flexibility measures (Boguszewski et al., 2017; Couture et al., 2015; Griefahn et al., 2017; Kelly and Beardsley, 2016; Mohr et al., 2014; Murray et al., 2016; Skarabot et al., 2015 Wilke et al., 2019). Six of these demonstrated an increase in flexibility after FR. These studies showed an increase in hip flexion ROM (Mohr et al., 2014; Murray et al., 2016), knee flexion ROM (Murray et al., 2016), as well as ankle dorsi-flexion ROM (Kelly and Beardsley, 2016; Škarabot et al., 2015). As discussed earlier though, FR was more effective in increasing flexibility when combined with another intervention such as SS (Mohr et al., 2014; Škarabot et al., 2015). Two studies showed that FR on its own did not increase flexibility (Couture et al., 2015; Griefahn et al., 2017). There appears to be consensus that FR acutely increases flexibility, however, the time course of effects may be limited to 10 min (Behara and Jacobson, 2017; Cheatham et al., 2017a; MacDonald et al., 2013; Monteiro et al., 2017a; Morales-Artacho et al., 2017; Peacock et al., 2014, 2015; Su et al., 2017). In the only study to explore the longer term effects of Freiwald et al. (2016) showed that FR three times a week for four weeks resulted in an increase in flexibility in stand and reach scores. They also mentioned that FR effects were comparable to those of scientifically proven contract-relax PNF stretching method (Jones et al., 2015).

No specific protocol appeared to be more effective, but, a bout of FR for 45–90 s seemed to be beneficial for an acute improvement in flexibility. The only study which may have shown one protocol to be more effective than the other was described by Peacock et al. (2015), where FR targeting the muscles in the medio-lateral axis improved sit-and-reach scores when compared to FR in the anterio-posterior axis. This was possibly due to the fact that FR in the medio-lateral axis involved direct FR of the hamstrings. Most the studies showed positive effects when FR was used on an isolated muscle.

One of the studies that failed to find acute improvements in ROM did not specify the instructions given to their participants on pressure exerted (Couture et al., 2015) and the other study instructed participants to use their body weight while respecting pain (Griefahn et al., 2017). Differences in instructions may have affected the outcomes of the studies. Couture et al., 2015 also utilized a conventional uniform polystyrene foam roller with high density (Couture et al., 2015), which has been shown to exert less pressure, while the other study did not specify the FR used (Griefahn et al., 2017). Curran et al. (2008) have demonstrated the difference in pressure from different FR and have hypothesized that the more pressure exerted may have a greater effect on outcomes. The importance of pressure is reinforced by the results of Bradbury-Squires et al. (2015) and Sullivan and Silvey (2013) who both used an especially designed apparatus to control the pressure while using a roller massager. This increased the internal validity of the studies and both studies found improvement in 'movement efficiency' (Curran et al., 2008; Sullivan and Silvey, 2013). These findings may add strength to the importance of the type of FR used and the pressure instructions being given (Cheatham et al., 2015).

4.4. Pressure Pain Threshold (PPT)

Five studies focused on the measurement of PPT (Cheatham et al., 2017; Cheatham and Kolber, 2017; Cheatham and Stull 2018a, 2018b; Wilke et al., 2018)). As suggested above, FR may have its effect on ROM by reducing neural inhibition of the connective tissue (Cheatham et al., 2017a; Cheatham et al., 2017b; MacDonald et al., 2014; Vaughan et al., 2014). Neural inhibition may improve the stretch tolerance of the connective tissue and thus increase ROM (MacDonald et al., 2014). Neural inhibition may also occur secondary to changes in circulation. It is theorized that one of the mechanisms of action of FR is through the promotion of active blood flow and moving the interstitial fluid back into circulation via arterial dilatation (MacDonald et al., 2014; MacDonald et al., 2013; Okamoto et al., 2014; Peacock et al., 2014; Pearcey et al., 2015). This may induce a warming and thixotropic effect with neural feedback mechanisms (MacDonald et al., 2014; MacDonald et al., 2013). Notably, Vaughan et al. (2014) showed that increases in PPT were transient, only lasting 5 min suggesting that these changes might be temporary adaptations to dynamic mechanisms.

