



UNIVERSITY OF CAPE TOWN

DEPARTMENT OF HEALTH AND REHABILITATION SCIENCES

DIVISION OF PHYSIOTHERAPY

MSc in Exercise and Sports Physiotherapy

DISSERTATION

Does Foam Rolling have a Positive Effect on Performance and Recovery from Post Exercise Induced Muscle Damage: A Systematic Review of the Literature to Guide Practitioners on the use of Foam Rolling

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Contents

PART 0: PREAMBLE	4
Thesis Abstract.....	5
Thesis Outline	6
Acknowledgements	7
Plagiarism Declaration	8
Abbreviations and Acronyms.....	9
PART A: INTRODUCTION AND SCOPE OF THESIS.....	10
Introduction	11
Fascia.....	12
Myofascial Release (MR).....	13
Self-Myofascial Release (SMR)	14
Exercise Induced Muscle Damage (EIMD) and Delayed Onset of Muscle Soreness (DOMS)	15
Recovery	15
Performance	16
Foam Rolling	17
Purpose of Review	17
PART B: RESEARCH PROTOCOL.....	18
Abstract.....	19
Background	20
Review Question.....	22
Objectives	22
Methods.....	22
Search Strategy	22
Electronic Search	22
Search of Other Sources	23
Data Collection and Analysis.....	23
Selection Criteria.....	23
Data Extraction	25
Critical Appraisal	25
Registration.....	26
Discussion	27
Acknowledgements	27

Funding	27
Availability of Data and Materials	27
Authors' Contributions	27
Competing Interests	27
Consent	28
Ethical Consideration	28
PART C: SYSTEMATIC REVIEW MANUSCRIPT	29
ABSTRACT.....	31
INTRODUCTION.....	33
Background.....	33
Review Question.....	35
Objectives	35
METHODS.....	36
Search Strategy	36
<i>Electronic Search</i>	36
<i>Search of Other Sources</i>	36
Data Collection and Analysis.....	37
<i>Selection Criteria</i>	37
<i>Critical Appraisal</i>	37
<i>Data Extraction and Synthesis</i>	38
Registration.....	38
RESULTS	39
Selection Process	39
Data Collection and Analyses	40
<i>Quality of studies</i>	40
Performance	41
Recovery	45
<i>Exercise Induced Muscle Damage (EIMD) and Delayed Onset of Muscle Soreness (DOMS)</i>	45
<i>Flexibility</i>	46
<i>Pressure Pain Threshold (PPT)</i>	47
<i>Other</i>	48
DISCUSSION	50
Performance	50
Recovery	54

<i>Exercise Induced Muscle Damage (EIMD) and Delayed Onset of Muscle Soreness (DOMS)</i>	54
<i>Flexibility</i>	57
<i>Pressure Pain Threshold (PPT)</i>	58
<i>Other effects</i>	59
LIMITATIONS	60
RECOMMENDATIONS	61
CONCLUSION.....	62
ACKNOWLEDGMENTS.....	64
REFERENCES.....	65
FIGURES AND TABLES	74
APPENDICES	96
PART D: SUMMARY AND CONCLUSION.....	105
Summary	106
Conclusion.....	108
References	109
Appendices	120

PART 0: PREAMBLE

Thesis Abstract

Foam rolling is a form of myofascial release performed by the individual using their body weight, as opposed to the pressure being applied by the clinician. Foam rolling is currently used by athletes at all levels, from recreational to elite athletes. Foam rolling is used as a warm up to aid performance and/or recovery. This study aims to review the literature to determine if foam rolling enhances performance, positively affects recovery from exercise induced muscle damage, and whether there is a consensus on the protocol to achieve performance and recovery enhancement. Seven electronic databases, Google Scholar, Science Direct, Pubmed Central, Pubmed, ISI Web of Science, Medline and Scopus, were searched using terms related to foam rolling between January 2006 and April 2017. Published articles that included foam rolling as a recovery intervention and/or a performance enhancing tool were included in the study and assessed using the PEDro scale for methodological quality ratings.

This dissertation will consolidate and add to the knowledge on the use of foam rolling. It will highlight when foam rolling should be used and recommend a specific protocol that should be used for performance and/or recovery purposes. This may address the confusion around when foam rolling should be used and show foam rolling to be effective as a recovery tool or for enhancing performance. This may help with better management of athletes by sports personnel, and in turn improve their performance and enhance their recovery.

A total of 33 articles met the inclusion criterion and were systematically reviewed. There is evidence supporting the use of foam rolling in a warm-up consisting of dynamic stretching and an active warm-up to enhance performance; mainly through its effects on flexibility while maintaining muscle contractility. There is also evidence supporting the use of foam rolling to enhance recovery from exercise induced muscle damage and delayed onset of muscle soreness, with its main effects being the shortening of time to return to baseline performance, flexibility and pressure pain threshold. The mechanism by which foam rolling acts seems to be a neural response to pressure exerted. Sixty to ninety seconds of foam rolling may suffice to achieve the above desired effects. Further research is needed to determine the exact mechanisms of action of foam rolling, as well as the risks that may be associated with foam rolling.

Thesis Outline

A mini-dissertation is a requirement for an MSc degree in Exercise and Sports Physiotherapy. This is the first systematic review dissertation submitted for this degree. Based on the format used in other Departments of the Faculty of Health Sciences, it has been suggested that four sections are required for this dissertation – (A) Introduction and scope, (B) Research protocol, (C) Publishable version of the systematic review, and (D) Summary and conclusions. These four sections are outlined as follows:

Part A provides the introduction and scope of the dissertation. This will highlight the topics that surround foam rolling (FR). For example, Fascia, myofascial release, self-myofascial release, exercise induced muscle damage and delayed onset of muscle soreness, performance, recovery and FR.

Part B consists of the review protocol. This section provides a background to foam rolling and outlines the review's methodology. The protocol provides a background and structure for the full systematic review in Part C.

Part C is the full systematic review prepared for submission for publication in the Journal of Bodywork and Movement Therapies as per the instructions for authors (Appendix A). This section has been formatted according to the requirement of the journal, and is thus different in format to the other chapters which has been formatted as per Departmental guidelines. The structure follows that of the previous section in the description of the background as well as outlining the methodology followed. The results of the search are reviewed and discussed in detail.

Part D is the summary and conclusion. This section aims to align the conclusion of the results with the objectives of the review to answer the questions posed. A brief summary is included, highlighting key points of the review and recommendations for clinical practice as well as future research.

Acknowledgements

A big thank you to all three supervisors, specifically Sharief Hendricks who played the main role in the development of my dissertation, and who adapted to the changes that were made over the past few years. All your efforts shall forever be appreciated. To Wayne Lombard for his professional view on the content of the dissertation. To Romy for joining as my supervisor and helping with the methodology and structure of the dissertation. Theresa Burgess, your patience, encouragement and timely support has got me through the MSc.

My family and friends have had to put up with me throughout the duration of the MSc in Sports and Exercise Physiotherapy course. This must have been a difficult task. Without your patience and support, the completion of this dissertation and my MSc would not have been possible.

Thank you all for sacrificing your time to help me achieve my goals.

Plagiarism Declaration

1. I, **Hayd'n Hill (HLLHAY001)** know that plagiarism is wrong. Plagiarism is to use another's work and pretend that it is one's own.
2. I have used the **APA (American Psychological Association) style** for citation and referencing. Each contribution to, and quotation in, this Proposal from the work(s) of other people has been attributed, and has been cited and referenced.
3. This Dissertation is my own work.
4. I have not allowed, and will not allow, anyone to copy my work with the intention of passing it off as his or her own work.
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Name: **Hayd'n Hill**

Signature:

Signed by candidate

Date: 24/06/2018

Abbreviations and Acronyms

FR Foam Rolling

MR Myofascial Release

SMR Self-Myofascial Release

EIMD Exercise Induced Muscle Damage

DOMS Delayed Onset of Muscle Soreness

ROM Range of Motion

SS Static Stretching

DS Dynamic Stretching

PPT Pressure Pain Threshold

SH Sharief Hendricks

WL Wayne Lombard

RP Romy Parker

PART A: INTRODUCTION AND SCOPE OF THESIS

Introduction

Foam Rolling (FR) is a popular intervention used by rehabilitation and fitness professionals for the physically active population (Beardsley & Škarabot, 2015; Cheatham et al., 2015; Freiwald et al., 2016b; Healey et al., 2014). Foam rollers are typically cylindrical in shape and are made of densely packed foam, to which body weight is applied to as a form of self-massage. Physical activity can be defined as ‘any bodily movement produced by skeletal muscles that result in energy expenditure’ (Allender et al., 2006; Sallis et al., 2000). There are numerous benefits associated with being physically active (Brown et al., 2015). For example, physical activity is associated with reduced all-cause mortality and disability (Hespanhol et al., 2016). Further to physical activity, participation in sport is considered an important component to a healthy lifestyle as it reduces the risk of various diseases and may contribute to better social and physical performance (Van Beijsterveldt et al., 2012). For example, physical activity and sport has been used in many countries to curb obesity in children (Allender et al., 2006). However, being physically active and participating in sport also presents a certain level of risk to the individual, the incidence and severity of which is influenced by the type of physical activity or sport (Brown et al., 2015; Fuller & Drawer, 2004).

Individuals participating in sport or physical activity commonly experience exercise induced muscle damage (EIMD), resulting in delayed onset of muscle soreness (DOMS) after a bout of unaccustomed physical activity (Beardsley & Škarabot, 2015; Cheatham et al., 2015; Freiwald et al., 2016b; Macdonald et al., 2014). EIMD is further characterized by muscle soreness, muscle swelling, temporary muscle damage, an increase in intramuscular protein and passive muscle tension, and a decrease in muscular strength and flexibility (Macdonald et al, 2014). EIMD and the symptoms of DOMS have been reported to decrease performance (Beardsley & Škarabot, 2015; Cheatham et al., 2015; Freiwald et al., 2016b; Macdonald et al, 2014). With increased levels of physical activity and/or unaccustomed activities, the individual is at an increased risk of sustaining a musculoskeletal injury which can often turn out to be debilitating due to training with EIMD and DOMS (Baltich et al., 2014; Schiff et al., 2010). Besides the significant discomfort and disability that may be associated with injuries, injuries may also be associated with considerable medical expenses (Schiff et al., 2010). This is where FR and self-myofascial release (SMR) may add value by reducing the costs of hiring a professional.

