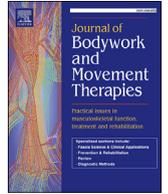




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Fascia Science and Clinical Applications

## A systematic review and meta-analysis of the effects of foam rolling on range of motion, recovery and markers of athletic performance

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## ABSTRACT

**Objective:** To conduct a systematic review with meta-analysis assessing the effects of foam rolling on range of motion, laboratory- and field-based athletic measures, and on recovery.

**Data sources:** MEDLINE, PubMed, EMBASE, SPORTDiscus and Science Direct were searched (2005–June 2018).

**Study selection:** Experimental and observational studies were included if they examined the effects of foam rolling on measures of athletic performance in field or laboratory settings.

**Data extraction:** Two investigators independently assessed methodologic quality using the Physiotherapy Evidence Database (PEDro) Scale. Study characteristics including participant age, sex and physical activity status, foam rolling protocol and pre- and post-intervention mean outcome measures were extracted.

**Data synthesis:** A total of 32 studies (mean PEDro = 5.56) were included in the qualitative analysis, which was themed by range of motion, laboratory-based measures, field-based measures and recovery. Thirteen range of motion studies providing 18 datasets were included in the meta-analysis. A large effect ( $d = 0.76$ , 95% CI 0.55–0.98) was observed, with foam rolling increasing range of motion in all studies in the analysis.

**Conclusions:** Foam rolling increases range of motion, appears to be useful for recovery from exercise induced muscle damage, and there appear to be no detrimental effect of foam rolling on other athletic performance measures. However, except range of motion, it cannot be concluded that foam rolling is directly beneficial to athletic performance. Foam rolling does not appear to cause harm and seems to elicit equivalent effects in males and females.

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## 1. Introduction

Fascia is described as a key component of connective tissue (Threlkeld, 1992), where myofascial wraps and encases muscles, forming connective chains running from the cranium to the toes (Myers, 2013). It has been proposed that when negatively altered through modified muscle function, i.e. from overstress, injury, imbalance or fatigue (MacDonald et al., 2013a), fascia can stiffen as a result of the development of fascial crosslinks and can consequently generate uneconomical movement patterns (Bushell et al., 2015; Kaltenborn, 2006). The change in fascia quality is suggested

to negatively influence sporting performance (MacDonald et al., 2013b).

Myofascial release is a therapeutic intervention for releasing soft tissue from areas of abnormally tight fascia (Miller and Rockey, 2006; Prentice, 2003). Myofascial release treatment involves targeted, directional low loading mechanical forces aimed at restoring optimal tissue length and improving function (Ajimsha et al., 2015). High or sustained pressure applied via myofascial release is suggested to cause golgi tendon organs to detect sensations of altered tension in the musculature, eliciting relaxation of muscle fibres (Miller and Rockey, 2006). A popular approach to self-myofascial release (SMFR) has emerged in the form of foam rolling, a technique whereby individuals use their own body mass to exert compressive rolling forces along targeted musculature, following the orientation of the specific muscle being mobilized (Pearcey

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et al., 2015).

The use of foam rollers in athletic and recreationally active populations has seen notable increases in recent years due to myofascial release being associated with performance enhancements (Barnes, 1997; MacDonald et al., 2013b; Renan-Ordine et al., 2011). Advocates of foam rolling contend that it can assist in correcting muscular imbalances, improve neuromuscular efficiency, improve range of motion and improve markers of strength and power (Curran et al., 2008; Peacock et al., 2014, 2015; Skarabot et al., 2015; Swann and Graner, 2002). While conflicting evidence has been reported into the efficacy of foam rolling in these areas (Healy et al., 2015; Peacock et al., 2014; Roylance et al., 2013), importantly, it is suggested that the benefits reported have occurred without negative effects on physical performance (Halperin et al., 2014; Sullivan et al., 2013).

Since 2013, there has been a proliferation of literature published that evaluates the effects of foam rolling on a variety of markers of athletic performance and has included evaluation pre- and post-exercise (Cavanaugh et al., 2017; D'Amico and Paolone, 2017; Janot et al., 2013; MacDonald et al., 2013a; Pearcey et al., 2015). As an indication of the contemporary interest in this area, three reviews have been published since 2015 (Beardsley and Skarabot, 2015; Cheatham et al., 2015; Wiewelhove et al., 2019), however these reviews have not focused solely on the application of foam rollers, have included other modalities (for example roller massage, stick, blades, tennis ball) or have included broad outcome measures beyond markers of athletic performance, for example on arterial function. To the best of our knowledge, no quantitative synthesis via meta-analysis specifically focusing on the effects of foam rolling has been conducted to date and therefore the pooled effects are unknown. Given the wide uptake of foam rolling among recreational and professional athletes, meta-analysis of this topic would strengthen the ability to specifically draw conclusions on the effectiveness of foam rolling as an intervention which will be beneficial to both users and healthcare practitioners. Therefore, the purpose of this study was to;

- 1) critically appraise the current evidence specific to foam rolling on markers of athletic performance and recovery via qualitative synthesis
- 2) establish the effect of this treatment intervention via meta-analysis
- 3) establish if harmful effects of the application of foam rolling have been published

## 2. Methods

A protocol for this study was registered with PROSPERO (Hammond et al., 2015).

### 2.1. Search strategy

MEDLINE, PubMed, EMBASE, SPORTDiscus, and Science Direct databases were searched for English language, peer reviewed sources. The search strategy for MEDLINE is presented in Table 1. In addition, Current Controlled Trials and the WHO International Clinical Trials Registry Platform for ongoing and recently completed trials were searched, as well as the table of contents of the following journals: British Journal of Sports Medicine, Medicine and Science in Sports and Exercise, Journal of Athletic Training, The Journal of Strength and Conditioning Research and Strength & Conditioning Journal. All searches were conducted from 2005 to June 14, 2018. Following the search, reference lists were reviewed, and subsequently electronic forward citation searches were

**Table 1**

MEDLINE (Ovid format) search strategy.

1	Foam roll\$.mp.
2	Self-myofascial release.mp.
3	Self-massage.mp.
4	1 or 2 or 3
5	exp Athletic performance/
6	exp Range of motion, articular/
7	Range of movement
8	Flexibility
9	exp Muscle strength/
10	exp Muscle tonus/
11	MVIC
12	Muscle adj6 power
13	Muscle adj6 activation
14	Peak torque
15	Speed
16	Acceleration
17	VO2 max
18	Maximal oxygen uptake
19	Agility
20	Reaction time
21	exp Muscle fatigue/
22	Muscle adj6 soreness
23	Muscle adj6 damage
24	exp Lactic acid/
25	exp Muscle, skeletal/
26	5 or 6 or 7 or 8 or 9 or 10 or 11 or 12 or 13 or 14 or 15 or 16 or 17 or 18 or 19 or 20 or 21 or 22 or 23 or 24 or 25
27	4 and 26

conducted in Google Scholar for all relevant articles located. Experts and colleagues working in the subject area were also asked to notify the authors on the existence of new or ongoing studies, which were also considered for inclusion.

### 2.2. Inclusion and exclusion criteria

Randomized controlled trials, clinical trials, cross-over studies and quasi-experimental studies evaluating the use of self-myofascial release via a foam roller in laboratory or field settings for athletic performance in male or female adolescents (>15 years) and adults were included in this review. Studies were included in which at least one group in the trial comprised participants treated with foam rolling before or after exercise. Foam rolling was defined as self-myofascial release involving a repetitive rolling action over a muscle group using any type of foam roll e.g. dense or rigid. Studies including single or multiple bouts of foam rolling within a single session or over more than one day were included. The authors aimed to include trials that compared the use of foam rolling versus a passive or control intervention (rest, no treatment or placebo treatment) or active interventions including, but not limited to, warm up, cool-down, stretching, massage baseline measures or exercise. It also aimed to include trials that compared different durations or dosages of foam rolling.

Studies involving injured participants and sedentary individuals and studies focusing on other myofascial modalities (static trigger point massage with an implement, therapist applied roller massage or myofascial release, and therapist or self-applied instrument assisted myofascial techniques) were excluded. Trials that did not report any of the primary outcomes were also not included in the review.

#### 2.2.1. Primary outcomes

- 1) Flexibility, range of motion

- 2) Muscle contractile properties (e.g. maximal voluntary isometric contraction (MVIC), muscle power, muscle strength/activation, peak torque)
- 3) Maximal oxygen uptake
- 4) Markers of fatigue (e.g. lactate)
- 5) Speed, acceleration, agility, reaction time
- 6) Exercise-induced muscle damage, delayed onset muscle soreness (DOMS)

#### 2.2.2. Secondary outcomes

- 1) Adverse effects of foam rolling
- 2) Differences of effects between males and females

#### 2.3. Study selection

Two review authors (BS, RM) independently selected trials for inclusion. After the removal of duplicates, the titles and abstracts of publications obtained by the search strategy were screened, and any study that was obviously outside the scope of the review was removed. The full text of any papers that potentially met the review inclusion criteria were obtained. The same two review authors then independently selected trials for inclusion in the review according to the inclusion and exclusion criteria, using a standardized form to record their choices. In the event of disagreement between the review authors, this was resolved by consensus or by third party adjudication (LH).

#### 2.4. Quality assessment

To assess for risk of bias in the included studies, two review authors (BS, RM) independently assessed risk of bias of studies meeting the inclusion criteria using the PEDro scale (<http://www.pedro.org.au/english/downloads/pedro-scale/>). To minimize bias in the interpretation of this scale, prior to assessing the included studies, the review authors assessed three unrelated studies that were not included in the current review; disparities in judgements were reviewed and discussed before any of the included studies were evaluated. Each of the included studies was graded for risk of bias by being assigned a score from 0 to 10 (criterion 1 was excluded from the score according to PEDro guidelines), and were considered to be moderate to high quality if achieving a score of  $\geq 6$  (<http://www.pedro.org.au/english/downloads/pedro-statistics/>). Any disagreements between review authors regarding the risk of bias assessment were resolved by consensus or by adjudication of the third author (LH).