4.5. Other effects

Foam rolling seems to reduce stress, but no more so than passive rest (Kim et al., 2014). A reduction in stress may enhance recovery from an intense exercise bout or competition as it may reduce the physical stress experienced on these occasions (Kim et al., 2014). A further mechanism by which FR may enhance recovery is through a reduction in arterial stiffness, improvements of endothelial function and enhancements in blood flow (Hotfiel et al., 2017). These changes may help recovery from an exercise bout due to the reductions in smooth muscle tension and the increase of its pliability following the application of pressure. In addition, pressure applied by a FR seems to stimulate the release of plasma nitric oxide (Okamoto et al., 2014). Circulatory changes after FR were still present 30 min after the intervention (Hotfiel et al., 2017). While some studies propose that these effects are due to an increase in muscle temperature, Murray et al. (2016) found no increase in muscle temperature. It is thus assumed that FR stimulates a vaso-neural response via the mechanical pressure applied through FR.

For most recovery studies, the duration of FR for a specific muscle group ranged between 30s and 60s, and this was repeated 3 to 5 times (sets) with 10s–30s rest periods between each set (Couture et al., 2015; Griefahn et al., 2017; Hotfiel et al., 2017; Kelly and Beardsley 2016; Mohr et al., 2014; Rey et al., 2017; Romero-Moraleda et al., 2017; Romero-Moraleda et al., 2019; Skarabot et al., 2015; Wilke et al., 2018; Wilke et al., 2019; Zorko et al., 2016). Like the performance studies, it seems that rolling for a total of 90s or more is required to obtain any recovery benefits from FR.

4.6. Limitations

There was a large amount of heterogeneity in the studies included in the review. The variation in study findings may be a result of the variations in outcome measures, skeletal areas foam rolled, the FR tool used and the intensity (pressure) applied with the foam roller. In some studies, the participants were instructed to exert as much pressure as tolerable (Aune et al., 2019; Cavanaugh et al., 2017; MacDonald et al., 2013) and in other studies, there were no instructions described (Behara and Jacobson, 2017; Healey et al., 2014; Jones et al., 2015). Some studies tested elite athletes (Jones et al., 2015; Behara and Jacobson, 2017; Murray et al., 2016) while others tested students at the college they attended (Kelly and Beardsley, 2016; Hotfiel et al., 2017; Zorko et al., 2016). Athletically trained individuals and those who have performed FR before may respond differently to those who are not trained and have never used FR before. Almost all these studies lacked a true control as both the control groups underwent a warm up to avoid injury to the participants. In addition, there were no sham control groups which would provide insight into whether the effects of FR were placebo. As such, the lack of control or sham groups may affect the true significance of the results within the studies.

Limitations of the review itself include, the use of the PEDro scale, the lack of a risk of bias analysis and the focus on English studies only. The PEDro scale is primarily designed for randomized control trials, which means some studies may have lost points and were excluded from the final total. Also, a risk of bias analysis was not conducted, which affects the confidence level of the review. Lastly, the current review selected studies published in English only. Studies on the effects of FR are growing across the globe, and some these studies may not be published in English journals. This should be considered in future reviews.

5. Conclusion

FR may reduce muscle stiffness and increase ROM and should be used in combination with dynamic stretching and active warm-up before a training session. Furthermore, the optimum dosage to achieve these flexibility benefits seems to be 90s–120s of FR. FR reduced DOMS and increased PPT, and therefore may optimize recovery from training. Future studies on the effects of FR should include true controls or sham groups, and consider the FR experience of the athlete.

6. Clinical relevance

- FR appears to be a good tool to use for or during a warm up to increase flexibility but it is advised to be used in combination with DS and active warm-up.
- FR can be used after an exercise bout to enhance recovery from EIMD and symptoms of DOMS.
- A slow undulating 30s–60s bout of FR, 3 to 5 times (sets) with 10s–30s rest periods between each set may be optimal for both performance and recovery.
- During resistance training, FR between sets may be detrimental to ones ability to continually produce force.

Declaration of competing interest

The authors have no conflict of interest.