Prevention of injuries in sport has fast become a growing field of research in recent years, focusing on a warm up, cool down, specific conditioning and the effects they have on injury rates (Schiff et al., 2010). Recovery techniques are often seen as a way of preventing injuries by reducing fatigue and/or the effect of training with symptoms of EIMD and DOMS (Howatson et al., 2012; Zainuddin et al.,

2005b). Examples of these recovery techniques are cryotherapy, contrast temperatures, light exercise, compression garments, massage, myofascial release (MR) and more recently, SMR through FR (Kovacs & Baker, 2014; Macdonald et al., 2014; Pearcey et al., 2015).

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 & Mclaughlin, 2014). Myofascial Release is an umbrella term for a wide variety of manual therapy techniques involving a low load of pressure slowly being directed to the fascia and muscles in order to exert a change in the myofascial complex (McKenney et al., 2013). Self-myofascial release is a form of self-massage where a tool is often used to recreate the effects of massage or MR (Healey et al., 2014). The FR research is in its infancy, but the technique has particularly gained favour amongst athletes and their recreational counterparts over the past few years (Bushell et al., 2015). Foam Rollers are sold by practitioners and at sporting outlets. They have been advocated to increase performance, improve recovery, increase flexibility, reduce symptoms of DOMS, reduce pain and stress, affect arterial function and modulate the autonomic nervous system (Bushell et al., 2015; Curran et al., 2008; Ebrahim & Elghany, 2013; Healey et al., 2014; Kim et al., 2014; Macdonald et al., 2014; Macdonald et al., 2013; Mohr et al., 2014; Okamoto et al., 2013; Peacock et al., 2014; Peacock et al., 2015; Pearcey et al., 2015; Roylance et al., 2013). To obtain these implied results, it is not clear when to use the FR and what protocols to prescribe. In various studies FR has been used as part of a warm up routine with the aims of increasing flexibility and performance, whereas in other studies FR has been used as a recovery intervention from DOMS or fatigue (Beardsley & Škarabot, 2015; Cheatham et al., 2015; Freiwald et al., 2016b). Knowing what protocol to prescribe is important in an era of evidence-based practice, and to prescribe the most effective treatments available.

Fascia

The physiological mechanisms of how FR works are not clear, but most literature points towards the fascia (Freiwald et al., 2016a; Schleip, 2003; Simmonds et al., 2012). This could be due to SMR being linked to similar mechanisms as MR to explain the effects on fascia (Hou et al., 2002; Mauntel et al., 2014). Fascia is a relatively new field of research and there are slightly different definitions and some disagreements (Klingler et al., 2012). The Fascia Research Congress (2012) defines fascia as “the soft tissue component of the connective tissue system that permeates the human body” including “all fibrous connective tissues, aponeuroses, ligaments, tendons, retinaculae, joint capsules, organ and vessel tunics, the epineurium, the meninges, the periosteum, and all the endomysial and intermuscular fibers of the myofasciae” (Klingler et al., 2012; Guidera et al., 2014). Fascia is therefore likened to a web that spreads throughout the human body, surrounding all muscles and

organs (Barnes, 1997; Shah & Bhalara, 2012). It has been hypothesised that restrictions in one part of the body may cause stress to the surrounding structures (Schleip, 2003), as fascia seems to be involved with the biomechanics of the musculoskeletal system (Klingler et al., 2012). Fascia can become inflamed and thus potentially cause pain, which would affect its proposed properties in force transmission and contraction of, for example, smooth muscles, and thus affect the surrounding tissues (Benjamin, 2009; Freiwald et al., 2016a; Klingler et al., 2012).

Fascia has been reported to be richly innervated with nerve endings and contains mechanoreceptors (Benjamin, 2009; Freiwald et al., 2016a; Stecco et al., 2008; Yahia et al., 1992), making fascia susceptible to the mechanical stress that exercise may bring. It has been proposed that through EIMD, the fascia tightens in response to trauma, and may be partly responsible for restrictions and an increase in tension throughout the body (Barnes, 1997; Healey et al., 2014; Shah & Bhalara, 2012). The increase of tension may be through the formation of crosslinks and the change of the ground substance viscosity from a gel to a solid form (Macdonald et al., 2014). Alteration in stiffness of the fascia, has shown fascia to have a decreased water content (Klingler et al., 2012). Through these restrictions, fascia may become dehydrated, less pliable, less responsive to movement and may result in symptoms of pain, abnormal mechanics and decreased soft tissue extensibility (Healey et al., 2014; Macdonald et al., 2014). The symptoms of crosslink formation and delayed onset of muscle soreness seem to be closely related and may be interconnected. These restrictions are commonly referred to as myofascial trigger points which can be defined as tender spots in discrete, taut bands of hardened muscle that produce local and referred pain, with or without palpation (Bron et al., 2011; Klingler et al., 2012). Over the years, manual techniques have been used to treat these musculoskeletal deformities (McKenney et al., 2013). Myofascial Release is one of these manual techniques (Ajimsha et al., 2014; McKenney et al., 2013).

Myofascial Release (MR)

It is believed that the term myofascial release was first coined in 1981 by Chila, Peckam and Manheim who ran a course at Michigan State University, titled "Myofascial Release" (McKenney et al., 2013). MR is a collection of techniques that generally involves specifically guided low load, long duration mechanical forces to manipulate the myofascial complex (Ajimsha et al., 2014; Barnes, 1997). MR is intended to restore optimal length, decrease pain, and improve function of this myofascial complex (Ajimsha et al., 2014; Barnes, 1997). The two approaches are the direct MR techniques, and the indirect MR techniques. The direct MR technique is thought to work directly over the restricted fascia by practitioners applying direct pressure using knuckles, elbows or tools. The indirect MR technique involves guided movement of a gentle stretch along the path of least

resistance until free movement is achieved (Ajimsha et al., 2014). Shah et al (2012) summarises MR as a manual massage technique for stretching the fascia and releasing its bonds, thus facilitating a positive change (Shah & Bhalara, 2012). In recent years, MR has become a broad term covering a variety of techniques including the Graston technique, trigger point release, SMR, structural integration (Rolfing) and many others (Kim et al., 2014; Simmonds et al., 2012).

Weerapong et al (2005) have categorised the possible effects of massage into four categories: biomechanical, physiological, neurological and psychological. However, the effects have been further differentiated into two types, mechanical and neurophysiological (Schleip, 2003; Simmonds et al., 2012). The mechanical mechanisms associated with MR and SMR include thixotropy, piezoelectricity, fascial adhesions, cellular responses, fluid flow, fascial inflammation, and myofascial trigger points (Barnes, 1997; Schleip, 2003). There are two main components of the neurophysiological mechanisms, the Golgi reflex arc and the other involving mechanoreceptors (Schleip, 2003; Simmonds et al., 2012; Stecco et al., 2008).

It has been proposed that the golgi tendon organs' response to ischemic compression may be one of the physiological mechanisms to achieve the effects of SMR (Macdonald et al., 2014). The golgi tendon reacts to the change in muscle tension and responds by inducing the relaxation of muscle spindles which may result in an increased joint range of motion (ROM) (Fama, 2011; Miller & Rockey, 2006; Tozzi, 2012). SMR has become popular, with many tools developed to produce the same effect as MR (Curran et al., 2008; Halperin et al., 2014).

Self-Myofascial Release (SMR)

Self-Myofascial Release is seen as a self-massage technique where, instead of a therapist providing manual pressure, the individual uses their own body mass to exert pressure on their soft tissue (Beardsley & Škarabot, 2015; Cheatham et al., 2015; Freiweld et al., 2016b; Healey et al., 2014). Examples of SMR tools include a roller massager (Brown et al., 2015; Sullivan & Silvey, 2013), a stick (Mikesky et al., 2002) and a tennis ball (Grieve et al., 2015). Self-Myofascial Release has been popularised through the implementation of FR in the last decade. It has been proposed that a sweeping motion throughout the muscle length be performed causing pressure on the soft tissue and generating friction (Freiweld et al., 2016b; Macdonald et al., 2014). It is believed that this may lead to a warming effect on the fascia causing it to take a fluid like form (Thixotropic effect), breaking up fibrous adhesions between layers of fascia and thus restoring soft tissue extensibility (Freiweld et al., 2016b; Macdonald et al., 2013). A foam roller is relatively cheap and is a once-off expense that when applied correctly may have significant benefits to the athlete or the physically active individual.

Exercise Induced Muscle Damage (EIMD) and Delayed Onset of Muscle Soreness (DOMS)

Delayed Onset of Muscle Soreness is seen as a set of symptoms of EIMD, which is primarily caused by unaccustomed exercise with a large eccentric component (Barnett, 2006). When individuals are exposed to exercise to which they are unaccustomed, it may result in microtrauma as well as an inflammatory response at a cellular level (Macdonald et al., 2013; Pumpa et al., 2014). This can be self-limiting and is characterised by pain, swelling, decreased range of motion (ROM) and the loss of muscle function (Macdonald et al., 2014; Zainuddin et al., 2005a). These symptoms are most severe at 24 and 48 hours post EIMD (Sarabon et al., 2013). Alleviating the symptoms of DOMS is, therefore, important for the recovery process. For athletes who train often and participate in frequent competitions or tournaments, DOMS is a common obstacle that effects performance (Pumpa et al., 2014; Zainuddin et al., 2005b). While affecting athletes, DOMS may also become an obstacle to recreational and sedentary counterparts who exercise and may be intensified for recreational and sedentary individuals (Barnett, 2006). The symptoms of DOMS may be closely linked to the role of fascia, an interconnecting soft tissue, and its restrictions (Macdonald et al., 2014; Shah & Bhalara, 2012). Therefore, it is important to understand the effect DOMS has on recovery, ROM, and performance (Macdonald et al., 2014; Pearcey et al., 2015).