#### 2.5. Data extraction

A customized form was created for data extraction (to obtain study details on methodology, eligibility criteria, interventions including detailed characteristics of the exercise protocols and the foam rolling protocol employed, comparisons, outcome measures and participant characteristics including age, sex and sporting level). Subsequently, one review author (LH) independently extracted relevant data for the remaining included papers. Data were extracted for immediately post-foam rolling, as well as further follow up times where reported. For studies involving DOMS, the typical follow-up times of up to 1, 24, 48, 72, 96 and more than 96 h post intervention were used. Primary authors were contacted to obtain or clarify any omitted data.

#### 2.6. Statistical analysis

All of the data extracted were examined by the review authors in order to determine their suitability for meta-analysis. For range of motion, 18 data sets from 13 studies that were deemed comparable were identified and these data were included in the meta-analysis. For each of these, Cohens *d* and Confidence Intervals (95% CI) were calculated to establish the effect size from pre-to immediately post-foam rolling. For all studies with the exception of one (Couture et al., 2015), an increase in score indicated a positive effect of the treatment. For Couture et al. (2015), in which an increase in score corresponded to a negative effect of treatment, the effect size was multiplied by  $-1$  to ensure all scales pointed in the same direction (Leard et al., 2007). Assessment of heterogeneity between comparable trials was evaluated with  $I^2$  statistics. Values of  $I^2$  were interpreted as follows: 0%–40% might not be important; 30%–60% may represent moderate heterogeneity; 50%–90% may represent substantial heterogeneity; and 75%–100% may represent considerable heterogeneity (Leard et al., 2007). Results of the comparable trials were pooled using a random-effects model. The choice of the model was guided by the moderate heterogeneity identified (Neyeloff et al., 2012). For all other thematic areas there were insufficient trials, or studies were too heterogenous (in both application of foam rolling and outcomes measure recorded) in order to perform meta-analysis.

### 3. Results

#### 3.1. Included studies

Two hundred and thirty-four potential articles were identified from the search (Fig. 1). Of these, 197 were excluded based on the title or abstract. Thirty-two articles met the inclusion criteria. All included studies were published over a five-year period (2013–2018), indicating the contemporary interest in this area. The mean PEDro score of these papers was 5.56 (Table 2). The papers were organised into the following themes for analysis: range of motion (Behara and Jacobson 2015; Bushell et al., 2015; Cheatham et al., 2017; Couture et al., 2015; Garcia-Gutiérrez et al., 2017; Griefahn et al., 2017; Junker & Stöggl; Kelly and Beardsley 2016; MacDonald et al., 2013b; Macgregor et al., 2018; Markovic, 2015; Mohr et al., 2014; Monterio et al., 2018; Morales-Artacho et al., 2017; Morton et al., 2015; Peacock et al., 2015; Roylance et al., 2013; Škarabot et al. (2015); Su et al., 2016; Vygotsky et al., 2015), laboratory based measures (Behara and Jacobson, 2015; Cavanaugh et al., 2017; D'Amico and Paolone, 2017; Garcia-Gutiérrez et al., 2017; Healy et al., 2015; Jones et al., 2015; Janot et al., 2013; MacDonald et al., 2013b; Macgregor et al., 2018; Monterio et al., 2017; Morales-Artacho et al., 2017; Morton et al., 2015; Su et al., 2016), field based measures (Behara and Jacobson, 2015; Healy et al., 2015; Jones et al., 2015; Peacock et al., 2014, 2015) (Table 3) and recovery (Fleckenstein et al., 2017; Kalén et al., 2017; MacDonald et al., 2013a; Pearcey et al., 2015; Romero-Moraleda et al., 2017) (Table 4). The thematic grouping of field based measures was defined as practically applied tests that have higher external validity compared to laboratory tests that tend to demonstrate higher reliability. As such, some outcomes e.g. force, power, velocity appear in both groupings but are measured differently. Of the 20 studies identified that focussed on foam rolling and range of motion, eight were subsequently excluded from the meta-analysis due to an inability to calculate an effect size for the study as raw data were unavailable (MacDonald et al., 2013b; Peacock et al., 2014, 2015; Roylance et al., 2013; Kay and Blazevich, 2012; Macgregor et al., 2018; McHugh and Cosgrave, 2010; Morales-Artacho et al., 2017), due to methodological heterogeneity

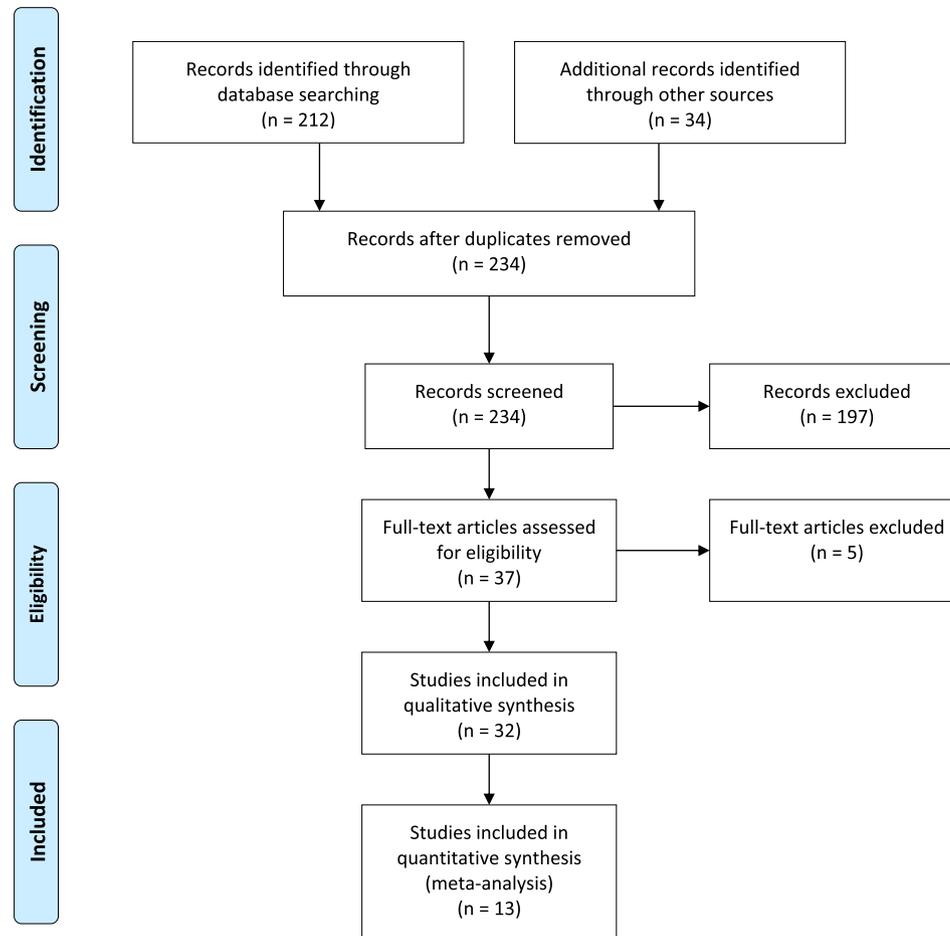


Fig. 1. PRISMA search strategy flow chart.

(Vygotzky et al., 2015) and one where the intervention was applied for recovery purposes (MacDonald et al., 2013a).

### 3.2. Range of motion studies

The largest number of studies located ( $n = 20$ , pooled mean age  $22.72 \pm 3.32$  years) investigated effects of foam rolling on range of motion. The mean PEDro score was 5.60. Thirteen studies investigated range of motion measured in degrees (Behara and Jacobson, 2015; Bushell et al., 2015; Cheatham and Baker, 2017; Couture et al., 2015; MacDonald et al., 2013b; Macgregor et al., 2018; Mohr et al., 2014; Monterio et al., 2018; Morales-Artacho et al., 2017; Morton et al., 2015; Su et al., 2016; Vygotzky et al., 2015) and nine studies investigated muscle length measured in centimeters (Garcia-Gutiérrez et al., 2017; Junker and Stöggl, 2015; Kelly and Beardsley, 2016; Peacock et al., 2014, 2015; Roylance et al., 2013; Su et al., 2016; Vygotzky et al., 2015), with all studies involving foam rolling to the lower limb or trunk. Only two of these studies included investigations of effects of range of motion taking place over more than one day (3 days [Macgregor et al., 2018] and 3 weeks [Bushell et al., 2015]).

Seven of the identified studies included a comparator modality (Garcia-Gutiérrez et al., 2017; Markovic, 2015; Mohr et al., 2014; Monterio et al., 2018; Roylance et al., 2013; Škarabot et al., 2015; Su et al., 2016) and seven included a control group (Bushell et al., 2015; Griefahn et al., 2017; Junker and Stöggl, 2015; Kelly and Beardsley, 2016; Macgregor et al., 2018; MacDonald et al., 2013b; Morales-Artacho et al., 2017).

The majority of studies identified a positive increase in RoM following the application of foam rolling compared to baseline measurements or control (Garcia-Gutiérrez et al., 2017; Griefahn et al., 2017; Junker and Stöggl, 2015; Kelly and Beardsley, 2016; MacDonald et al., 2013b; Markovic, 2015; Mohr et al., 2014; Monterio et al., 2018; Morton et al., 2015; Peacock et al., 2015; Roylance et al., 2013; Su et al., 2016). Eight of fourteen studies with a comparator modality, such as instrument assisted soft tissue therapy or roller massage, demonstrated no significant difference in RoM between groups with the application of only foam rolling (Behara and Jacobson, 2015; Bushell et al., 2015; Cheatham et al., 2017; Couture et al., 2015; Morales-Artacho et al., 2017; Roylance et al., 2013; Škarabot et al., 2015; Vygotzky et al., 2015).

Only one study (Markovic, 2015) found a greater improvement in RoM with the application of instrument assisted soft tissue therapy compared to foam rolling.

The meta-analysis included eighteen effect sizes from thirteen studies reflecting a total of 330 participants (see Fig. 2). All effect sizes were positive, indicating an improvement in range of motion following foam rolling, and the weighted mean effect size was  $d = 0.76$ , 95% CI (0.55–0.98), representing a large effect.