References

Aboodarda, S.J., Spence, A.J., Button, D.C., 2015. Pain pressure threshold of a muscle tender spot increases following local and non-local rolling massage. BMC Muscoskelet. Disord. 16 (1), 265.
Ajimsha, M.S., Al-Mudahka, N.R., Al-Madzhar, J.A., 2014. Effectiveness of myofascial release: systematic review of randomized controlled trials. J. Bodyw. Mov. Ther. 19 (1), 102–112.
Aune, A.A.G., Bishop, C., Turner, A.N., Papadopoulos, K., Budd, S., Richardson, M., Maloney, S.J., 2019. Acute and chronic effects of foam rolling vs eccentric exercise on ROM and force output of the plantar flexors. J. Sport. Sci. 37 (2), 138–145.
Barnes, M.F., 1997. The basic science of myofascial release : morphologic change in connective tissue. J. Bodyw. Mov. Ther. 4 (1), 231–238.
Baumgart, C., Freiwald, J., Kuhnemann, M., Hotfiel, T., Huttel, M., Hoppe, M.W., 2019. Foam rolling of the calf and anterior thigh: biomechanical loads and acute effects on vertical jump height and muscle stiffness. Sports 7 (1), 1–10.
Beardsley, C., Skarabot, J., 2015. Effects of self-myofascial release: a systematic review. J. Bodyw. Mov. Ther. 19 (4), 747–758.
Behara, B., Jacobson, B.H., 2017. Acute effects of deep tissue foam rolling and dynamic stretching on muscular strength, power, and flexibility in division i linemen. J. Strength Cond. Res. 31 (4), 888–892.
Boguszewski, D., Falkowska, M., Adamczyk, J.G., Białoszewski, D., 2017. Influence of foam rolling on the functional limitations of the musculoskeletal system in healthy women. Biomed. Hum. Kinet. 9 (1), 75–81.
Bradbury-Squires, D.J., Noftall, J.C., Sullivan, K.M., Behm, D.G., Power, K.E., Button, D.C., 2015. Roller-massager application to the quadriceps and knee-joint range of motion and neuromuscular efficiency during a lunge. J. Athl. Train. 50 (2), 133–140.
Bushell, J.E., Dawson, S.M., Webster, M.M., 2015. Clinical relevance of foam rolling on hip extension angle in a functional lunge position. J. Strength Cond. Res. 29 (9), 2397–2403.
Cavanaugh, M.T., Aboodarda, S.J., Hodgson, D.D., Behm, D.G., 2017. Foam rolling of quadriceps decreases biceps femoris activation. J. Strength Cond. Res. 31 (8), 2238–2245.
Cheatham, S.W., Kolber, M.J., 2017. Does roller massage with a foam roll change pressure pain threshold of the ipsilateral lower extremity antagonist and contralateral muscle groups? An exploratory study. J. Sport Rehabil. 27 (2), 165–169.
Cheatham, S.W., Kolber, M.J., Cain, M., 2017. Comparison of video-guided, live instructed, and self-guided foam roll interventions on knee joint range of motion and pressure pain threshold: a randomized controlled trial. Int. J. Sport. Phys. Ther. 12 (2), 242–249.
Cheatham, S.W., Kolber, M.J., Cain, M., Lee, M., 2015. The effects of self-myofascial release using a foam roll or roller massager on joint range of motion, muscle recovery, and performance: a systematic review. Int. J. Sport. Phys. Ther. 10 (6), 827–838.
Cheatham, S.W., Stull, K.R., 2018a. Comparison of a foam rolling session with active joint motion and without joint motion: a randomized controlled trial. J. Bodyw. Mov. Ther. 22 (3), 707–712.
Cheatham, S.W., Stull, K.R., 2018b. Comparison of three different density type foam rollers on knee range of motion and pressure pain threshold: a randomized controlled trial. Int. J. Sport. Phys. Ther. 13 (3), 474–482.
Couture, G., Karlik, D., Glass, S.C., Hatzel, B.M., 2015. The effect of foam rolling duration on hamstring range of motion. Open Orthop. J. 9, 450–455.
Curran, P.F., Fiore, R.D., Crisco, J.J., 2008. A comparison of the pressure exerted on soft tissue by 2 myofascial rollers. J. Sport Rehabil. 17 (4), 432–442.
D'Amico, A., Paolone, V., 2017. The effect of foam rolling on recovery between two eight hundred metre runs. J. Hum. Kinet. 57, 97–105.
Fleckenstein, J., Wilke, J., Vogt, L., Banzer, W., 2017. Preventive and regenerative foam rolling are equally effective in reducing fatigue-related impairments of muscle function following exercise. J. Sport. Sci. Med. 16 (4), 474–479.