Recovery

Current research shows that DOMS may develop between several and 24 hours after exercise and its symptoms may peak between the first 24 hours and 72 hours. DOMS may take 7-10 days to resolve after an exercise bout (Brown et al., 1997; Brummit, 2008). Elite athletes cannot afford to passively recover in this time with the ever increasing demands of training and competition placed on them throughout the season (Barnett, 2006; De Nardi et al., 2011). Thus strategies to enhance or speed up the recovery process, from one stimulus to the next, are becoming increasingly important (Barnett, 2006; De Nardi et al., 2011). Among these recovery interventions are cryotherapy, contrast temperatures, light exercise, compression garments and massage (Kovacs & Baker, 2014; Macdonald et al., 2014). The above mentioned techniques are believed to improve the athletes' adaptation and future performance (Kovacs & Baker, 2014). Massage is a popular method amongst athletes and coaches, and has been commonly used by many therapists as a recovery tool for thousands of years (Arroyo-Morales et al., 2008; Brummit, 2008).

Massage has been used as a tool to enhance recovery after exercise, enhance athletic performance, enhance flexibility and as an intervention for musculoskeletal injuries (Brummit, 2008; Robertson et al., 2004; Zainuddin et al., 2005a; Zainuddin et al., 2005b). Massage is also believed to positively

influence relaxation and a state of “wellbeing”, which may help prepare an athlete for competition (Brummit, 2008). The efficacy of massage is questionable, but it has been shown to have a positive effect on perceived pain (Zainuddin et al., 2005b) and an improvement in mental state (Brummit, 2008). Hilbert et al (2003) suggested that the effects of massage on the severity of DOMS are positive, but only after 48 hours (Brummit, 2008). It has been suggested that SMR through FR may mimic the effects of massage and MR (Healey et al., 2014; Mauntel et al., 2014).

Performance

Performance enhancement is of particular interest to those working with elite sports teams or individual athletes. There are many ways to enhance performance. For example, through a specific training regime. Specifically, for this study, we are interested in how FR can enhance performance. In the FR literature, performance has been described as how well a task is performed, the outcome of that task, as well as looking at muscle contractile properties or muscle activation (Cheatham et al., 2015; Freiwald et al., 2016b; Su et al., 2017).

A single exercise session usually comprises of four phases: warm-up, stretching, conditioning or sports-specific training and a cool down (Su et al., 2017). The warm-up phase may consist of 5-10 minutes of low to moderate intensity physical activity, and is generally recommended to prepare the body for strenuous activity (Su et al., 2017). Coaches, athletes, trainers and clinicians commonly use a warm-up prior to competition or physical activity (Jones et al., 2015; Su et al., 2017). This may be to prevent injury and/or to enhance the performance of a physical activity. A warm-up may traditionally involve submaximal aerobic exercise or static stretching. However, static stretching may be detrimental to sprint and jump performance (Jones et al., 2015; Su et al., 2017). Research suggests a dynamic warm-up, consisting of exercises aimed to improve range of motion and simulate specific movements of a sport or activity is preferential to maximize performance (Jones et al., 2015). Essentially, a warm up should increase joint flexibility and improve muscle activation to have desirable effects on performance. Massage is another traditional method used pre- and post-participation to enhance performance and aid recovery (Fletcher, 2010). Like static stretching, pre-performance massage may negatively affect performance (Jones et al., 2015) due to the associated decrease in muscle activation despite increases in flexibility and decreasing perceived muscle pain (Behara & Jacobson, 2017).

Foam Rolling is said to aid the warm-up procedure through improving blood flow, strength and jump performance, anaerobic capacity, flexibility in terms of ROM, sensory-motor function and coordination, stress-relaxation, a reduction of DOMS and pain, as well as reducing muscle and connective tissue tone (Freiwald et al., 2016b). However, previous FR research on performance

enhancement has been limited, with most of the research focusing on flexibility and recovery from EIMD and DOMS (Cheatham et al., 2015).

Foam Rolling

It is common to see foam rollers used in practices, gyms and fitness centres (Cheatham et al., 2015; Freiwald et al., 2016b; Su et al., 2017). There are many types of foam rollers that vary in size, density, and firmness. The most commonly used may be the 6" uniform polyester foam roller (bio-foam roller) as it is cheaper than the polyvinyl chloride core with a neoprene cover (multilevel rigid roller) (Curran et al., 2008; Healey et al., 2014; Macdonald et al., 2013; Sherer, 2013). Foam Rolling, in general, is often used by fitness enthusiasts and athletes prior to their work out, possibly to increase flexibility, and post work out for the possibility of the reduction in DOMS. Research on those effects is limited, thus one cannot be sure how and when FR should be used. Curran et al (2008) has proposed that the multilevel rigid roller may have a deeper influence on the soft tissue as there is more pressure exerted by the body on the foam roller.

Purpose of Review

This systematic review is intended to provide evidence which can guide practitioners and trainers on how best to use a foam roller for performance and recovery purposes. All health care professionals have an ethical responsibility to use evidence-based treatments. This also applies when working in a sporting environment from the recreational to the elite level. This systematic review may provide a rationale to support practitioners in introducing foam rollers to their practice and assist to guide practitioners in the effective use of the equipment.

The focus of this systematic review will be on how foam rollers influence performance and recovery. The manuscript will be edited according to the instructions for authors of the Journal of Bodyworks and Movement. The Journal's requirements are presented in the Appendix A.

PART B: RESEARCH PROTOCOL

**The effect of Foam Rolling on Performance and Recovery following Exercise
Induced Muscle Damage: A Systematic Review Protocol**

Abstract

Background: Self-myofascial release (SMR) has been popularized through foam rolling (FR). Foam Rolling is a form of myofascial release (MR) performed by the individual using their body weight, as opposed to the pressure being applied by the clinician. Foam Rolling is currently used by athletes at all levels, from recreational to elite. This study aims to review the literature to determine if FR enhances performance, positively affects recovery from EIMD, and whether there is a consensus on the protocol to achieve this enhancement.

Methods: A customized search strategy will be utilized to search seven electronic databases, Google Scholar, Science Direct, Pubmed Central, Pubmed, ISI Web of Science, Medline and Scopus. This will be done using search terms related to FR between January 2006 and April 2017. Published journals that included foam rolling as a recovery intervention and/or a performance enhancing tool will be included in the study and assessed using the PEDro scale for methodological quality ratings.

Discussion: Several studies investigating the effects of FR have drawn contrasting conclusions regarding when FR should be used and what it is best used for. Following a previous literature search on FR, performance and recovery will be the two areas that will be reviewed in this study. This systematic review will therefore gather and critically appraise all relevant data to generate a conclusion, clinical guidelines and research recommendations.

Systematic Review Registration: PROSPERO – CRD42017064976

Keywords: Foam rolling, Myofascial roller, Self-myofascial release, myofascial release, Performance, Recovery, Exercise induced muscle damage, Flexibility, Delayed onset of muscle soreness

Abbreviations: FR, Foam Rolling; SMR, Self-Myofascial Release; MR, Myofascial Release; EIMD, Exercise Induced Muscle Damage; DOMS, Delayed Onset of Muscle Soreness; SS, Static Stretching; DS, Dynamic Stretching; PPT, Pressure Pain Threshold.

Background

Foam Rolling (FR) is a popular intervention used by rehabilitation and fitness professionals for the physically active population (Healey et al., 2014). Foam rollers are typically cylindrical in shape and are made of densely packed foam, to which body weight is applied to as a form of self-massage. Physical activity may be defined as 'any bodily movement produced by skeletal muscles that result in energy expenditure' (Allender et al., 2006; Sallis et al., 2000). Physical activity has grown in popularity over the last decade as there are many benefits associated with it including a reduction in all-cause mortality, disability, and an enhancement of mental and physical wellbeing (Allender et al., 2006; Brown et al., 2015; Hespanhol et al., 2016). Participation in sport is also considered an important component to a healthy lifestyle as it reduces the risk of various diseases and may contribute to better social and physical performance (Van Beijsterveldt et al., 2012).

Individuals participating in sport or physical activity commonly experience exercise induced muscle damage (EIMD), resulting in delayed onset of muscle soreness (DOMS) after a bout of unaccustomed physical activity (Macdonald et al., 2014). While EIMD ultimately plays an important role in performance enhancement, it also results in a short term decrease in performance (Sarabon et al., 2013). With increased levels of physical activities and/or unaccustomed activities resulting in EIMD, one becomes at increased risk of sustaining a musculoskeletal injury if there is not adequate rest or recovery during this adaptation phase (Baltich et al., 2014; Schiff et al., 2010). Besides the significant discomfort and disability that may be associated with injuries, injuries may also be associated with considerable medical expenses (Schiff et al., 2010). This is where FR and self-myofascial release (SMR) may be beneficial by reducing the costs of hiring a professional, as there are claims that SMR through FR may attenuate the symptoms of EIMD and thus possibly decrease the risk of injury (Healey et al., 2014; Macdonald et al., 2014; Pearcey et al., 2015).

Prevention of injuries in sport has fast become a growing field of research in recent years, focusing on a warm up, cool down, specific conditioning and the effects they have on injury rates (Schiff et al., 2010). Recovery techniques are often seen as a way of preventing injuries by reducing fatigue and/or the effect of training with symptoms of EIMD and DOMS (Howatson et al., 2012; Zainuddin et al., 2005b). Examples of these recovery techniques are cryotherapy, contrast temperatures, light exercise, compression garments, massage, Myofascial release (MR) and more recently, SMR through FR (Kovacs & Baker, 2014; Macdonald et al., 2014; Pearcey et al., 2015).

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; Freiwald et al., 2016b; Peacock et al., 2014; Vaughan &

Mclaughlin, 2014). Myofascial Release is an umbrella term for a wide variety of manual therapy techniques involving a low load of pressure slowly being directed to the fascia and muscles in order to exert a change in the myofascial complex (McKenney et al., 2013). Self-Myofascial Release is a form of self-massage where a tool is often used to recreate the effects of massage or MR (Healey et al., 2014). The FR research is in its infancy, but the technique has rapidly gained popularity amongst athletes and their recreational counterparts (Bushell et al., 2015; Freiwald et al., 2016b). Foam Rollers are sold by practitioners and in sports stalls and have been advocated to increase performance (Healey et al., 2014; Macdonald et al., 2013; Peacock et al., 2015; Peacock et al., 2014), improve recovery (Macdonald et al., 2014; Pearcey et al., 2015), increase flexibility (Bushell et al., 2015; Drušković et al., 2014; Ebrahim & Elghany, 2013; Macdonald et al., 2013; Mohr et al., 2014; Peacock et al., 2015; Roylance et al., 2013), reduce DOMS and pain (Macdonald et al., 2014; Pearcey et al., 2015; Vaughan & Mclaughlin, 2014), affect arterial function (Okamoto et al., 2014), and modulate the autonomic nervous system (Kim et al., 2014). In the FR literature, performance has been described as how well a task is performed, the outcome of that task, as well as looking at muscle contractile properties or muscle activation (Cheatham et al., 2015; Freiwald et al., 2016b; Su et al., 2017).