### 3.3. Laboratory based measures

Thirteen studies investigating a wide range of laboratory-based outcomes, including torque, velocity, power, impulse, force, tendon stiffness, maximal voluntary contraction, electromechanical delay, half relaxation time, EMG and tetanus, were identified. Twelve of

**Table 2**  
PEDro ratings for included studies.

Study	Methodological Quality Criteria											Quality Score
	1	2	3	4	5	6	7	8	9	10	11	
Behara and Jacobsen (2015)	1	1	1	1	0	0	0	1	1	1	1	7
Bushell et al. (2015)	1	0	0	1	0	0	0	1	1	1	1	5
Cavanaugh et al. (2017)	1	1	0	1	0	0	0	1	1	1	1	7
Cheatham et al. (2017)	1	1	0	1	1	0	1	1	1	1	1	9
Couture et al. (2015)	1	0	0	1	0	0	0	1	1	1	1	4
D'Amico and Paolone (2017)	1	1	0	1	1	0	0	1	1	1	1	8
Fleckenstein et al. (2017)	1	1	0	1	0	0	0	1	1	1	1	7
García-Gutiérrez et al. (2017)	1	1	0	1	0	0	0	1	1	1	1	7
Griefahn et al. (2017)	1	1	1	1	0	1	1	1	1	1	1	10
Healey et al. (2015)	1	1	0	1	0	0	0	0	1	1	1	5
Janot et al. (2013)	1	1	0	1	0	0	1	1	1	1	1	7
Jones (2015)	1	0	0	1	0	0	0	0	1	1	1	5
Junker and Stöggli (2015)	1	1	0	1	0	0	0	0	1	1	1	5
Kalén et al. (2017)	1	1	0	1	0	0	0	1	1	1	1	7
Kelly and Beardsley (2016)	1	1	0	1	0	0	0	1	1	1	1	6
MacDonald et al. (2013a)	0	1	0	1	0	0	0	0	0	1	1	4
MacDonald et al. (2013b)	1	1	0	1	0	0	0	1	1	1	1	6
Macgregor et al. (2018)	1	1	0	1	0	0	0	1	1	1	1	7
Markovic (2015)	1	1	0	1	0	0	0	0	0	1	1	4
Mohr et al. (2014)	0	1	0	1	0	0	0	0	0	1	1	4
Monteiro et al. (2017)	1	1	0	1	0	0	0	1	1	1	1	7
Monteiro et al. (2018)	1	1	0	1	0	1	1	1	1	1	1	9
Morales-Artacho et al. (2017)	1	1	0	1	0	0	0	1	1	1	1	6
Morton et al. (2015)	0	1	0	1	0	0	0	0	0	1	1	4
Peacock et al. (2014)	1	0	0	1	0	0	0	0	0	1	1	3
Peacock et al. (2015)	0	0	0	0	0	0	0	0	0	1	1	2
Pearcey et al. (2015)	0	1	0	1	0	0	0	0	0	0	1	3
Romero-Moraleda et al. (2017)	1	1	0	1	1	1	1	1	1	1	1	10
Roylance et al. (2013)	1	1	0	1	0	0	0	1	1	1	1	6
Škarabot et al. (2015)	1	1	1	1	0	0	0	0	0	1	1	5
Su et al. (2016)	1	1	0	1	0	0	0	1	1	1	1	7
Vygotksy et al. (2015)	1	0	0	1	0	0	0	1	1	1	1	5

these studies involved recreational athletes and one study was performed with elite collegiate athletes (Behara and Jacobson, 2015) (pooled mean age  $22.70 \pm 3.30$  years). Seven studies involved male participants, one involved female participants and the remaining five investigated males and females together. The mean PEDro score was 5.85. The majority of papers focused on acute responses, with two studies investigating foam rolling over more than one day (3 days [Macgregor et al., 2018] and 4 days [Monterio et al., 2017]). Twelve studies provided control or comparator groups (e.g. dynamic stretch, passive stretch, planking) for comparison. Within these studies incidences of no significant differences between groups were reported in seven studies (Behara and Jacobson, 2015; D'Amico and Paolone, 2017; García-Gutiérrez et al., 2017; Healy et al., 2015; Janot et al., 2013; Jones et al., 2015; Morton et al., 2015) with two studies (Macgregor et al., 2018; Su et al., 2016) reporting significantly improved outcomes following the use of foam rolling between groups. One study included a comparator group but made no analytical comparison within the study findings reported (Cavanaugh et al., 2017), and one study included no comparator or control (Monterio et al., 2017). No studies were identified that investigated the effect on maximal oxygen uptake.

### 3.4. Field based measures

In the five studies included for analysis of field-based measures, outcomes investigated included power, speed, velocity, strength, force and agility. All five investigations were conducted with physically or recreationally active individuals to lower limb muscles, (pooled mean age of  $22.02 \pm 1.93$  years) with only one investigation including female subjects (Healy et al., 2015). The

mean PEDro score of these studies was 4.20 which is the lowest methodological quality identified for this review. No field-based studies were identified that investigated the effect of foam rolling on field-based measures over more than one day. Four of the studies provided control or comparator groups (e.g. dynamic stretch, planking, dynamic warm up) for comparison. Three of the studies (Behara and Jacobson, 2015; Healy et al., 2015; Jones et al., 2015) reported no differences between groups, with one study (Peacock et al., 2014) reporting significant improvements in performance following foam rolling compared to a dynamic warm up.

### 3.5. Measures of recovery

Five studies were located that investigated the effect of foam rolling on recovery from exercise (See Table 4). All were conducted in young participants (pooled mean age  $23.36 \pm 2.91$  years), and the mean PEDro score of these papers was 5.6. Two studies used the same muscle damage protocols to induce DOMS, and measured performance parameters at pre-test, post 0 h, post 24 h, post 48 h, post 72 h (MacDonald et al., 2013a; Pearcey et al., 2015), whereas Romero-Moraleda et al. (2017) took measurements at baseline, immediately post- and 48 h post-damaging exercise, with the foam rolling delivered at 48 h post-exercise. Two further studies examined the effect of foam rolling on recovery, but not from eccentric, damaging exercise; Fleckenstein et al. (2017) considered the effects on neuromuscular fatigue 5 min after a fatiguing protocol, and Kalén et al. (2017) looked at lactate clearance following a simulated water rescue in lifeguards. All studies included a comparator (e.g. running, neurodynamic mobilisation) (Kalén et al., 2017; Romero-Moraleda et al., 2017) or control group (Fleckenstein et al., 2017; MacDonald et al., 2013a; Pearcey et al., 2015) with findings indicating that foam rolling attenuated the effects of muscle damage in comparison to control groups.

### 3.6. Adverse effects of foam rolling

No studies included within this review identified any adverse or harmful effects from the application of foam rolling.

## 4. Discussion

This systematic review and meta-analysis present a novel set of findings on the effects of foam rolling on a range of important athletic measures. This work represents a new synthesis of contemporary evidence for this popular tool.

### 4.1. Effect of foam rolling on range of motion

This review shows that foam rolling has a large, positive effect upon range of motion immediately following application ( $d = 0.76$ , 95% CI (0.55–0.98)), and that the positive effects of foam rolling on range of motion are elicited irrespective of the measurement method, the foam rolling dosage application or the sex of the participants. Foam rolling has been shown to consistently bring about an increase in both joint range of motion and muscular length. For an athletic population, the importance of a change in range of motion is dependent upon multiple factors such as the joint involved, individual baseline measurement and/or the specific demands of a given sporting activity. The minimum clinically important difference for hip flexion for example, has not yet been established however the values found in this analysis are in agreement with published evidence within this field (Hammer et al., 2017). The increase in range of motion observed may be attributed to a number of factors including tissue extensibility, temperature, perfusion, fatiguing factors, and realignment of tissue

**Table 3**  
Performance measures summary.

Author & Date	Sample	FR Protocol	Control/Comparator Group	Muscle Group	Performance Measure	Outcome/Significant	Narrative Grouping
Behara and Jacobson (2015)	N = 14 NCAA Division 1 Offensive Linemen 20.04 ( $\pm 1.41$ ) years old, 6 years + participation in organized sport	1 min per muscle group (bilaterally) totalling 8 min s.	Comparator group, Dynamic Stretch (same muscles) Control group, no intervention	Hamstrings Quadriceps Gluteals Gastrocnemius	Tendo Speed Analyser of Counter-Movement Jump (x3) for Power (W) and Velocity ( $m \cdot s^{-1}$ ); Baseline Bubble Inclinometer for Hip Flexion pRoM ( $^{\circ}$ ); Biodex System 4 Pro <sup>®</sup> dynamometer for Peak and Average Isometric Torque in Knee Flexion and Extension (N•m)	1. No significant differences between groups 2. Peak CMJ Power = No Significant Diff 3. Average CMJ Power = No 4. Peak CMJ Velocity = No 5. Average CMJ velocity = No 6. Peak Torque (Knee Ext) = No 7. Average Torque (Knee Ext) = No 8. Peak Torque (Knee Flex) = No 9. Average Torque (Knee Flex) = No 10. pRoM = Significant Increase (p = 0.0001)	Field, Laboratory and ROM
Bushell et al. (2015)	N = 31, physically active (min 1.5 h s p/wk), 21.35 ( $\pm 2.44$ ) years old, n = 19 males, n = 12 females	3 $\times$ 1 min (30sec rest) between lunges of sessions 1&2 and for 5 separate unsupervised sessions occurring on different days in the week between sessions 1 and 2.	Control group, no intervention	Quadriceps	Hip Extension Angle ( $^{\circ}$ ) via Dartfish software	1. No Significant diff between control and intervention groups immediately or across all 6 lunges 2. Yes – within group (intervention) – Significant increase in hip extension within session 2 (p = $\leq 0.05$ ; r = -0.11) 3. No significant diff within group) in hip extension from baseline to session 3	ROM
Cavanaugh et al. (2017)	N = 18, recreationally active, males n = 10, 25 $\pm$ 4.6, females n = 8, 21.75 $\pm$ 3.2	4 $\times$ 45 s (15 s rest)	Control group, no intervention	Quadriceps and Hamstring	EMG (mV) Perceived Pain (VAS)	1. Significant decrease in Bicep Femoris activation (P = 0.015) 2. No significant sex-based interactions 3. Significant interaction between perceived pain and muscle group rolled (P < 0.001) 4. No comparator conclusions made	Laboratory
Cheatham et al. (2017)	N = 45, n = 28 males, n = 17 females, 26 $\pm$ 6.5	1 $\times$ 2 min s	Comparator group, instruction of foam	Quadriceps (left only)	Pressure Pain Threshold (kPa) ROM ( $^{\circ}$ )	1. Significant increase in PPT in all conditions	ROM