Freiwald, J., Baumgart, C., Kuhnemann, M., Hoppe, M.W., 2016. Foam-Rolling in sport and therapy – potential benefits and risks: Part 2. Sports. Orthop. Traumatol. 32 (3), 267–275.
Griefahn, A., Oehlmann, J., Zalpour, C., von Piekartz, H., 2017. Do exercises with the Foam Roller have a short-term impact on the thoracolumbar fascia? - a randomized controlled trial. J. Bodyw. Mov. Ther. 21 (1), 186–193.
Grieve, R., Goodwin, F., Alfaki, M., Bourton, A.J., Jeffries, C., Scott, H., 2015. The immediate effect of bilateral self myofascial release on the plantar surface of the feet on hamstring and lumbar spine flexibility: a pilot randomised controlled trial. J. Bodyw. Mov. Ther. 19 (3), 544–552.
Guillot, A., Kerautret, Y., Queyrel, F., Schobb, W., Di Rienzo, F., 2019. Foam rolling and joint distraction with elastic band training performed for 57 weeks respectively improve lower limb flexibility. J. Sport. Sci. Med. 18, 160–171.
Hall, M., Smith, C.J., 2018. The effects of an acute bout of foam rolling on hip range of motion on different tissues. Int. J. Sport. Phys. Ther. 13 (4), 652–660.
Hansen, A., Beltz, N.M., Janot, J., Martenson, A., Siegmann, A., Jagielo, A., Erdmann, A., Wiggins, M., 2016. A dose-response relationship between myofascial release and anaerobic power output in active college-aged males. J. Fit. Res. 5 (2), 10–17.
Healey, K.C., Hatfield, D.L., Blanpied, P., Dorfman, L.R., Riebe, D., 2014. The effects of myofascial release with foam rolling on performance. J. Strength Cond. Res. 28 (1), 61–68.
Hotfiel, T., Swoboda, B., Krinner, S., Grim, C., Engelhardt, M., Uder, M., Heiss, R.U., 2017. Acute effects of lateral thigh foam rolling on arterial tissue perfusion determined by spectral Doppler and power Doppler ultrasound. J. Strength Cond. Res. 31 (4), 893–900.
Jones, A., Brown, L.E., Coburn, J.W., Nofall, G.J., 2015. Effects of foam rolling on vertical jump performance. Int. J. Kinesiol. Sport. Sci. 3 (3), 38–42.
Kalen, A., Perez-Ferreiros, A., Barcala-Furelos, R., Fernandez-Mendez, M., Padron-Cabo, A., Prieto, J.A., Rios-Ave, A., Abelairas-Gomez, C., 2017. How can lifeguards recover better? A cross-over study comparing resting, running, and foam rolling. AJEM (Am. J. Emerg. Med.) 35 (12), 1887–1891.
Kelly, S., Beardsley, C., 2016. Specific and cross-over effects of foam rolling on ankle dorsiflexion range of motion. Int. J. Sport. Phys. Ther. 11 (4), 544–551.
Killen, B.S., Zelizney, K.L., Ye, X., 2018. Crossover effects of unilateral static stretching and foam rolling on contralateral hamstring flexibility and strength. J. Sport Rehabil. 1–27.
Kim, K., Park, S., Goo, B.O., Choi, S.C., 2014. Effect of self-myofascial release on reduction of physical stress: a pilot study. J. Phys. Ther. Sci. 26 (11), 1779–1781.
Lee, C.L., Chu, I.H., Lyu, B.J., Chang, W.D., Chang, N.J., 2018. Comparison of vibration rolling, nonvibration rolling, and static stretching as a warm-up exercise on flexibility, joint proprioception, muscle strength, and balance in young adults. J. Sport. Sci. 36 (22), 2575–2582.
MacDonald, G.Z., Button, D.C., Drinkwater, E.J., Behm, D.G., 2014. Foam rolling as a recovery tool after an intense bout of physical activity. Med. Sci. Sport. Exerc. 46 (1), 131–142.
MacDonald, G.Z., Penney, M.D., Mullaley, M.E., Cuconato, A.L., Drake, C.D., Behm, D.G., Button, D.C., 2013. An acute bout of self-myofascial release increases range of motion without a subsequent decrease in muscle activation or force. J. Strength Cond. Res. 27 (3), 812–821.
Macgregor, L.J., Fairweather, M.M., Bennett, R.M., Hunter, A.M., 2018. The effect of foam rolling for three consecutive days on muscular efficiency and range of motion. Sport. Med. Open 4 (1), 26.
Maher, C.G., Sherrington, C., Herbert, R.D., Moseley, A.M., Elkins, M., 2003. Reliability of the PEDro Scale for rating quality of randomized controlled trials.