However, clarity is needed on when FR should be used, and what protocols should be prescribed, to obtain the results described above. In a previous literature search conducted in 2015, it was found that in various studies, FR has been used as part of a warm up routine with the aims of increasing flexibility and performance, whereas in other studies FR has been used as a recovery intervention from DOMS or fatigue. The current review will focus on the effects of FR on performance and recovery as the two main components. Knowing what protocol to prescribe is important to guide evidence-based practice.

Review Question

Does Foam Rolling have an effect on Performance and Recovery following Exercise Induced Muscle Damage?

Objectives

1. To identify current knowledge on the effects of Foam Rolling on performance and recovery post EIMD.
2. To identify whether a specific Foam Rolling protocol has been found to enhance performance.
3. To identify whether a specific Foam Rolling protocol has been found to enhance recovery.
4. To consider the current research on Foam Rolling and its effects on performance and recovery for training implications and further research recommendations.

Methods

The protocol was developed according to the Preferred Reporting Items of Systematic Reviews and Meta-Analyses Protocol (PRISMA-P) guidelines (Shamseer et al., 2015) and has been registered on PROSPERO database (CRD42017064976). The PRISMA-P checklist is included as an additional file below (Appendix B).

Search Strategy

Electronic Search

A customized search strategy (Figure 1) will be 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 will be 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 will be limited to journals published in English between January 2006 and April 2017.

Search of Other Sources

Reference lists of articles identified will be hand searched to source additional articles. In addition, reference lists of previous systematic reviews or literature reviews identified will be screened to identify further potential articles. By nature of the intervention and the scope of the systematic review, articles selected will be restricted to experimental studies and randomized control trials (RCT's).

Data Collection and Analysis

Selection Criteria

A three-step method will be followed to identify studies to be reviewed. Databases will be searched by one reviewer to identify potential titles and abstracts. The titles and abstracts will be screened for eligibility by two reviewers independently using the inclusion and exclusion criteria outlined in Table 1. The full text of all studies identified through screening will be obtained after duplicates are removed. The full text of studies that include FR as an intervention will be reviewed (Figure 1). Should there be a disagreement between reviewers, a consensus will be reached through discussion. If an agreement cannot be reached, a third reviewer will be requested to make the final decision.

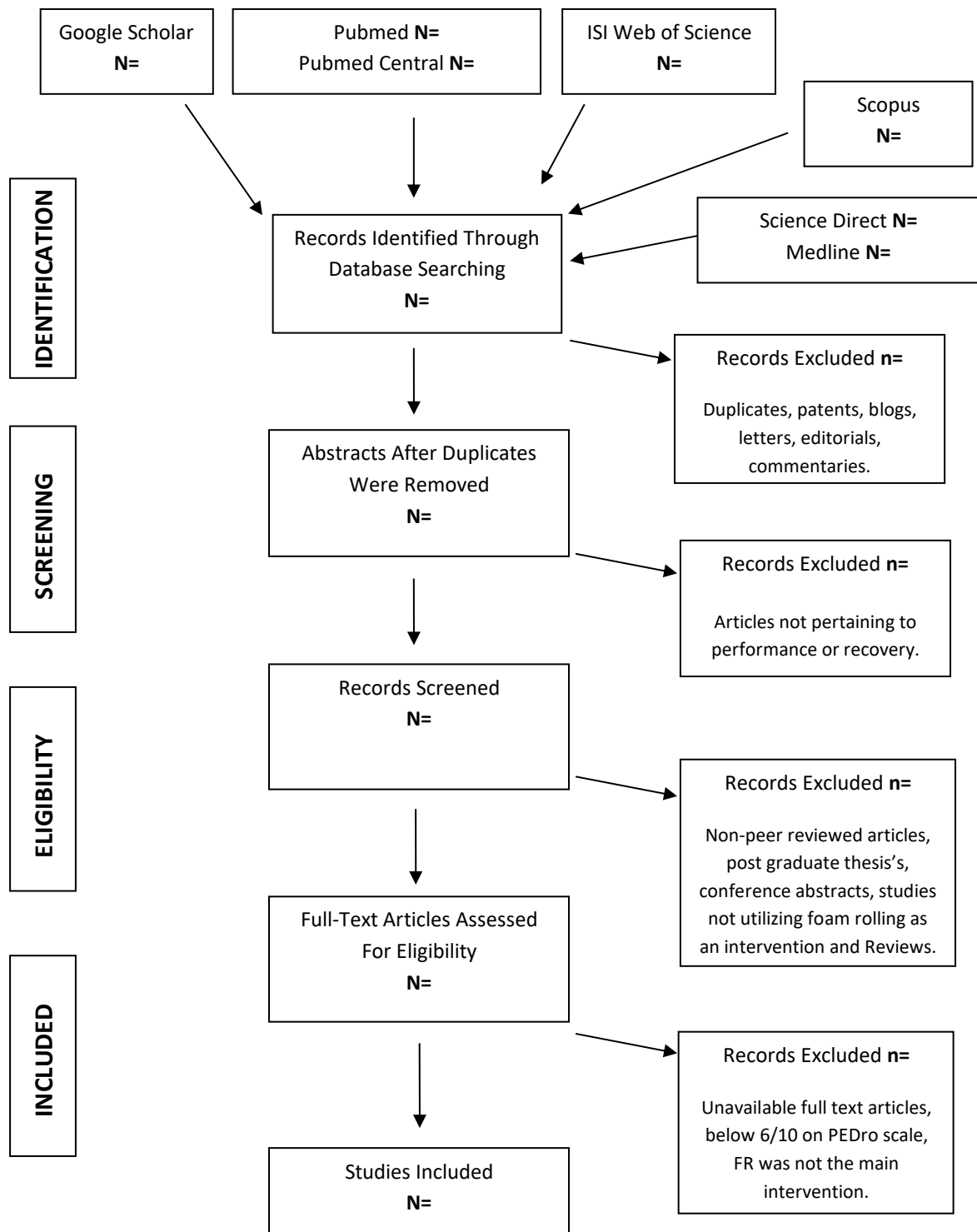


Figure 1: Summary of the study collection process

Articles will be included if they meet the following criteria: published between January 2006 and April 2017, available full text in English, peer reviewed, and they are an intervention type study using a foam roller as the primary intervention for recovery (Table 1). Literature reviews and systematic reviews will not be included, but rather used to screen the reference list for articles that the search may have missed.

Table 1: Inclusion and exclusion criteria to be 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.
<ol style="list-style-type: none"> 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 	<ol style="list-style-type: none"> 1. Date Range: January 2006 – April 2017 2. Language: English 3. Journal Type: Peer Reviewed Journals 4. Study Design: Intervention type study using a foam roller 5. Foam Rolling utilised as a tool to enhance performance and/or recovery

Data Extraction

Included articles will go through data extraction by one reviewer using a customized pre-set summary table. The information that will be extracted includes: title, sample demographics, study characteristics, type of foam roller, foam rolling protocol, the outcome measure and data, findings and the PEDro score. A PEDro score will be given to each article by the author, that total score will be added into the summary table for convenience.

Critical Appraisal

The studies will go through a methodological quality assessment using the Physiotherapy evidence database (PEDro) scale scores (2015). The clinical trial quality will be assessed using the PEDro scale and will be 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 criterion leads to 1 point being awarded as it is very clear and unambiguous. For each criterion the study meets, 1 point will be awarded. This scale applies only to experimental studies. In

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

this review, PEDro scores between 6-10 points will be considered to be of high quality evidence; PEDro scores of between 4-5 points will be considered to be of moderate quality; and PEDro scores between 0-3 will be considered to be of poor quality (Maher et al., 2003; Mauntel et al., 2014). The PEDro scores for each study will be finalized via a consensus discussion between two reviewers. If an agreement cannot be reached, a third reviewer will be requested to make the final decision. It is important to note that the PEDro scale does not evaluate clinical usefulness.

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

Registration

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

Discussion

Given the popularity of FR, specifically amongst sporting groups, it is important to generate an evidence-based conclusion regarding the application of FR to enhance performance and recovery from EIMD. The proposed systematic review will therefore explore the efficacy of FR as a tool to enhance performance and recovery. FR is cost-effective, easy to travel with and can be used at convenient times. Foam Rolling is used as a SMR by athletes where their body weight can be used to their satisfaction. As such, outcomes of the review which are significant will guide athletes and clinicians on how to best use a FR to achieve the above-mentioned results. The findings of the review may reinforce the implementation of FR to enhance performance and recovery, thus applying evidence-based practice to the management of athletes.

Acknowledgements

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Funding

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Availability of Data and Materials

Not applicable.

Authors' Contributions

HH drafted the protocol, SH and RP conceptualized and edited the protocol, WL conceptualized and edited the content. All authors approved the final manuscript.

Competing Interests

The authors declare that they have no competing interests.

Consent

Not applicable

Ethical Consideration

Systematic reviews do not require formal ethical or confidential considerations as the data presented in this review will be from studies that have obtained ethical approval prior to the publication of the articles. Therefore, no ethical procedures have been completed for this review.

PART C: SYSTEMATIC REVIEW MANUSCRIPT

**Does Foam Rolling have a Positive Effect on Performance and Recovery
from Post Exercise Induced Muscle Damage: A Systematic Review of the
Literature to Guide Practitioners on the use of Foam Rolling**

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ABSTRACT

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 from exercise induced muscle damage (EIMD). This study aims to review the literature to determine if FR enhances performance, positively affects recovery from EIMD, and whether there is a consensus on the protocol to achieve this enhancement.