			rolling No control group			2. Significant increase in ROM 3. No significant dif between ROM and PPT.	
Couture et al. (2015)	N = 33, recreationally active, 20 ( $\pm 1.5$ ) years old, n = 19 males, n = 14 females	4 $\times$ 30sec "long sets" (30sec rest) and 2 $\times$ 30sec "short sets" (30sec rest)	Comparator group, different application time of foam rolling	Hamstrings	Passive knee extension test ( $^{\circ}$ ) via inclinometer	1. No significant difs across all conditions or between genders 2. No comparator conclusions made	ROM
D'Amico and Paolone (2017)	N = 16 trained males, 20.5 $\pm$ 3.3	1 $\times$ 30 s per muscle group	Control group, 30min passive rest	Glut, Hip flexors, Quads, ITBS, Adductors, Gastrocnemius	Run time (mins) Stride length and hip extension VCO <sub>2</sub> Blood Lactate (mmol)	1. No significant effect of FR on any variables 2. No significant differences between groups for run time	Laboratory
Garcia-Gutiérrez et al. (2017)	N = 38, n = 19 males, 21.8 $\pm$ 2.7, n = females, 19.5 $\pm$ 7.2, recreationally active	3 $\times$ 20sec	Control group, no foam roll or vibration	Tricep Surae	ROM (cm) MVIC (kg)	1. Significant increase in ROM in FR and FR + vibration groups 2. No significant difference in MVIC between groups	ROM and Laboratory
Griefahn et al. (2017)	N = 38, n = 13 males, n = 25 females 23.34 $\pm$ 2.58, active for 3 h s per week	3 $\times$ 30sec per muscle	Control group, no intervention	Glut Max, Erector Spinae, Latissimus Dorsi	ROM (MMST) (cm) Fascial Mobility (mm)	1. No significant different in lumbar flexion 2. Significant increase in fascial mobility (P < 0.001) 3. No significant difference in mechanosensitivity 4. FRG (1.7915 mm) to the CG (0.0139 mm), this show also a highly significant result (p < 0.001).	ROM
Healey et al. (2015)	N = 26, healthy college, (21.56 $\pm$ 2.04 years, n = 13 men, n = 13 women), recreationally active	1 $\times$ 30sec on each muscle	Comparator group, Planking exercise	Quadriceps; Hamstrings; ITB; Gastrocnemius; Latissimus Dorsi; Rhomboids	Vertec Vertical Jump for Height (cm) and Power (W) (3xrapid jumps); Isometric Squat Force (N) (10sec) via force plate; Pro Agility -5-10-5 test (sec);	1. No significant difs in Power, Height, Force, Agility. 2. No significant difs between groups	Field, Laboratory
Janot et al. (2013)	n = 23; 20.3 $\pm$ 1.4 Healthy adults (n = 9 male, n = 14 female)	3 $\times$ 30sec	Control group, no intervention Comparator group, Static Stretching (SS)	Gluteals, Quadriceps, Hip Flexors, Hamstrings, Gastrocnemius, Adductors, ITB	Peak Power Output (PPO) (W), Percent Power Drop (PPD) (%), Max Power (MPO) (W), Av. Power (APO) via Wingate Test (W)	Whole sample analysis showed - 1. No significant difs in PPD, PPO, MPO or APO or between groups Gender split analysis showed - 1. Significant increase in Male PPO (p=<0.05) in FR & SS groups 2. Female PPD significant	Laboratory

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Table 3 (continued)

Author & Date	Sample	FR Protocol	Control/Comparator Group	Muscle Group	Performance Measure	Outcome/Significant	Narrative Grouping
						decreased (p=<0.05) 3. Male PPD significant increased (p=<0.05) 4. Absolute PPO was not significantly (p > 0.05) affected following MFR compared to the control trial in women 5. Relative PPO, absolute and relative MPO, and absolute and relative APO were not significantly (p > 0.05) altered by either treatment modality compared to the control trial in both men and women	
Jones et al. (2015)	N = 20 recreationally trained males, 24.05 (±2.02) years old	1 × 30sec per muscle (bilaterally); 40 rolls per min	Control group, rolling skateboard	Gastrocnemius; Quadriceps; Hamstrings; Gluteals	Vertical Jump Height (cm), Impulse (N*s-1), Ground Reaction, Force (N*Kg-1), Take off Velocity (m*s-1) via force plate	1. No significant diffs in all tests 2. No significant diffs between conditions	Field and Laboratory
Junker and Stöggl (2015)	N = 40, healthy males, 31.3 (±9.2) years old	3 × 30–40sec (10 reps per leg) applied bilaterally	Control group, no intervention	Hamstrings	Sit and reach test (cm)	1. Significant increase between Foam Roll and Control group (p = 0.033) 2. Significant increase within Foam Roll group (p = 0.001)	ROM
Kelly and Beardsley (2016)	N = 26, control group n = 13 5 males 8 females 24.4 ± 1.7, FR group n = 13 8 males, 5 females, 24.8 ± 2, recreationally active	3 × 30 s (10 s rest) Dominant side only	Control group, no intervention on contralateral limb	Tricep Surae	ROM (cm)	1. No significant between group effects 2. Significant within group effects of FR of both rolled and contralateral limbs (p = 0.00)	ROM
Macgregor et al. (2018)	N = 16, recreationally active males 25 years (±4.4) yrs	2 min of foam rolling on 3 consecutive days	Control group, rest	Quadriceps	Tensiomyography (mechanical properties) (mm/s), modified active kneeling lunge (°)	1. Foam rolling protected decline of MVC compared to rest 2. Statistically reduced EMG post-foam rolling compared to rest 3. Greater radial displacement of muscle belly in foam rolling condition compared to rest	ROM, Laboratory

MacDonald et al. (2013b)	N = 11 healthy university males 22.3 ( $\pm 3.8$ ) years old	2 $\times$ 1min (30sec rest), 3 –4 reps per minute	Control group, no foam rolling	Quadriceps	RFD (N*s-1), Force (N), MVC (N) via Wheatstone Bridge stain gauge (BioPac Systems); Twitch Force via DS7AH Digitimer), Tetanus, Muscle Inactivation, ½ relaxation time	<p>4. No change in ROM across time or between condition</p> <ol style="list-style-type: none"> <li>1. No Significant diff in Force, RFD or Muscle Activation between groups</li> <li>2. Significant increase in ROM post foam rolling at post 2 and 10 min (<math>p = 0.001</math>)</li> <li>3. Significant -ve correlation between quad force and knee ROM (<math>p = 0.01</math>) pre-test, no longer present post-test at 2 &amp; 10min in Foam Roll group,</li> <li>4. Significant -ve correlation remained (<math>p = 0.05</math>) for control group) at 2 &amp; 10min</li> </ol>	Laboratory and ROM
Markovic (2015)	N = 20, regional level male soccer players, 19 ( $\pm 2$ ) yrs	n = 10 2 $\times$ 1min per muscle	Comparator group, instrument assisted soft tissue therapy	Quadriceps; Hamstrings	Supine Passive Knee Flexion ( $^{\circ}$ ); Passive Straight Leg Raise ( $^{\circ}$ ) via digital inclinometer before, immediate and 24 h s	<ol style="list-style-type: none"> <li>1. Significant increase in immediate knee and hip range of motion</li> <li>2. Effects were higher for the FAT group (pre-to post-test gains in knee and hip ROM: 13.1<math>^{\circ}</math> and 15.2<math>^{\circ}</math>; or 10% and 19%) vs. FR group (pre-to post-test gains in knee and hip ROM: 6.6<math>^{\circ}</math> and 7.0<math>^{\circ}</math>, or 5% and 9%)</li> </ol>	ROM
Mohr et al. (2014)	N = 40, 22 ( $\pm 3.8$ ) yrs, healthy but with less than 90 ( $^{\circ}$ ) hamstring flexibility	n = 10, 3 $\times$ 1 min (30sec rest), 1sec inferior – 1 s superior cadence	Control group, no intervention	Hamstring	Passive Hip Flexion ( $^{\circ}$ ) via bubble inclinometer	<ol style="list-style-type: none"> <li>1. Significant increase in passive hip-flexion ROM (<math>p = 0.001</math>)</li> <li>2. Combined FR/Static Stretch had a greater change in passive hip-flexion ROM compared with the Static Stretching (<math>p = 0.04</math>), FR (<math>p = 0.006</math>), and control (<math>p = 0.001</math>)</li> <li>3. There were no significant differences between any of the other treatments (<math>P &gt; 0.09</math>)</li> </ol>	ROM
Monteiro et al. (2017)				ITB, Lpatisissimus dorsi			Laboratory (continued on next page)

Table 3 (continued)