Phys. Ther. 83 (8), 713–722.
Martínez-cabrera, F.I., Núñez-sánchez, F.J., 2016. Acute effect of a foam roller on the mechanical properties of the rectus femoris based on tensiomyography in soccer players. Int. J. Hum. Mov. Sport Sci. 4 (2), 26–32.
McKenney, K., Elder, A.S., Elder, C., Hutchins, A., 2013. Myofascial release as a treatment for orthopaedic conditions: a systematic review. J. Athl. Train. 48 (4), 522–527.
Mohr, A.R., Long, B.C., Goad, C.L., 2014. Effect of foam rolling and static stretching on passive hip-flexion range of motion. J. Sport Rehabil. 23 (4), 296–299.
Monteiro, E.R., Costa, P.B., Correa Neto, V.G., Hoogenboom, B.J., Steele, J., Silva Novaes, J.D., 2019a. Posterior thigh foam rolling increases knee extension fatigue and passive shoulder range-of-motion. J. Strength Cond. Res. 33 (4), 987–994.
Monteiro, E.R., da Silva Novaes, J., Cavanaugh, M.T., Hoogenboom, B.J., Steele, J., Vingren, J.L., Škarabot, J., 2019b. Quadriceps foam rolling and rolling massage increases hip flexion and extension passive range-of-motion. J. Bodyw. Mov. Ther. 23 (3), 575–580.
Monteiro, E.R., Neto, V.G., 2016. Effect of different foam rolling volumes on knee extension fatigue. Int. J. Sport. Phys. Ther. 11 (7), 1076–1081.
Monteiro, E.R., Skarabot, J., Vigotsky, A.D., Brown, A.F., Gomes, T.M., Novaes, J.D., 2017a. Acute effects of different self-massage volumes on the fms (tm) overhead deep squat performance. Int. J. Sport. Phys. Ther. 12 (1), 94–104.
Monteiro, E.R., Skarabot, J., Vigotsky, A.D., Brown, A.F., Gomes, T.M., Novaes, J.D., 2017b. Maximum repetition performance after different antagonist foam rolling volumes in the inter-set rest period. Int. J. Sport. Phys. Ther. 12 (1), 76–84.
Monteiro, E.R., Vigotsky, A., Skarabot, J., Brown, A.F., Ferreira de Melo Fiuza, A.G., Gomes, T.M., Halperin, I., da Silva Novaes, J., 2017c. Acute effects of different foam rolling volumes in the interset rest period on maximum repetition performance. Hong Kong Physiother. J. 36, 57–62.
Monteiro, E.R., Vigotsky, A.D., Novaes, J.D.S., Skarabot, J., 2018. Acute effects of different anterior thigh self-massage on hip range-of-motion in trained men. Int. J. Sport. Phys. Ther. 13 (1), 104–113.
Morales-Artacho, A.J., Lacourpaille, L., Guilhem, G., 2017. Effects of warm-up on hamstring muscles stiffness: cycling vs foam rolling. Scand. J. Med. Sci. Sport. 27 (12), 1959–1969.
Murray, A.M., Jones, T.W., Horobeanu, C., Sproule, J., 2016. Sixty seconds of foam rolling does not affect functional flexibility or change muscle temperature in adolescent athletes. Int. J. Sport. Phys. Ther. 11 (5), 756–776.
Okamoto, T., Masuhara, M., Ikuta, K., 2014. Acute effects of self-myofascial release using a foam roller on arterial function. J. Strength Cond. Res. 28 (1).
Peacock, C.A., Krein, D.D., Antonio, J., Sanders, G.J., Silver, T.A., Colas, M., 2015. Comparing acute bouts of sagittal plane progression foam rolling vs. Frontal plane progression foam rolling. J. Strength Cond. Res. 29 (8), 2310–2315.
Peacock, C.A., Krein, D.D., Silver, T.A., Sanders, G.J., KA, v.C., 2014. An acute bout of self-myofascial release in the form of foam rolling improves performance testing. Int. J. Exerc. Sci. 7 (3), 202–211.
Pearcey, G.E., Bradbury-Squires, D.J., Kawamoto, J.E., Drinkwater, E.J., Behm, D.G., Button, D.C., 2015. Foam rolling for delayed-onset muscle soreness and recovery of dynamic performance measures. J. Athl. Train. 50 (1), 5–13.
Rey, E., Padrón-Cabo, A., Costa, P.B., Barcala-Furelos, R., 2017. The effects of foam rolling as a recovery tool in professional soccer players. J. Strength Cond. Res. 33 (8), 2194–2201.