Methods: A customised search strategy was utilised to search seven electronic databases, Google Scholar, Science Direct, Pubmed Central, Pubmed, ISI Web of Science, Medline and Scopus. This was done using search terms related to FR between January 2006 and April 2017. Published articles that included foam rolling as a recovery intervention and/or a performance enhancing tool were included in the study and assessed using the PEDro scale for methodological quality ratings. Qualitative data were extracted from each study.

Results: A total of 33 articles met the inclusion criteria. Sixteen studies focused on performance and seventeen studies were included as recovery studies. Of the recovery studies, three studies were about exercise induced muscle damage (EIMD) and delayed onset of muscle soreness (DOMS), three on pressure pain threshold (PPT), nine on flexibility and three categorised as 'other' under recovery. The mean and median PEDro score was seven, with a range of 6-10.

Conclusion: Foam Rolling may be included in a warm-up consisting of dynamic stretching and an active warm-up to enhance performance primarily through its effects on flexibility while maintaining muscle contractility. Foam Rolling can be used to enhance recovery from EIMD and DOMS, with its main effects being the shortening of time to return to baseline performance, flexibility and normalising PPT. Sixty to ninety seconds of FR may suffice to achieve the above desired effects.

Systematic Review Registration: PROSPERO – CRD42017064976

Keywords: Foam rolling, Myofascial roller, Self-myofascial release, myofascial release, Performance, Recovery, Exercise induced muscle damage, Flexibility, Delayed onset of muscle soreness

INTRODUCTION

Background

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 2016b; Healey et al 2014). This tool is typically cylindrical in shape and consists of densely packed foam. It has derived from myofascial release (MR) which is 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 systematic reviews have been done in 2015 on the effects of SMR (Beardsley & Škarabot 2015; Cheatham et al 2015) and it appears to have 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 & Škarabot 2015; Cheatham et al 2015). Both the authors of the previous reviews acknowledged that the research on the effects of SMR is still emerging and there was no current consensus on a FR protocol (Beardsley & Škarabot 2015; Cheatham et al 2015). The two systematic reviews were not only on FR but included various other SMR tools. A review on FR in 2016 reported that there was minor scientific evidence to support the use of FR to enhance athletic performance through its effects on enhancing underlying mechanical and physiological mechanisms as well as the low risk of potential harmful effects (Freiwald et al 2016b).

Performance and prevention of injuries in sport has fast become a growing field of research in recent years, and it is of particular interest to strength and conditioning coaches, physiotherapists and various other sports professionals with these professionals focusing on a warm up, cool down, specific conditioning and the effects they have on injury rates and performance (Schiff et al 2010). In an exercise session deployed by these sports professionals, the session usually comprises of four phases: warm-up, stretching, conditioning or sports-specific training and a

cool down (Su et al 2017). These phases may be structured to enhance performance and prevent injuries. It is in the consideration of these goals where FR may fit in as FR has been advocated to increase performance (Healey et al 2014; Macdonald et al 2013; Peacock et al 2015; Peacock et al 2014), improve recovery (Macdonald et al 2014; Pearcey et al 2015), increase flexibility (Baltich et al 2014; Bushell et al 2015; Drušković et al 2014; Macdonald et al 2014; Macdonald et al 2013; Mohr et al 2014; Peacock et al 2015; Roylance et al 2013), reduce delayed onset of muscle soreness (DOMS) and pain (Macdonald et al 2013; Pearcey et al 2015; Vaughan & Mclaughlin 2014), affect arterial function (Murray et al 2016), and modulate the autonomic nervous system (Kim et al 2014). This shows that FR may be deployed in a warm-up as well as a cool-down routine, either on its own or combined with other techniques. In the FR literature, performance has been described as how well a task is performed, the outcome of that task, as well as looking at muscle contractile properties or muscle activation (Cheatham et al., 2015; Freiwald et al., 2016b; Su et al., 2017).

Coaches, athletes, trainers and clinicians commonly use a warm-up prior to competition or physical activity and a cool down post-competition or physical activity (Jones et al 2015; Su et al 2017). A warm-up may traditionally involve submaximal aerobic exercise or static stretching (SS). However, SS may be detrimental to sprint and jump performance (Jones et al 2015; Su et al 2017). Research has suggested a dynamic warm-up, consisting of exercises aimed to improve range of motion (ROM) and simulate specific movements of a sport or activity is preferential to maximize performance (Jones et al 2015). Essentially, a warm up should increase joint flexibility and improve muscle activation to have desirable effects on performance. Recovery techniques are often seen as a way of preventing injuries by reducing fatigue and/or the effect of training with symptoms of EIMD and DOMS (Howatson et al 2012; Zainuddin et al 2005a; Zainuddin et al 2005b). Examples of these recovery techniques are cryotherapy, contrast temperatures, light exercise, compression garments, massage, MR and more recently, SMR through FR (Kovacs & Baker 2014; Macdonald et al 2014; Pearcey et al 2015).

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 & Mclaughlin 2014). Foam Rolling has rapidly gained popularity amongst athletes and their recreational counterparts (Bushell et al 2015), despite the FR research being in its infancy. Clarity is needed on when FR should be used, and what protocols should be prescribed to obtain the results described above. In a previous literature search in 2015, it was found that in various studies FR has been used as part of a warm up routine with the aims of increasing flexibility and performance, whereas in other studies FR has been used as a recovery intervention from EIMD and DOMS or fatigue. Therefore, this review will focus on performance and recovery as the two main components. Knowing what protocol to prescribe is important to guide evidence-based practice. To our knowledge, this is the first systematic review focusing on FR and its effects on performance and recovery from EIMD and DOMS.

Review Question

Does Foam Rolling have an effect on Performance and Recovery following Exercise Induced Muscle Damage?

Objectives

1. To identify current knowledge on the effects of Foam Rolling on performance and recovery post EIMD.
2. To identify whether a specific Foam Rolling protocol has been found to enhance performance.
3. To identify whether a specific Foam Rolling protocol has been found to enhance recovery.
4. To consider the current research on Foam Rolling and its effects on performance and recovery for training implications and further research recommendations.

METHODS

This review has undergone a systematic approach in order to identify the knowledge surrounding foam rolling and its relation to enhancing performance and recovery from exercise. The protocol was developed according to the Preferred Reporting Items of Systematic Reviews and Meta-Analyses Protocol (PRISMA-P) guidelines (Shamseer et al 2015) and has been registered on PROSPERO database (CRD42017064976).

Search Strategy

Electronic Search

A customized search strategy (Figure 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 will be 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 April 2017.

Search of Other Sources

Reference lists of articles identified were searched to source additional articles. In addition, reference lists of previous systematic reviews or literature reviews identified were screened to identify further potential articles. By nature of the intervention and the scope of the systematic review, articles selected were restricted to experimental studies and randomized control trials (RCT's).

Data Collection and Analysis

Selection Criteria

A three-step method was followed to identify the studies that were reviewed. Databases were searched by one reviewer (HH) to identify potential titles and abstracts. The titles and abstracts were screened for eligibility by two reviewers independently (HH & 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 (Figure 1). There were no disagreements between reviewers on the articles that were included; therefore, a third reviewer was not needed to make final decisions regarding the inclusion or exclusion of articles.

Articles were included if they met the following criteria: published between January 2006 and April 2017, available full text in English, peer reviewed, and they were an intervention type study using a foam roller as the primary intervention for performance and/or recovery. Literature reviews and systematic reviews were not included, but rather were used to screen the reference list for articles that the search may have missed. Studies were excluded if they failed to meet the inclusion criteria and if they had met the exclusion criteria described in Table 1.

Critical Appraisal

The studies went through 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 in this study, all 11 criteria are scored (Table 2). Each of the 11 criterion 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 6-11 points were considered to be of high quality evidence; PEDro

scores of between 4-5 points were considered to be of moderate quality; and PEDro scores between 0-3 were considered to be of poor quality (Maher et al 2003; Mauntel et al 2014). The PEDro scores for each study were finalized via a consensus discussion between two reviewers, HH & SH (Table 3). Agreement was reached; therefore, a third reviewer was not needed to make the final decision. It is important to note that the PEDro scale does not evaluate clinical usefulness and can only be applied to experimental studies.

Data Extraction and Synthesis

Included articles went through data extraction process by one reviewer (HH) using a customized pre-set summary table. The information that was extracted included title, sample demographics, study characteristics, type of foam roller, pressure instructions, foam rolling protocol, the outcome measure and data, findings and the PEDro score. A PEDro score was given to each article and the total score was added into the summary table (Table 5.1 & 5.2).

Registration

In accordance with the Preferred Items for Reporting Systematic Reviews and Meta-analyses for Protocols (PRISMA-P) guidelines (Appendix B), 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).

RESULTS

Selection Process

Selection of the studies started with 3897 titles that were identified through the database search. Three thousand seven hundred and seventy titles were excluded as they were either duplicate, patents, blogs, letters, editorials and/or commentaries. Many of the titles did not contain an abstract and were not research articles.

A total of 127 abstracts were obtained, and screened to obtain full text articles. Forty-three 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 84 articles that were screened for eligibility. A further 40 articles were excluded as the main focus was not on Performance or Recovery from DOMS. Forty-four full-text articles were assessed for eligibility. A further 11 full text articles were excluded due to the full text article being unavailable, articles were not performance or recovery based, and some studies were excluded due to low PEDro scores. Thirty-three 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 Figure 1. Table 4.1 and 4.2 were added to simplify the results and help the reader understand in a specific study that was included found FR to make a change and if that author recommended FR. A more in depth summary of the included studies is presented in Table 5. Table 5.1 represents the performance studies and Table 5.2 represents the recovery studies.

The 33 studies that were included in this review were then divided into categories involving performance (16 studies) and recovery (17 studies). Due to the inclusive nature of this study, under recovery, the studies were subdivided according to outcome. These subdivisions were: DOMS (three studies), flexibility (eight studies), PPT (three studies), and 'other' (three studies). A

total of 17 studies included for recovery. Some of these subdivisions were not specifically recovering from EIMD or DOMS, but may help in the resolution of these symptoms and were therefore added in order to add to the knowledge around FR and how it may work. Specifically, PPT and flexibility were commonly used in recovery studies as measures for recovery from EIMD and DOMS.