Author & Date	Sample	FR Protocol	Control/Comparator Group	Muscle Group	Performance Measure	Outcome/Significant	Narrative Grouping
	N = 20 recreationally active, resistance trained females, 26.2 ( $\pm 6.4$ ) yrs	1 $\times$ 30 s, 1 $\times$ 60 s, 1 $\times$ 90 s, 1 $\times$ 120 s (total 300 s) on each side over 4 consecutive days	No control group or comparator modality		Functional Movement Screen Overhead deep squat	1. FMS overhead deep squat improved significantly after 90 and 120 s of ITB foam rolling in FR only group 2. No other statistically significant differences were observed	
Monteiro et al. (2018)	N = 18 recreationally active, resistance trained males, 26.5 ( $\pm 4.2$ ) yrs	1 $\times$ 120 s set	Comparator group, roller massage	Quadriceps	Passive hip flexion and extension ( $^{\circ}$ )	1. Hip flexion statistically increased immediately after foam rolling and maintained the increase at 10, 20 and 30 min post-foam rolling 2. Hip extension statistically increased immediately after foam rolling and maintained the increase at 10 and 20 min post-foam rolling 3. FR was statistically superior in improving hip extension ROM as compared to RM immediately post intervention relative to the baseline values 4. Greater statistical increases in hip flexion ROM were also achieved in the FR condition as opposed to RM immediately post intervention and at 10- and 30-min post intervention	ROM
Morales-Artacho et al. (2017)	N = 14 physically active males, 26.6 ( $\pm 4.5$ ) yrs	1-min bilateral set followed by 10 $\times$ 1 min sets on alternating leg, with 30 s rest between sets (total time 15 min)	Control group, rest Comparator group, Cycling Mixed (Cycling + FR)	Hamstrings	Passive knee extension on isokinetic dynamometer at 2 $^{\circ}$ /seconds, passive torque (N•m), muscle stiffness (Pa)	1. No significant difference in range of motion after foam rolling 2. Cycling (5min) and Mixed (5 & 30min) increased ROM 3. No significant changes in torque	ROM, Laboratory

Morton et al. (2015)	N = 19, male, 22 (±3) yrs, recreationally active	4 reps x 1min (15–30 s rest between reps)	Comparator group, Static stretch	Hamstrings	Passive Knee Extension (°) via Biodex dynamometer, Rate of Torque Development (N•m), Peak Passive Torque (N•m), Muscle Stiffness (Pa), MVIC (Nm)	<p>observed in foam rolling condition</p> <ol style="list-style-type: none"> <li>Reduction in stiffness at 5min post FR, Cycling and Mixed maintained up to 30 min</li> <li>Significant reduction in torque at 5min in Cycling and Mixed compared to no changed in control and FR groups</li> </ol>	ROM, Laboratory
Peacock et al. (2014)	N = 11 physically active males 22.18 (±2.18) yrs	1 × 5 rolls per 30sec	Comparator group, dynamic warm up (DWU)	Erector spinae; Multifidus; Gluts; Hamstrings; Calf; Quads; Hip flexors; Pectoralis major & minor	V Jump - vertec (cm) Standing Long Jump (cm) Agility - (18.3 pro agility test) (sec) 1RM bench press (kg) 37 m sprint (sec)	<ol style="list-style-type: none"> <li>Significant increase in V. Jump (p = 0.012) compared to DWU</li> <li>Significant increase in Standing Long Jump (p = 0.007) compared to DWU</li> <li>Significant increase in Agility (p = 0.001) compared to DWU</li> <li>Significant difference in 37 m Sprint time (p = 0.002) compared to DWU</li> <li>Significant increase in 1RM (p = 0.024) compared to DWU</li> </ol>	Field
Peacock et al. (2015)	N = 16 athletically trained males, 21.9 (±2.0) yrs	Med-Lat 1 × 5 rolls per 30sec Ant-post 5 rolls per 30sec	No control group	M-L group = Erector Spinae; Gluts; Hamstring; Pec Major; Gastroc; Quads	V. Jump vertec (cm) Broad Jump (cm) Agility 5-10-5 test (sec) Bench Press NFL rep out	<ol style="list-style-type: none"> <li>Significant increase in ROM in Anteroposterior group (p = 0.003)</li> </ol>	Field and ROM

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Table 3 (continued)

Author & Date	Sample	FR Protocol	Control/Comparator Group	Muscle Group	Performance Measure	Outcome/Significant	Narrative Grouping
Roylance et al. (2013)	N = 27 healthy university students, n = 14 male, n = 13 female, 22.7 ( $\pm 2.4$ ) yrs with sit and reach score <34.3 cm	10min total	Comparator group, static stretch and postural alignment exercise.	A-P group = Lats; Ext Obliques; Piriformis, Gluts; Peroneals, Adductors, ITB Erector spinae, Upper back, Gluteals Piriformis, Hamstrings, Gastrocnemius and Soleus	test Sit and Reach (cm)  Sit and Reach (cm)	2. No significant differences in all other tests  1. No change in acute ROM following FR in isolation 2. Significant increase in ROM with FR in combination with postural alignment exercise or static stretching 3. No comparator conclusions made	ROM
Škarabot et al. (2015)	N = 11, adolescent, trained swimmers (n = 6 males, n = 5 females), 15.3 ( $\pm 1.0$ ) yrs	3 sets x 30 s (15-sec rest between sets)	Comparator group, static stretching	Gastrocnemius/Soleus	Weight bearing lunge (cm)	1. No increase ROM by FR alone 2. Significant increase in ROM when FR + SS combined ( $p < 0.05$ ) 3. Post hoc testing revealed increases in passive ankle dorsiflexion ROM between baseline and post-intervention by 6.2% for SS ( $p < 0.05$ ) and 9.1% for FR + SS ( $p < 0.05$ ) but not for FR	ROM
Su et al. (2016)	N = 30, n = 15 male 21.47 $\pm$ 1.77, n-15 females 21.40 $\pm$ 1.18	3 $\times$ 30sec (per leg)	Comparator group, Static Stretch (SS) and Dynamic Stretch (DS)	Quadriceps and Hamstrings	Knee Flexion ( $^{\circ}$ ) Peak Torque (Nm) Sit and reach (cm) Modified Thomas test	1. Significant increase in modified Thomas test in all conditions ( $p < 0.017$ ) with significant greater increase with FR 2. Significant increase in knee extension peak torque ( $P = 0.003$ ) compared to SS 4. Significant increase in sit and reach ( $P < 0.001$ ) & compared to SS & DS 5. Significant increase in Knee Flexion ( $P < 0.017$ )	ROM and Laboratory
Vygotsky et al. (2015)	N = 23, healthy students (n = 7 male, n = 16 female) 22 ( $\pm 3.3$ ) yrs	2 sets x 60sec (30sec rest between sets)	No control group or comparator modality.	Quadriceps	Modified Thomas Test ( $^{\circ}$ )	1. No significant increase in ROM 2. No comparator conclusions made	ROM

**Table 4**  
Post-exercise recovery summary.

Author & Date	Sample	EIMD Protocol	FR dosage/Protocol	Control/comparator Group	Muscle Group	Markers of DOMS/EIMD	Findings
Fleckenstein et al. (2017)	N = 45, 23 males, 24.8 ± 2.3, 22 females 25 ± 2	Functional agility short term fatigue protocol, involving 3 maximum counter movement jumps, 20 s step up on a 40 cm box at 220 beats per minute, 3 × body weight squats, the pro-agility shuttle; repeated until participants can no longer maintain 90% maximum jump height. The minimum number of rounds to be performed was 3.	5 min rolling, each muscle treated bilaterally for 30 s each Preventative (prior to fatiguing) or regenerative (after fatiguing) Baseline, immediately after fatiguing exercise, 5 min post fatigue	No treatment control group	Quadriceps, Hamstrings, Adductors, ITB, Gastrocnemius	1. Maximum voluntary force strength index 2. Reactive strength index 3. Pain (VAS)	No significant differences between groups over time
Kalén et al. (2017)	N = 12, 24 ± 4.9, Surf Lifeguards	Running 10 m to water, swim 100 m with fins, gaining control of casualty, toeing casualty to shore, extracting casualty	1min per leg per muscle. Total rolling 20 min	No treatment control group Comparator group, (25 min sitting) or running (4 min walking, 16 min running, 5 min walking)	Quadriceps, ITB, Hamstring, Adductors and Gluteals	1. Blood Lactate 2. RPE	1. Post recovery lactate levels were significantly lower for foam rolling and running groups compared to passive recovery 2. No significant differences for lactate or RPE between groups
MacDonald et al. (2013a)	n = 20 Physically active, resistance trained (3 × per week or more) Foam roll: age 25.1 ± 3.6 yr; control: age 24.0 ± 2.8 yr Male	10 × 10 repetitions of back squat at 60% of 1 repetition maximum, with 2 min rest between each set	five exercises on both the right and left legs for two 60-s bouts each	No treatment control group	Anterior, Lateral, Posterior, and Medial aspect of the thigh, along with the gluteal muscles	1. Thigh girth 2. Muscle soreness 3. Muscle activation 4. MVC force 5. Vertical jump 6. Twitch force 7. Electromechanical delay 8. Rate of force development 9. Half relaxation time 10. Quadriceps passive ROM 11. Hamstrings passive ROM 12. Hamstrings dynamic ROM At pre-test, post 0 h, post 24 h, post 48 h, post 72 h	1. TF – Foam Rolling reduced TF with moderate to large size effect 2. RFD – Foam Rolling reduced RFD with large effect size at 72hr but no substantial between group differences 3. Potentiated Twitch Force (PTF) – between group differences at 48 and 72hr with foam rolling reducing PTF with large and moderate size effects 4. MVC – no between group differences 5. Voluntary Activation (VA) – between group differences at post 24,48 and 72 h with foam rolling increasing VA (moderate to large size effect) 6. ½ relaxation time – no between group differences 7. Passive Quad ROM showed increase in ROM with moderated effect size between groups at 48 and 72 h 8. Passive Hamstring ROM – Foam rolling showed increase in ROM with moderate effect size at 72 h s

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Table 4 (continued)