Richman, E.D., Tyo, B.M., Nicks, C.R., 2019. Combined effects of self-myofascial release and dynamic stretching on range of motion, jump, sprint, and agility performance. J. Strength Cond. Res. 33 (7), 1795–1803.
Romero-Moraleda, B., Gonzalez-Garcia, J., Cuellar-Rayo, A., Balsalobre-Fernandez, C., Munoz-Garcia, D., Morencos, E., 2019. Effects of vibration and non-vibration foam rolling on recovery after exercise with induced muscle damage. J. Sport. Sci. Med. 18 (1), 172–180.
Romero-Moraleda, B., La Touche, R., Lerma-Lara, S., Ferrer-Pena, R., Paredes, V., Peinado, A.B., Munoz-Garcia, D., 2017. Neurodynamic mobilization and foam rolling improved delayed-onset muscle soreness in a healthy adult population: a randomized controlled clinical trial. PeerJ 5, e3908.
Schleip, R., 2003. Fascial plasticity - a new neurobiological explanation. Part 2. J. Bodyw. Mov. Ther. 7 (2), 104–116.
Schroeder, J., Renk, V., Braumann, K.-M., Hollander, K., 2017. Acute Foam Rolling effects on contractile properties of the m. biceps femoris. Ger. J. Exerc. Sport. Res. 47 (4), 294–300.
Shamseer, L., Moher, D., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M., Shekelle, P., Stewart, L.A., group, t.P.-P., 2015. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015: elaboration and explanation. Br. Med. J. 7647 (349), 1–25.
Simmonds, N., Miller, P., Gemmell, H., 2012. A theoretical framework for the role of fascia in manual therapy. J. Bodyw. Mov. Ther. 16 (1), 83–93.
Skarabot, J., Beardsley, C., Stirn, I., 2015. Comparing the effects of self-myofascial release with static stretching on ankle range-of-motion in adolescent athletes. Int. J. Sport. Phys. Ther. 10 (2), 203–212.
Škarabot, J., Beardsley, C., Štirn, I., 2015. Comparing the effects of self-myofascial releases with static stretching on ankle range-of-motion in adolescent athletes. Int. J. Sport. Phys. Ther. 10 (2), 203–212.
Smith, J.C., Pridgeon, B., Hall, M.C., 2018. Acute effect of foam rolling and dynamic stretching on flexibility and jump height. J. Strength Cond. Res. 32 (8), 2209–2215.
Stecco, C., Porzionato, A., Macchi, V., Stecco, A., Vigato, E., Parenti, A., Delmas, V., Aldegheri, R., De Caro, R., 2008. The expansions of the pectoral girdle muscles onto the brachial fascia: morphological aspects and spatial disposition. Cells Tissues Organs 188 (3), 320–329.
Su, H., Chang, N.J., Wu, W.L., Guo, L.Y., Chu, I.H., 2017. Acute effects of foam rolling, static stretching, and dynamic stretching during warm-ups on muscular flexibility and strength in young adults. J. Sport Rehabil. 26 (6), 469–477.
Sullivan, K., Silvey, D., 2013. Roller-Massager application to the hamstrings increases sit-and-reach range of motion within five to ten seconds without performance impairments. Int. J. Sport. Phys. Ther. 8 (3), 228–236.
Vaughan, B., McLaughlin, P., Lepley, A.S., 2014. Immediate changes in pressure pain threshold in the iliotibial band using a myofascial (foam) roller. Int. J. Ther. Rehabil. 21 (12), 569–574.
Wilke, J., Niemeyer, P., Niederer, D., Schleip, R., Banzer, W., 2019. Influence of foam rolling velocity on knee range of motion and tissue stiffness: a randomized, controlled crossover trial. J. Sport Rehabil. 1–5.
Wilke, J., Vogt, L., Banzer, W., 2018. Immediate effects of self-myofascial release on latent trigger point sensitivity: a randomized, placebo-controlled trial. Biol. Sport 35 (4), 349–354.
Williams, W., Selkow, N.M., 2019. Self-myofascial release of the superficial back line improves sit-and-reach distance. J. Sport Rehabil. 1–19.
Zorko, N., Skarabot, J., Garcia-Ramos, A., Stirn, I., 2016. The acute effect of self-massage on the short-term recovery of muscle contractile function. Kinesiol. Slov. 22 (3), 31–40.