Data Collection and Analyses

Quality of studies

The mean PEDro score of the included studies was seven, with a range of 6-10 points out of 11 and a median of seven. 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. Although the studies were in the high quality of evidence range, the majority were in the lower half of the range (6-10 points out of 11). This shows that the quality between the included studies varied from the low end of high-quality evidence to the high end. The most common criteria that were neglected were the fulfillment of the blinding criteria (PEDro scale questions 5-7). The majority of the studies failed to mention the 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 (Tables 3). Table 2 shows the criteria for each category that had to be met to obtain a positive score, which is case is indicated as a "1". The mean PEDro score as 7, with a range from 6-10. Beyond summarising the quality of the studies, the data did not allow for statistical analyses as the outcome measures varied and data was represented differently throughout.

Performance

The research of FR on performance enhancement has increased since a review on SMR previously done in 2015 (Cheatham et al 2015). There were 16 studies that measured the effects of FR on performance measures (Behara & Jacobson 2017; Cavanaugh et al 2016; Hansen et al 2016; Healey et al 2014; Jones et al 2015; Macdonald et al 2013; Martínez-cabrera & Núñez-sánchez 2016; Monteiro 2016; Monteiro et al 2017a, 2017b, 2017c; Morales-Artacho et al 2017; Peacock et al 2015; Peacock et al 2014; Sagiroglu et al 2017; Su et al 2017). All 16 studies fall in the lower range of high quality of evidence on the PEDro scale (mean 6.68; range 6-8 points). There were variations in sample sizes, population studied, outcome measures used, the FR tool used, the protocol used, and the instructions given with regard to pressure applied (Table 5.1). The most common type of FR used was a multi-level rigid roller which consists of a PVC pipe surrounded by foam with 68.75% of the studies using this type of roller. This was previously suggested to be the most effective FR type as it exerts more pressure (Curran et al 2008).

Most (43.75%) of the studies instructed the participants to apply as much pressure as possible while FR (Cavanaugh et al 2016; Macdonald et al 2013; Monteiro et al 2017a, 2017b, 2017c; Sagiroglu et al 2017), but instructions were commonly not mentioned comprising of 43.75% of the studies (Behara & Jacobson 2017; Healey et al 2014; Jones et al 2015; Monteiro 2016; Morales-Artacho et al 2017; Peacock et al 2015; Peacock et al 2014) (Table 5.1). Performance FR protocols varied from rolling a muscle group unilaterally to rolling a muscle group bilaterally; rolling for one set of 30-120s to rolling for four sets of 30-45s; the pace of rolling being controlled by a metronome, instructing participants to roll the entire length of the muscle five times in 30s. These variations may severely influence the results (table 5.1). It seems that those who FR for 30s and those who FR for more than 120s were mostly the studies that reported negative results for FR on performance (Cavanaugh et al 2016; Healey et al 2014; Jones et al 2015; Sagiroglu et al 2017).

Table 4.1 shows that 11 (68.75%) show no change in performance measurements. Foam Rolling does not seem to impede performance but appears to be recommended by authors as a performance enhancing tool due to its effects on flexibility prior to a bout of exercise (Table 4.1 and table 5.1). Due to FR effects on flexibility during a warm-up, studies recommended that FR should replace SS (Behara & Jacobson 2017) and possibly be used in combination with dynamic stretching (DS) (Su et al 2017) and active warm-up routines (Martínez-Cabrera & Núñez-sánchez 2016; Morales-Artacho et al 2017). Apart from improvements in flexibility (Behara & Jacobson 2017; Macdonald et al 2013; Morales-Artacho et al 2017; Su et al 2017) and the maintenance of muscle contractility (Behara & Jacobson 2017; Hansen et al 2016; Healey et al 2014; Jones et al 2015; Martínez-Cabrera & Núñez-Sánchez 2016; Morales-Artacho et al 2017; Su et al 2017), it is suggested that FR maintains muscle passive stiffness (Martínez-Cabrera & 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). Given the above results, it is suggested that FR is used as a warm-up for sports that require flexibility and force production (Macdonald et al 2013; Su et al 2017).

Macdonald et al (2013) reported that slow undulating FR of the quadriceps increases knee ROM in a modified lunge position ($p < 0.001$). Knee ROM increased by 10° and 8° at two and 10 minutes respectively, suggesting an increase in ROM may only last 10 minutes (Macdonald et al 2013). Although Hansen et al (2016) did not find any significant alteration in anaerobic power output during a Wingate test or the Monark anaerobic test, they suggested that FR should be avoided as a warm-up to increase the body's performance during exercise. This could be due to the time it may take to FR and the authors possibly believing other methods may be used during a warm-up. Morales-Artacho et al (2017) reported that no significant changes were found in passive hip flexion flexibility in the control group or the FR group, suggesting that FR alone may not induce flexibility changes. This contradicts the above studies that report increases in flexibility with FR, although a combination of FR and other techniques seem to be superior to FR alone.

The majority of the studies (62.5%) reported no increase or decrease in performance tests following FR (Behara & Jacobson 2017; Hansen et al 2016; Healey et al 2014; Jones et al 2015; Macdonald et al 2013; Martínez-Cabrera & 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 2015; Peacock et al 2014). Peacock et al (2014) reported, in the first study, that using FR alone was effective at improving power through the vertical jump ($72.97 \pm 10.60\text{cm}$), agility through a pro-agility test ($4.80 \pm 0.16\text{s}$), strength through a one repetition maximum bench press ($103.68 \pm 20.47\text{kg}$), and speed through a 37-meter sprint ($4.95 \pm 0.21\text{s}$) when compared to a dynamic warm-up routine using physically active, athletic healthy males. The second study from Peacock et al (2015) reported overall score increases in National Football League drills for two different protocols of FR, however no results were presented for the performance of these drills and only results were presented for flexibility improvements with the sit-and-reach test. The drills or tests included the vertical jump, broad jump, shuttle run and bench press. Other tests included subjective scaling and the sit-and-reach testing. The reported increase in performance may be due to the general warm-up performed in both studies. This consisted of a five-minute active warm-up including jogging, mobility drills and 'flow maneuvers' (Peacock et al 2014; Peacock et al 2015). Peacock et al (2015) reported that athlete preference exists, athletes preferring the medio-lateral axis FR progressions compared to the antero-posterior axis progressions. These were the two FR protocols followed in the study. Monteiro et al (2017a) reported that FR increased the performance of the functional movement screen's overhead deep squat scores. These improvements improved from a baseline score of 1-2 to 2-3. The increase in performance of this task was attributed to FR effects on flexibility (Monteiro et al 2017a).

Several studies (31.25%) conclusively did not support FR for performance enhancement (Monteiro 2016; Monteiro et al 2017b, 2017c; Morales-Artacho et al 2017; Sagioglu et al 2017). It was found that FR did not enhance performance of a single leg landing from a hurdle jump due

to a decrease in muscle activation of the biceps femoris when the quadriceps were exclusively rolled (Cavanaugh et al 2016) suggesting FR has an antagonistic effect. The authors recommended not exclusively FR the quadriceps as it may create muscle imbalances and lead to injury through reciprocal inhibition. Monteiro et al (2017c) found that FR, applied to the agonists during the inter-set rest period when performing resistance training through knee extension repetitions, reduced the amount of knee extension repetitions performed (Monteiro et al 2017c). These results were reproduced when FR was applied to the antagonists (Monteiro et al 2017b). In an earlier study by Monteiro et al (2016), the results suggested that inter-set FR showed, subjectively, a decline in the fatigue index which made the participants less fatigue resistant when performing a knee extension protocol (Monteiro 2016). The 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 2016; Monteiro et al 2017b; Morales-Artacho et al 2017).

Further, Sagioglu et al (2017) reported that FR may be detrimental to the performance of counter movement jump for up to 15-minutes post FR. This was due to FR showing an insignificant decrease in the counter movement jump performance (Sagioglu 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 may provide important indications for practitioners as they appear to be the first risks associated with FR

Recovery

Exercise Induced Muscle Damage (EIMD) and Delayed Onset of Muscle

Soreness (DOMS)

Foam Rolling seems to enhance recovery from EIMD and DOMS by assisting the participants to returning to their normal state in a shorter time (Macdonald et al 2014; Pearcey et al 2015) (Table 5.2). Three studies looked at the effect of FR on recovery from EIMD and DOMS (Macdonald et al 2014; Pearcey et al 2015; Zorko et al 2017). All three studies reported change (Table 4.2) with two of the studies supporting FR for enhancing recovery from EIMD and DOMS (Macdonald et al 2014; Pearcey et al 2015) while the third study found that both FR and passive rest had a small effect on acute recovery parameters , with no significant differences between the two interventions (effect size = 0.2 – 0.6), meaning that FR did not enhance short term recovery of muscle contractile function (Zorko et al 2017). This study looked at the acute effect of FR on short term recovery of muscle contractile function after inducing peripheral fatigue with a knee extension protocol. (Zorko et al 2017). All the studies fall in the lower range of high quality of evidence on the PEDro scale (mean 6.33; range 6-7 points).

On one occasion, FR was reported to decrease muscle soreness (>75% likelihood) while improving vertical jump height, muscle activation, and passive and dynamic ROM. They also found that FR negatively affected evoked contractile properties of the muscle (Macdonald et al 2014). On another occasion, FR effectively reduced DOMS (767.14 ± 168.73 kPa) and associated decrements in most of the dynamic performance measures, thus enhancing muscle recovery (Pearcey et al 2015). Zorko et al (2017) was the only study not supporting the use of FR for recovery purposes, although this utilized a fatiguing protocol, instead of a DOMS inducing protocol used by the other studies. This study showed that FR appears to be equally effective as passive rest for short-term recovery of muscle contractile function with improvements and after both foam rolling (5.5 –

16.2%) and passive rest (4.7 – 8.3%) with no differences between the two when maximal voluntary isometric contraction and direct muscle stimulation of the quadriceps were tested 30minutes post a fatiguing protocol (Zorko et al 2017).