Author & Date	Sample	EIMD Protocol	FR dosage/Protocol	Control/comparator Group	Muscle Group	Markers of DOMS/EIMD	Findings
Pearcey et al. (2015)	n = 8 Recreationally resistance trained males age = 22.1 ± 2.5 years, height = 177.0 ± 7.5 cm, mass = 88.4 ± 11.4 kg	10 × 10 repetitions of back squat at 60% of 1 repetition maximum, with 2 min rest between each set	45 s bout followed by 15 s rest, to a total of 20 min including rest times. Performed directly after test measures, 24 h post, and 48 h post.	No treatment control group	Quadriceps, Adductors, Hamstrings, Iliotibial (IT) band, and Gluteal muscles	<ol style="list-style-type: none"> <li>1. Pressure-pain threshold of the quadriceps</li> <li>1. Sprint speed (30-m sprint time)</li> <li>2. Power (broad-jump distance)</li> <li>3. Change-of-direction speed (T-test)</li> <li>4. Dynamic strength-endurance (maximal back 15-squat repetitions at 70% of 1RM).</li> </ol> At pre-test, post 0 h, post 24 h, post 48 h, post 72 h	<ol style="list-style-type: none"> <li>9. Dynamic Hamstring ROM showed increase in ROM with moderated effect size at 24 h s</li> <li>10. Moderate size effect in reducing DOMS at 24 h s.</li> <li>11. Large size effect in reducing DOMS at 48 h s and 72 h s.</li> <li>1. Moderate effect on Sprint time at 24 h s and 72 h s</li> <li>2. Small effect on broad jump at 24 h s but large effect at 72 h s</li> <li>3. Agility unlikely to be affected by foam rolling by an amount greater than the smallest worthwhile change post exercise</li> <li>4. Moderate effect on dynamic strength-endurance at 48 h s post-exercise. Unlikely to have any meaningful effect at 24 h s or 72 h s.</li> <li>5. Moderate effect on the decline in pressure pain threshold at 24 h s and a large effect at 48 h s. Unlikely to have any meaningful effect at 72 h s.</li> </ol>
Romero-Moraleda et al. (2017)	N = 32, 21 males, 11 females, age 22.2 ± 2.2 years	100 drop jumps (5 × 20 with 2 min rest) from a 0.5 m high box	1 session of 5 × 1 min sets with 30 s rest to the quadriceps; outcome measurements immediately taken at baseline, after muscle damage and post foam rolling (over a 48-h period)	Comparator group, Neuro-muscular treatment (femoral neurodynamic mobilization)	Quadriceps	<ol style="list-style-type: none"> <li>1. Change in numeric pain rating scale</li> <li>2. Surface EMG</li> <li>3. Strength (MVIC)</li> </ol>	<ol style="list-style-type: none"> <li>1. Significant reduction in pain post foam rolling, with no significant differences between groups</li> <li>2. Strength: After treatment, only the FR group had a statistically significant improvement (p &lt; 0.01) in strength compared to pre-treatment.</li> <li>3. MVIC: vastus medialis and vastus lateralis improved significantly in both groups (p &lt; 0.01); while the rectus femoris only significantly improved in the FR group (p &lt; 0.01) compared to pre-treatment.</li> <li>4. Maximal peak activation: no significant differences between the groups</li> </ol>

## Range of Motion

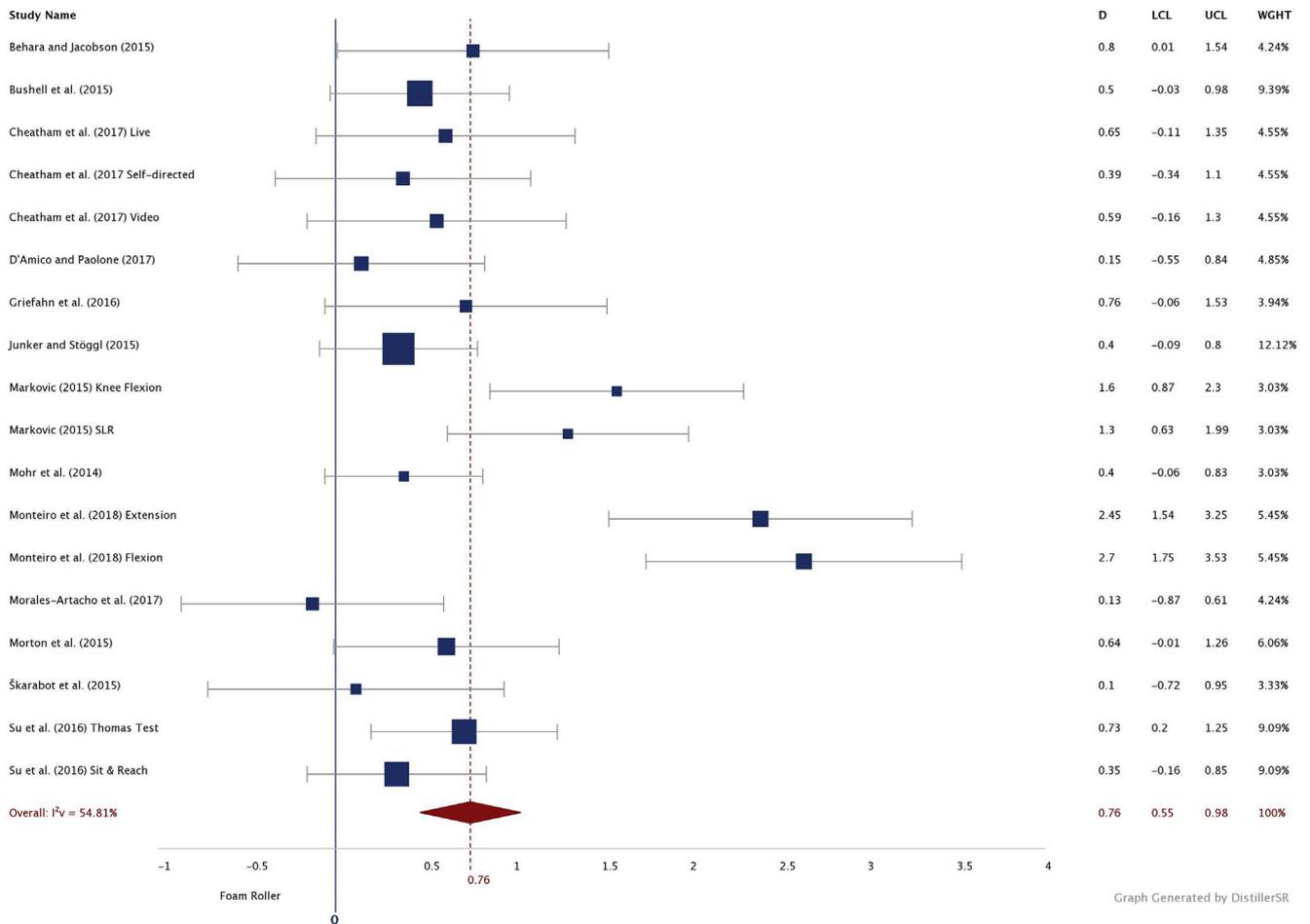


Fig. 2. Forest plot to show the meta-analysis of foam rolling on range of motion.

fibres (Madding et al., 1987; McHugh and Cosgrave, 2010; Gajdosik, 2001; Wepple and Magnusson, 2010). However, while the acute effects are evident, the chronic effects are not, and it cannot be concluded that foam rolling has a positive effect on range of motion or flexibility over time. It should also be noted that a wide range of methods were used to assess range of motion, and while these are well established (e.g. goniometry, inclinometry, isokinetic dynamometry, sit and reach test amongst other) and have generally shown good to excellent levels of reliability (Charlton et al., 2015; Drouin et al., 2004; Kolber and Hanney, 2012; Konor et al., 2012), measurement error could contribute to these positive findings.

#### 4.2. Effect of foam rolling on laboratory-based measures

Findings are equivocal with regards the effects of foam rolling on laboratory-based measures. Seven investigations found no significant improvements (Behara and Jacobson, 2015; D'Amico and Paolone, 2017; Garciz-Gutiérrez et al., 2017; Healy et al., 2015; Jones et al., 2015; Morales-Artacho et al., 2017; MacDonald et al., 2013b), and seven studies showing significant positive effects (peak power output and percentage power drop [Janot et al., 2013], passive peak torque [Su et al., 2016], rate of torque development, maximal voluntary contraction and tendon stiffness [Morton et al., 2015], protecting the decline in MVIC [Macgregor et al., 2018], reduced EMG [Cavanaugh et al., 2017], improved FMS score

[Monterio et al., 2017], and reduced muscle stiffness and increased knee extension peak torque [Morales-Artacho et al., 2017]). However, inconsistencies are apparent in the application of the foam rolling between studies, with protocols ranging from a single 30 s bout per muscle through to ten sets of 60 s, making direct comparison of studies challenging. Nevertheless, findings suggest that multiple sets of application may be required to elicit an effect, as no beneficial response from a single set application was consistently reported (Behara and Jacobson, 2015; D'Amico and Paolone, 2017; Healy et al., 2015; Jones et al., 2015). This suggests that a dose-response relationship may be present. There were also no differences in responses found between male and female participants. To explain the increases in performance measures, it has been proposed that myofascial release may result in increases in alpha-motor neuron activity and output, while subjects who undertook foam rolling are also able to maintain muscle activity due to less neural inhibition as a result of healthier connective tissue permitting better communication from afferent receptors in the connective tissue (Janot et al., 2013; MacDonald et al., 2013a).

#### 4.3. Effect of foam rolling on field-based measures

Collectively the evidence suggests that there is no detrimental effect of up to 120 s of pre-exercise foam rolling on subsequent field-based measures. Four studies (Behara and Jacobson, 2015;

Healy et al., 2015; Jones et al., 2015; Peacock et al., 2015) indicated that lower limb foam rolling had no effect on power, speed and agility, and Peacock et al. (2014) reported positive responses in these aspects of athletic measures following foam rolling. These findings show similarities with the literature on static stretching, for example, Kay and Blazevich (2012) proposed that short durations of stretching (<60 s) can be performed pre-exercise without compromising maximal muscle measures. Further to this, the results from foam rolling studies reflect positively against reports that suggest static stretching to single muscles over 100 s (2 sets x 50 s) may be detrimental to power-based activities e.g. counter movement jump (Cornwell et al., 2001). However, no investigation included in this analysis has conducted foam rolling dosage greater than 120 s. The low to moderate quality rating of these studies indicate that the findings of these studies should be interpreted with caution. It has been proposed that the variability in effectiveness of foam rolling on field-based performance measures may lie in the complexity of the test itself (Pearcey et al., 2015); minimal changes were reported for multidirectional tests (e.g. T-test), which are associated with greater degrees of motor control, coordination and multiple muscle interactions, in comparison to the more notable changes on unidirectional tests e.g. sprint test. As noted in relation to laboratory-based measures, there is inconsistency on the dosage of foam rolling applied making direct comparisons between studies difficult.