Flexibility

Self-Myofascial Release through FR appears to lead to increases in flexibility in 60.6% of the studies (Table 5.2). The following eight studies looked at enhancing flexibility, which is an important component for recovering from a bout of exercise and possibly for injury prevention. On average, the flexibility studies were some of the higher scoring studies on the PEDro scale (mean 7.125; range 6-9 points). Flexibility was the most common component evaluated throughout the eligible studies, with eight of the 33 studies focusing only on flexibility measures, and 12 other studies including flexibility measures (Behara & Jacobson 2017; Cavanaugh et al 2016; Cheatham et al 2017a; Macdonald et al 2014; Macdonald et al 2013; Monteiro 2016; Morales-Artacho et al 2017; Peacock et al 2015; Peacock et al 2014; Pearcey et al 2015; Sagioglu et al 2017; Su et al 2017). The most commonly used FR (37.5%) was the Grid foam roller (Kelly & Beardsley 2016; Murray et al 2016; Škarabot et al 2015) and in 75% of the studies the participants were advised to exert as much pressure as possible (Kelly & Beardsley 2016; Mohr et al 2014; Murray et al 2016; Škarabot et al 2015), while respecting pain (Griefahn et al 2017; Junker & Stoggl 2015).

The positive findings for FR on flexibility outweighed those against FR, six to two. FR seemed to enhance hip flexion ROM on four occasions (Junker & Stoggl 2015; Mohr et al 2014; Murray et al 2016; Roylance et al 2013), knee flexion ROM (Murray et al 2016) as well as ankle dorsi-flexion ROM (Kelly & 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 dorsi-flexion 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 affect (Kelly & 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 showed that a 4-week FR program, of rolling 3 times a week, increased hamstring flexibility (baseline: -3.9 ± 8.0 cm, post-intervention: -0.9 ± 8.7 cm) and had comparable results with proprioceptive neuromuscular facilitation stretching. While flexibility improved using this protocol, it was also shown that FR did not have an effect on muscle contractility or temperature (Murray et al 2016). One study found FR to have no effect on flexibility on its own (Roynance et al 2013) but increased ROM when combined with postural alignment exercises. Two further studies showed FR improved flexibility when used on its own (Kelly & Beardsley 2016; Murray et al 2016), and had an enhanced effect when combined with SS and/or postural alignment exercises (Junker & Stoggl 2015; Mohr et al 2014; Roynance et al 2013; 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.

Pressure Pain Threshold (PPT)

Three studies focused on the measurement of PPT (Cheatham et al 2017a; Cheatham et al 2017b; Vaughan & Mclaughlin 2014). The mean PEDro score was 7.66 and the range from 6-10 points.

All three studies found that FR significantly increased (normalized) the PPT immediately (Cheatham et al 2017a; Cheatham et al 2017b; Vaughan & Mclaughlin 2014). It was shown that an acute increase in PPT occurred for up to 2-minutes post FR (Cheatham et al 2017a; Cheatham et al 2017b). It was also shown that the effects of FR on PPT were ameliorated 5-minutes post FR (Vaughan & Mclaughlin 2014). Cheatham et al (2017a) tested the application of three different

instructional strategies, video guided, live instructed and self-guided. The instructional strategies used in the application of the FR did not affect the results with all strategies showing similar change in knee ROM (4.9 ± 1.8 degrees) and significant changes in PPT (145.3 ± 77.4 kPa) (Cheatham et al 2017a).

Other

Three studies fall into the category of “other” under the recovery section (Hotfiel et al 2017; Kim et al 2014; Okamoto et al 2013). All of the studies scored a six on the PEDro scale, leaving the studies at the low end of the high methodological quality rating (Hotfiel et al 2017; Kim et al 2014; Okamoto et al 2013).

One study showed that SMR induced with a foam roller did not affect the reduction of physiological stress, measured by the serum cortisol level. In this study the participants performed a thirty-minute 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). Two other studies explored effects on blood flow (Hotfiel et al 2017; Okamoto et al 2013). One of the studies showed that SMR using a foam roller reduces arterial stiffness and improves vascular endothelial function (Okamoto et al 2013). The other study found that local blood flow increases significantly after FR of the lateral thigh, with a baseline Vmax (peak flow) of $7.2 \pm 2.6 \text{ cm}\cdot\text{s}^{-1}$ and immediately after the intervention being $12.5 \pm 5.0 \text{ cm}\cdot\text{s}^{-1}$ (Hotfiel et al 2017). However, neither study compared FR with any other strategy.

Recovery FR protocols varied from rolling a muscle group unilaterally, to rolling a muscle group bilaterally; rolling for one set of 30s-120s to rolling for three or four sets of 30s-45s; the pace of rolling being controlled by a metronome, instructing participants to roll the entire length of the muscle five times in 30s, or just instructing participants to roll a muscle group 21 times. Some of

the protocols involved rolling a muscle and holding the FR on a tender while performing active movements, while another rolled a muscle group in a fluid motion only to find a tender point on hold the FR on that tender point for 90s. The variations in sample sizes, population studied, outcome measures used, the FR tool used, the protocol used, and the instructions given with regard to pressure applied These variations may severely influence the results (Table 5.2).

DISCUSSION

Performance

The majority of the studies reported that FR did not improve athletic performance, but at the same time, neither did it impede on various force and power outcome measures when FR was applied prior to performance measures. Foam rolling decreased performance of knee extensions when applied in between the knee extension sets. Given the increases shown in flexibility with no decrease in physical performance, FR appears to be a useful tool to use during a warm up, but, it would be advisable to use it in combination with an active warm-up or DS (Behara & Jacobson 2017; Morales-Artacho et al 2017; Peacock et al 2014; Su et al 2017). These results are encouraging as various studies have implicated massage and SS as impeding performance (Barnes 1997; Behara & Jacobson 2017; Haddad et al 2014; Healey et al 2014). This may suggest that FR may have a different effect to massage, however it could be due to pressure difference as FR is self-controlled and massage is controlled by a clinician. It appears that combining DS with FR has the potential to enhance performance as reported by Peacock et al (2014) and Su et al (2017), while Behara et al (2017) suggested that FR be a substitute for SS. Dynamic stretching has been found to improve athletic test performance on its own (Jaggers et al 2008). 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 & 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 (2016) was the only study to show a negative effect of FR by reporting a decrease in muscle activation of the biceps femoris and thus reported FR does not enhance performance (Cavanaugh et al 2016). This was only the case when the quadriceps were rolled alone, with the authors suggesting a possible antagonistic effect due to reciprocal inhibition when

rolling the quadriceps muscle group. This was the only study reporting a decrease in performance after FR, but the only measure was muscle activation when performing a landing task, but not how well a task was performed. Not indicating whether this decrease in muscle activation would negatively affect the performance of a task.

Monteiro et al (2016, 2017b, 2017c), on three separate occasions, found that using FR in between sets seemed to be detrimental to the ability to continually produce force during resistance training. This finding is significant as the timing of foam roller use needs to be considered as it can be detrimental to the type of activity that is going to be performed (Monteiro 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. This suggestion correlates with the findings of the performance studies displaying increases in flexibility (Behara & Jacobson 2017; Macdonald et al 2013; Morales-Artacho et al 2017; Peacock et al 2015; Peacock et al 2014; Sagiroglu et al 2017; Su et al 2017). An example of the performance enhancement of a task through improvements in flexibility is displayed in the study by Monteiro et al (2017), who showed improvements in functional movement screen scores with the overhead deep squat. The authors suggested that the improvements were more likely due to an increase in mobility, rather than stability (Monteiro et al 2017a).

The dosage of FR in terms of time (s) appears to be critical to affect. Monteiro et al (2017a) reported that the improvement in functional movement screen scores were only present in the group that rolled for more than 90s suggesting that 90s may be a threshold to achieve desired results. In another study, it was shown that FR for 30s did not improve the vertical jump (Jones et al 2015) and Healey et al (2013) showed no effect on performance of athletic tests when FR was performed for only 30s on each muscle. Behara & Jacobson (2017) and Su et al (2017) performed FR for more than 90s and found ROM enhancement. 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). Hansen et al found that FR for less than 90s, did not have any effect on anaerobic power. Previous studies have shown that 10-15min of massage decreased muscle force (Healey et al 2014; Macdonald et al 2014). Other studies found short duration massage increased ROM while maintaining muscle power (Goodwin et al 2007). It appears that the protocol of 60s to 90s of FR may coincide with the benefits seen with short duration massages (Macdonald et al 2014 Macdonald et al 2013), but this is not conclusive as massage has also said to impede performance (Barnes 1997; Behara & Jacobson 2017; Haddad et al 2014; Healey et al 2014). It is important to note that massage may typically be performed for lengthier periods, and this may affect the outcomes as well as the comparison between FR and massage. Given the above evidence, it seems 60s to 90s of FR on a muscle group may be effective for increasing flexibility but not for increasing power. More evidence points to rolling for 90s as the threshold to obtain benefits. This information suggests an inverted U-hypothesis of too little FR does not bring about the desired effect, too much diminished any benefit, but the middle seems to be optimal.

An important part of dosage may be the tempo of FR and the method of implementation. This may play its part in the variation of results. There is no evidence showing preference to using a metronome to control the tempo of FR or simply instructing someone to roll the length of the muscle for about 5-10 times in 30-45s. The majority of the studies utilized the more general approach of FR the entire length of the muscle 5-10 times in that 30s-45s. In addition, another instructed rolling at a slow undulating pace as another practical way to prescribe FR (Macdonald et al., 2013). From these studies it would appear that the allotted time of FR can be broken up into 2 sets of 45s or 3 sets of 30s to obtain the benefits of FR. The method used would come down to the athlete's preference and upper body strength (Table 5.1).