#### 4.4. Effect of foam rolling on recovery

All studies identified appeared to show positive effects of foam rolling in the context of post-exercise recovery; for exercise-induced muscle damage/DOMS, studies support the use of a daily bout of foam rolling to lower limb muscles up to 72 h following damaging exercise, compared to no intervention at all. Foam rolling attenuated the effects of muscle damage on muscle soreness/pain threshold, range of motion and performance-based measures of power and speed. However, there were no beneficial effects found for swelling, and evoked contractile properties. In their paper, MacDonald et al. (2013a) considered the possible mechanisms for the observed beneficial effects of foam rolling and suggest that foam rolling appears to have a beneficial effect on the connective tissues, most probably at the myotendinous junction, rather than being beneficial to muscle recovery; this is suggested on the basis that there was reduced muscle soreness while also having greater decrements to evoked contractile properties. They propose that the decrease in pain may have resulted in less neural inhibition. Collectively, this appears to make foam rolling helpful for dynamic movements. Foam rolling was also found to be beneficial compared to passive recovery for lactate clearance (Kalén et al., 2017) and demonstrated a non-significant trend for attenuating the effects of neuromuscular fatigue, measured by perceived exhaustion, muscle force and reactive strength index (Romero-Moraleda et al., 2017). In the wider literature of studies of DOMS, common methods to attenuate the symptoms include nutritional and pharmacological strategies, electrical, manual and cryotherapies, and exercise (Howatson and Van Someren, 2008). No study has compared foam rolling to these commonly used approaches to reduce the impact of DOMS, therefore it is not possible to identify whether foam rolling is any more effective than alternative, commonly adopted modalities. More recently published studies considering foam rolling and post-exercise recovery (Kalén et al., 2017; Roylance et al., 2013) have included comparators other than control (running and neurological mobilisation respectively), which performed as effectively as foam rolling in attenuating the effects of the exercise protocols.

#### 4.5. Limitations of the literature identified and generalizability of the results

The methodological quality of the studies performed in this area remain varied but has improved over time, with 18 of the 32 studies included in this review being considered as moderate to high quality, scoring 6 or greater on PEDro quality assessment (Behara and Jacobson, 2015; Cavanaugh et al., 2017; Cheatham et al., 2017; D'Amico and Paolone, 2017; Fleckenstein et al., 2017; Garcia-Gutiérrez et al., 2017; Griefahn et al., 2017; Janot et al., 2013; Kalén et al., 2017; Kelly and Beardsley, 2016; MacDonald et al., 2013b; Macgregor et al., 2018; Monterio et al., 2017; Monterio et al., 2018; Morales-Artacho et al., 2017; Romero-Moraleda et al., 2017; Roylance et al., 2013; Su et al., 2016). Encouragingly, the more recently published literature appears to be of higher methodological quality, however, the findings reported in this review should be interpreted in light of the risk of bias associated with the studies included. More studies are needed with stronger methodological rigour in this area of inquiry.

More specific methodological concerns with the studies in this review include that some studies involved a large physical contact area and duration of foam rolling and a large battery of performance measures, which has the potential to create inter-participant differences in both the fatiguing effects of a long bout of foam rolling, and differences in elapsed time from intervention to test. It is unclear whether randomization of order of both application of foam rolling and measurement of outcome tests was undertaken in order to reduce the chance of order effects influencing the findings. Furthermore, foam rolling is, by its very nature, a self-limiting activity and it is not possible to normalize or standardize the degree of pressure exerted by the foam roller on the muscles when self-administered, as opposed to being administered mechanically (Bradbury-Squires et al., 2015; Swann and Graner, 2002). Collectively, these factors have the potential to impact on participant performance measures and therefore, study outcomes.

The studies identified through this systematic review have focused on lower limb muscles and study populations comprised mainly of college-aged participants. It is unknown whether the same effects of foam rolling found within this review are present in older or pediatric populations, or following foam rolling to the upper limb muscles. The question of whether foam rolling has benefits to endurance-based athletes also remains unanswered. The majority of studies have identified the acute effects of foam rolling, but whether a dose-response relationship exists is unclear. The studies that have explored the effects of foam rolling have looked primarily at the presence of effects but have not considered in detail why these effects have been brought about.

#### 4.6. Limitations of this review

This is one of the first studies to attempt a meta-analysis of data from foam rolling literature, however conducting the meta-analysis was challenging. It was only possible to calculate effect sizes from pre- to post-intervention, which does not account for control or comparator, which would be usual for meta-analysis. Additionally, some papers qualified to be included in the meta-analysis, but the data could not be accessed, and therefore they were excluded from the quantitative synthesis.

This review, while narrower than previous reviews conducted on foam rolling, is still broad in its scope and attempts to compare a wide range of parameters that have been investigated in a range of ways. This variation within the published literature was also present within the different domains of this analysis, as evidenced within the range of motion meta-analysis which demonstrated moderate heterogeneity. Many studies judged as having low

methodological quality were included, which has the potential to introduce bias into the conclusions reported here.

## 5. Conclusion

There is a clear beneficial acute effect of foam rolling on range of motion, however longer-term effects remain unknown. There appears to be no detrimental effects of foam rolling on other athletic performance measures, but it cannot be concluded that foam rolling is directly beneficial to athletic performance markers including MVIC, muscle power, muscle strength/activation, peak torque, maximal oxygen uptake, speed, acceleration, agility or reaction time. Foam rolling appears useful for recovery from activity, but it is not possible to state whether it is any more or less effective than other commonly used modalities. Foam rolling does not appear to be harmful to an athlete through its application and while there are fewer studies that have included female participants, foam rolling seems to elicit equivalent effects in males and females. It is noteworthy that there has been a proliferation of research in this area since 2013, and this review reflects the infancy of the major research in this field. In order to develop the evidence base in this field, future research should be directed towards the following areas:

- 1) developing a better understanding of whether there is an optimal dosage or dose-response relationship
- 2) investigating the effects of long-term use of foam rolling to determine if any chronic effects exist
- 3) comparing the effects of foam rolling on DOMS with other commonly accepted approaches to recovery from damaging exercise, in order to better inform that body of evidence
- 4) conducting work into a more diverse population beyond young, active males, and considering its application for endurance-based athletes
- 5) developing a better understanding of the mechanisms by which foam rolling has its effect

## Clinical relevance

- In practical terms, these studies have demonstrated that it is neither harmful nor detrimental to performance for male or female athletes to perform foam rolling before or after activity.
- For athletes seeking an acute increase in muscle flexibility or joint range of motion, foam rolling is a useful tool to include as part of a warm up or pre-exercise activity.
- Coupled with the positive effects on muscle and tendon stiffness, this may be of particular use or importance for athletes involved in ballistic sports for which the stretch-shortening cycle is important (Morales-Artacho et al., 2017).
- Foam rolling is beneficial for reducing some of the common symptoms associated with exercise induced muscle damage.
- Given its effectiveness, ease of application and relative comfort (compared to cold water immersion for example) and relatively low cost, it may be preferential to athletes over other recovery modalities that are available.

## Declaration of competing interest

I can confirm there are no conflict of interests aligned with this investigation.

## References

Ajimsha, M.S., Al-Mudahka, N.R., Al-Madzhah, J.A., 2015. Effectiveness of myofascial

- release: systematic review of randomized controlled trials. *J. Bodyw. Mov. Ther.* 19, 102–112.
- Behara, B., Jacobson, B., 2015. The acute effects of deep tissue foam rolling and dynamic stretching on muscular strength, power and flexibility in division I linemen. *J. Strength Condit Res.* 31 (4), 888–892.
- Barnes, M.F., 1997. The basic science of myofascial release: morphological change in connective tissue. *J. Bodyw. Mov. Ther.* 1 (4), 231–238.
- Beardsley, C., Škarabot, J., 2015. Effects of self-myofascial release: a systematic review. *J. Bodyw. Mov. Ther.* 19 (4), 747–758.
- Bradbury-Squires, D.J., Nofall, 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 the lunge. *J. Athl. Train.* 50, 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 Condit Res.* 30 (9), 2397–2403.
- Cavanaugh, M., Aboodarda, S., Hodgson, D., Behm, D., 2017. Foam rolling of quadriceps decreases biceps femoris activation. *J. Strength Condit Res.* 31 (8), 2238–2245.
- Charlton, P.C., Mentiplay, B.F., Pua, Y., Clark, R.A., 2015. Reliability of concurrent validity of a smartphone, bubble inclinometer and motion analysis system for measurement of hip joint range of motion. *J. Sci. Med. Sport* 18, 262–267.
- Cheatham, S.W., Baker, R., 2017. Differences in pressure pain threshold among men and women after foam rolling. *J. Bodyw. Mov. Ther.* 21, 978–982.
- 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. Sports 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 roller or roller massage on joint range of motion, muscle recovery and performance: a systematic review. *Int. J. Sports Phys. Ther.* 10 (6), 827–838.
- Cornwell, A., Nelson, A.G., Heise, G.H., Sidaway, B., 2001. Acute effects of passive muscle stretching on vertical jump performance. *J. Hum. Mov. Stud.* 40, 307–324.
- Couture, G., Karliik, 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, L.J., Fiore, R.D., Crisco, J.J., 2008. A comparison of pressure exerted on soft tissue by 2 myofascial rollers. *J. Sport Rehabil.* 17, 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.
- Drouin, J.M., Valovich, T.C., Shultz, S.J., Gansnedder, B.M., Perrin, D.H., 2004. Reliability and validity of the Biodes system 3 pro isokinetic dynamometer velocity, torque and position measurements. *Eur. J. Appl. Physiol.* 91 (1), 22–29.
- Fleckenstein, J., Wilke, J., Vogt, L., Banzer, W., 2017. Preventive and regenerative foam rolling and equally effective in reducing fatigue-related impairments of muscle function following exercise. *J. Sports Sci. Med.* 16, 474–479.
- Gajdosik, R., 2001. Passive extensibility of skeletal muscle: review of the literature with clinical implications. *Clin. BioMech.* 16, 87–101.
- Garcia-Gutiérrez, M.T., Guillén-Rogel, P., Cochrane, D.J., Marin, P.J., 2017. Cross transfer acute effects of foam rolling with vibration on ankle dorsiflexion range of motion. *J. Musculoskelet. Neuronal Interact.* 18 (2), 262–267.
- 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, 186–193.
- Hammond, L., Skinner, B., Moss, R., 2015. A systematic review and meta-analysis on the effects of foam rolling on athletic performance. PROSPERO International prospective register of systematic reviews. [http://www.crd.york.ac.uk/PROSPERO/display\\_record.php?ID=CRD42015032520](http://www.crd.york.ac.uk/PROSPERO/display_record.php?ID=CRD42015032520).
- Hammer, A., Hammer, R., Lomond, K., O'Connor, P., 2017. Acute changes of hip joint range of motion using selected clinical stretching procedures: a randomized crossover study. *Muscoskel. Sci. Pract.* 32, 70–77.
- Healy, K.C., Hatfield, D.L., Blanpied, P., Dorfman, L.R., Riebe, D., Hatfield, D.L., 2015. The effects of myofascial release with foam rolling on performance. *J. Strength Condit Res.* 28, 61–68.
- Halperin, I., Aboodarda, S.J., Button, D.C., Anderson, L.L., Behm, D.G., 2014. Roller massage improves range of motion of plantar flexor muscles without subsequent decreases in force parameters. *Int. J. Sports Phys. Ther.* 9, 92–102.
- Howatson, G., Van Someren, K., 2008. The prevention and treatment of exercise-induced muscle damage. *Sports Med.* 38 (6), 483–503.
- Jones, A., Brown, L.E., Coburn, J.W., Noffal, G.J., 2015. Effects of foam rolling on vertical jump performance. *Int. J. Kinesiol. Sports Sci.* 3 (3), 38–42.
- Janot, J.M., Malin, B., Cook, R., Hagenbucher, J., Draeger, A., Jordan, M., Van Guilder, G., 2013. Effects of self-myofascial release and static stretching on anaerobic power. *J. Fit. Res.* 2, 41–54.
- Junker, D., Stöggel, T., 2015. The foam roll as a tool to improve hamstring flexibility. *J. Strength Condit Res.* 29 (12), 3480–3485.
- Kalén, A., Pérez-Ferreirós, A., Barcala-Furelos, R., Fernández-Méndez, M., Padrón-Cabo, A., Prieto, J., Ríos-Ave, A., Abelairas-Gómez, C., 2017. How can lifeguards recover better? A cross-over study comparing resting, running, and foam rolling. *AJEM (Am. J. Emerg. Med.)* 35, 1887–1891.
- Kaltenborn, J., 2006. The Foam Roll: a complement to any therapy. *Athl. Ther. Today J. Sports Health Care Prof.* 11, 38–39.
- Kay, A.D., Blazevich, A.J., 2012. Effect of acute static stretch on maximal muscle performance: a systematic review. *Med. Sci. Sports Exerc.* 44 (1), 154–164.

- Kelly, S., Beardsley, C., 2016. Specific and cross-over effects of foam rolling on ankle dorsiflexion range of motion. *Int. J. Sports Phys. Ther.* 11 (4), 544.
- Kolber, M.J., Hanney, W.J., 2012. The reliability and concurrent validity of shoulder mobility measurements using a digital inclinometer and goniometer: a technical report. *Int. J. Sports Phys. Ther.* 7 (3), 306–313.
- Konor, M.K., Morton, S., Echerson, J.M., Grindstaff, T.L., 2012. Reliability of three measures of ankle dorsiflexion range of motion. *Int. J. Sports Phys. Ther.* 7 (3), 279–287.
- Leard, J.S., Cirillo, M.A., Katsnelson, E., Kimiatek, D.A., Miller, T.W., Trebinčević, K., Garbalosa, J.C., 2007. Validity of two alternative systems for measuring vertical jump height. *J. Strength Condit Res.* 21 (4), 1296–1299.
- MacDonald, G.Z., Button, D.C., Drinkwater, E.J., Behm, D.G., 2013a. Foam rolling as a recovery tool after an intense bout of physical activity. *Med. Sci. Sports Exerc.* 46, 131–142.
- MacDonald, G., Penney, M., Mullaly, M., Cucnato, A., Drake, C., Behm, D.G., Button, D.C., 2013b. An acute bout of self-myofascial release increases range of motion without subsequent decrease in muscle activation or force. *J. Strength Condit Res.* 27, 812–821.
- Macgregor, L., Fairweather, M., Bennett, R., Hunter, A., 2018. The effect of foam rolling for three consecutive days on muscular efficiency and range of motion. *Sports Med.* 4 (26), 1–9.
- Madding, S., Wong, J., Hallum, A., Medeiros, J., 1987. Effect of duration of passive stretch on hip abduction range of motion. *J. Orthop. Sports Phys. Ther.* 8 (8), 409–416.
- Markovic, G., 2015. Acute effects of instrument assisted soft tissue mobilization vs. foam rolling on knee and hip range of motion in soccer players. *J. Bodyw. Mov. Ther.* 19, 690–696.
- McHugh, M.P., Cosgrave, C.H., 2010. To stretch or not to stretch: the role of stretching in injury prevention and performance. *Scand. J. Med. Sci. Sports* 20 (2), 169–181.
- Miller, J.K., Rockey, A.M., 2006. Foam roller shows No increase in the flexibility of the hamstring muscle group. *UW-L J. Undergrad. Res.* IX, 1–4.
- 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, 296–299.
- Monterio, E., Škarabot, J., Vigotsky, A., Brown, A., Gomes, T., Novaes, J., 2017. Acute effects of different self-massage volumes on the FMS overhead deep squat performance. *Int. J. Sports Phys. Ther.* 12 (1), 94–104.
- Monterio, E., Vigotsky, A., Novaes, J., Škarabot, J., 2018. Acute effects of different anterior thigh self-massage on hip range-of-motion in trained men. *Int. J. Sports 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. Sports* 27, 1959–1969.
- Morton, R.W., Oikawa, S.Y., Phillips, S.M., Devries, M.C., Mitchell, C.J., 2015. Self-myofascial release: No improvement of functional outcomes in 'tight' hamstrings. *Int. J. Sports Physiol. Perform.* 11 (5), 658–663.
- Myers, T., 2013. *Anatomy Trains: Myofascial Meridians for Manual and Movement Therapists*, second ed. Elsevier Ltd, London (UK).
- Neyeloff, J.L., Fuch, S., Moreira, L.B., 2012. Meta-analyses and Forest plots using a microsoft excel spreadsheet: step-by-step guide focusing on descriptive data analysis. *BMC Res. Notes* 5, 52.
- Peacock, C.A., Krein, D.D., Silver, T.A., Sanders, J., Von Carlowitz, K., 2014. An acute bout of self-myofascial release in the foam of foam rolling improves performance testing. *Int. J. Exerc. Sci.* 7, 202–211.
- 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 Condit Res.* 29, 2310–2315.
- Pearcey, G.E.P., Bradbury-Squires, D.J., Kawamoto, J., 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.
- Prentice, W.E., 2003. *Principles of Athletic Training: A Competency-Based Approach*, fifteenth ed. McGraw-Hill Education, Columbus (USA), pp. 85–90.
- Renan-Ordine, R., Albuquerque-Sendín, F., de Souza, D.P., Cleland, J.A., Fernández-de-Las-Peñas, C., 2011. Effectiveness of myofascial trigger point manual therapy combined with a self-stretching protocol for the management of plantar heel pain: a randomized controlled trial. *J. Orthop. Sports Phys. Ther.* 41 (2), 43–50.
- Romero-Moraleda, B., La Touche, R., Lerma-Lara, S., Ferrer-Peña, R., Paredes, V., Peinado A Muñoz-García, D., 2017. Neurodynamic mobilization and foam rolling improved delayed-onset muscle soreness in a healthy adult population: a randomized controlled clinical trial. *PeerJ* 1–18.
- Roylance, D.S., George, J.D., Hammer, A.M., Rencher, N., Gellingham, G.W., Hager, R.L., Myrer, W.J., 2013. Evaluating acute changes in joint range-of-motion using self-myofascial release, postural alignment exercises, and static stretches. *Int. J. Exerc. Sci.* 6 (4), 310–319.
- Škarabot, 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. Sports Phys. Ther.* 1, 203–212.
- Su, H., Chang, N., Wu, W., Guo, L., Chu, I., 2016. 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.M., Silvey, D.B., Button, D.C., Behm, D.G., 2013. Roller-massage application to the hamstrings increases sit-and-reach range of motion within five to ten seconds without performance impairments. *Int. J. Sports Phys. Ther.* 8, 228–236.
- Swann, E., Graner, S.J., 2002. Use of manual-therapy techniques in pain management. *Athl. Ther. Today* 7, 14–17.
- Threlkeld, A.J., 1992. The effects of manual therapy on connective tissue. *J. Strength Condit Res.* 72, 893–902.
- Vygotsky, A.D., Lehman, G.J., Contreras, B., Beardsley, C., Chung, B., Feser, E.H., 2015. Acute effects of anterior thigh foam rolling on hip angle, knee angle, and rectus femoris length in the modified Thomas test. *PeerJ* 3, 1281.
- Wepple, C., Magnusson, S., 2010. Increasing muscle extensibility: a matter of increasing length or modifying sensation? *Phys. Ther.* 90 (3), 438–449.
- Wiewelhoeve, T., Doweling, A., Schneider, C., Hottenrott, L., Myer, T., Kellmann, M., Pfeiffer, M., Ferrauti, A., 2019. A meta-analysis of the effects of foam rolling on performance and recovery. *Front. Physiol.* 10, 1–15.