Theories such as the neurophysiological effect and the mechanical effect have been proposed to explain the mechanisms through which FR may achieve its results (Schleip 2003; Simmonds et al

2012; Stecco et al 2008; Kelly & Beardsley 2016). The results of this review neither confirm or deny either theory and may indicate that both theories may work concurrently. However, more research is needed on this topic. In the performance studies, FR was shown to increase flexibility when SS also improved flexibility. The difference was that overall FR did not decrease muscle activation or force, where SS has been seen to decrease muscle activation and force. The different effects of FR and SS may show that the interventions may have different mechanisms by which they work. 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 & Mclaughlin 2014). There were studies that reported antagonistic effects when FR (Cavanaugh et al 2016; Monteiro et al 2017b), showing when an agonist is FR it effected the antagonist. These may be different examples of the neurophysiological theory, but these neurophysiological effects are induced by a mechanical force to the muscle and underlying tissue. Peacock et al (2015) showed that a FR protocol targeting anteroposterior axis of the body (sagittal plane) that did not target the hamstrings, did not improve sit-and-reach scores. It was recommended that FR should be directly applied to a muscle to yield the results shown in the FR protocol of mediolateral axis of the body (frontal plane) in the study, which targeted the hamstrings and improved sit-and-reach scores. This recommendation was possibly made according to the mechanical theory, but it is not clear. However, the quadriceps were also not FR in this study, and in the FR anteroposterior protocol. This did not allow for any antagonistic effects or neurophysiological effects to take place. Therefore, it cannot be concluded that a muscle needs to be directly FR in order to achieve a result or improvement in flexibility.

Further to the antagonistic effects of FR (Cavanaugh et al 2016; Monteiro et al 2017b; Monteiro et al 2017c), cross-over effects were reported by Kelly & Beardsley (2016) who found improvements in contralateral limb flexibility for up to 10 minutes (Kelly & 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 minutes and suggest global effects of SMR through a 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 as 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 the practitioners understand when FR can be optimally used.

The effects of FR and SMR have been studied in a more acute manner. Macdonald et al (2013) has shown that FR may have acute effects on flexibility with improvements that last up to 10-15 minutes. This was the only performance study looking at the lasting effects of FR. Further to FR, an SMR study by Halperin et al (2014) found a roller massager improved ankle ROM which lasted 10 min post-intervention. Most of the performance studies measured immediate effects that were monitored up to 15min post intervention.

Recovery

There are several aspects that may affect recovery after a bout of exercise. Due to the inclusive nature of this study, not only studies involving EIMD and DOMS were included, but studies that included flexibility measures, PPT measures, temperature measures and blood flow measures.

The above-mentioned may possibly affect recovery although the studies may not have specifically studied these effects on recovery measures or in a recovery context. Pressure pain threshold and flexibility were often included as measures of recovery in the EIMD and DOMS studies.

Exercise Induced Muscle Damage (EIMD) and Delayed Onset of Muscle Soreness (DOMS)

Foam Rolling appears to be beneficial for recovery from DOMS and its physical performance

decrements. Three studies reported on outcomes in this category. Two of the three studies dealing with DOMS, showed that FR reduces DOMS and thus helps recovery from EIMD (Macdonald et al 2014; Pearcey et al 2015). Both studies suggest FR may be a useful tool to enhance recovery from training or from competition through reducing decrements associated with DOMS. FR done immediately after post-test measurements (POST-0) was effective in reducing DOMS, in terms of muscle soreness, compared to the control group; at all three measurements points, i.e. POST-24, POST-48, POST-72. Recovery from performance decrements differed between the two studies as different outcome measures were in place (Macdonald et al 2014; Pearcey et al 2015). Overall, it seemed that FR was improving physical performance post a DOMS inducing protocol, but what is important to understand is that the improvements that were noted, were improvements in physical performance back to baseline.

This is still an encouraging result because returning back to baseline means that FR may be beneficial for athletes to recover and return to their normal performance faster.

One of the three studies reported that FR was just as effective as passive rest in enhancing short-term recovery (Zorko et al 2017). It is important to note that DOMS can have its main effects between 24-72 hours post EIMD activity. This lack of difference between FR and passive rest may be a reflection of the methods used in this study where short-term recovery of contractile muscle function was measured, and no array of athletic or flexibility testing were used i.e. the tests were not functional and had no perceived pain or flexibility measurements like the other two studies. There are a few reasons why this study by Zorko et al (2017) may report no enhancement of recovery. Firstly, Zorko et al (2017) used a fatiguing protocol of three sets of 15 knee extensions at 70% of 1RM. Both Pearcey et al (2015) and Macdonald et al (2014) used 10 sets of 10 reps back squat DOMS inducing protocol at 60% of the 1RM. The different protocols may have resulted in different amounts of EIMD. Secondly, Zorko et al (2017) conducted a post test at a minimum of

48 hours after the FR protocol which may be sufficient time to passively recover from a fatiguing protocol without intervention. Both Pearcey et al (2015) and Macdonald et al (2014) used a closely watched time component and showed that POST-24 hours, symptoms of DOMS were at their worst, where the control experienced the greatest symptoms of DOMS POST-48 hours after the DOMS inducing protocol. This may be an indication for improving recovery as Macdonald et al (2014) also showed that contractile properties were significantly better than the control group all the way from POST-24 to POST-78. Myofascial Release techniques have positive effects with the potential to reduce muscle soreness, decreasing inflammation, and/or reducing adhesions between layers (Ajimsha et al 2014; Mauntel et al 2014). With SMR displaying similar effects, it may explain parts of why there may be increases in ROM, a reduction in DOMS and improved recovery. 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 it may be that FR influences these inflammatory responses through one of the above mechanisms (Macdonald et al 2014). Macdonald et al (2014) reported that their participants who performed FR following the induction of DOMS could hold a longer contraction than the control group. They theorized that this was either due to the reduction of DOMS, and/or due to possible effects on neural inhibition. 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. As mentioned previously, the mechanisms by which FR are effective remain unclear.

Flexibility

Flexibility was the most common measure throughout all the included studies. The majority of the studies found that SMR through FR leads to an acute increase in ROM. Eight of the 34 included studies focused only on flexibility measures. Six of these demonstrated an increase in flexibility after FR. These studies showed that FR enhanced flexibility (Junker & Stoggl 2015; Kelly & Beardsley 2016; Murray et al 2016), but (as discussed earlier) FR was more effective in increasing flexibility when combined with another intervention such as SS (Mohr et al 2014; Roylance et al 2013; Škarabot et al 2015) and postural alignment exercises (Roylance et al 2013). Three studies showed that FR on its own did not increase flexibility (Couture et al 2015; Griefahn et al 2017; Roylance et al 2013). There appears to be consensus that FR acutely increases flexibility, however, the time course of effects may be limited to 10 minutes (Behara & Jacobson 2017; Cheatham et al 2017a; Macdonald et al 2013; Monteiro et al 2017a; Morales-Artacho et al 2017; Peacock et al 2015; Peacock et al 2014; Su et al 2017). In the only study to explore the longer term effects of FR, Junker et al (2015) 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 previously proven contract-relax PNF stretching method (Junker & Stoggl 2015).

No specific protocol appeared to be more effective for increasing flexibility, but, a bout of FR for 45 to 90 seconds seemed to be beneficial for an acute improvement. 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 antero-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.

Two of the three 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; Roylance et al 2013) and one 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. Two of these studies also utilized a conventional uniform polystyrene foam roller with high density (Couture et al 2015; Roylance et al 2013), 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 & 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 & 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).

Pressure Pain Threshold (PPT)

Three studies concentrated on PPT as the main outcome measure (Cheatham et al 2017a; Cheatham et al 2017b; Vaughan & Mclaughlin 2014) while a further study used PPT as an outcome measure for recovery from EIMD and DOMS (Macdonald et al 2014). 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 & Mclaughlin 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 2013; 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, Vaughn et al (2014) showed that increases in PPT were transient, only lasting five minutes suggesting that these changes might be temporary adaptations to dynamic mechanisms.

Other effects

Foam rolling seems to reduce physical stress, but no more so than passive rest (Kim et al 2014). A reduction in physical 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 2013). Circulatory changes after FR were recorded as still present 30 minutes 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.

The majority of the recovery studies seemed to roll a specific muscle group for 45s to 90s to reap recovery benefits. The time was often split into 3 sets of 30s with a rest period of 15s-30s.

Combining this information with the information in the performance studies, it seems as if there is more evidence to support the use of FR for 45s to 90s. This time may or may not be separated into sets of smaller timings, such as 2 sets of 45s and/or 3 sets of 30s.

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 and in other studies, there were no instructions described. Most of the studies are limited by a small sample size and the lack of generalizable samples. Some studies tested elite athletes while others tested students at the college they attended. Athletically trained individuals and those who have performed FR before may respond differently to those who are not trained and have never 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 or meaning responses. The lack of control or sham groups may affect the true significance of the results within the studies. Martinez-Cabrera & Núñez-Sánchez (2016) showed that the control group, which was an active warm-up group, showed similar improvements in flexibility when compared to FR. This may show the significance of having a true control group in the studies, as an active warm-up may show similar improvements to FR.

There are two limitations to this review: the use of the PEDro scale and the inclusion of studies not directly related to recovery. Only using the PEDro scale as a methodological exclusion tool could have resulted in certain study types being excluded due to the PEDro scale being primarily designed for randomized control trials. An example may be studies using a cross-over design. The inclusion of studies which did not directly relate to recovery may have reduced the internal validity of this review. However, the inclusion of the flexibility, PPT and 'other' studies added benefit through information obtained.

RECOMMENDATIONS

Due to the variations in sample sizes, objective measures for performance and/or recovery, instructions related to pressure applied on the roller, and different foam rolling protocols, the results will show a lot of variation. Standardisation of the above may help in determining a true protocol and thus the effectiveness of foam rolling. Other methods of self-myofascial release may be included in future studies or reviews as they may have similar effects as foam rolling, even though the method of application may differ. The findings of this study may help future research to narrow in on a protocol and produce a high level of evidence randomised control trials with a large sample size.

CONCLUSION

Participation in sport and physical activity has numerous health benefits. However, those participating in sport and physical activities commonly experience EIMD, through DOMS, after a bout of unaccustomed exercise. Delayed onset of muscle soreness can be self-limiting and is characterised by pain, swelling, decreased ROM and the loss of muscle function. This may place the affected person at risk of injury and result in decreased competition time for the athlete, and decreased time being physically active and thus reducing health benefits. Foam Rolling has risen in popularity over the last decade and is sold by practitioners and in sports stalls. This may be a good thing as the literature shows that a FR protocol of 45 to 90 seconds is most likely effective enough to induce acute positive effects on flexibility and the reduction of DOMS, without impeding on performance measures. These times may be separated into 2 or 3 sets.

The literature shows that FR most likely does not improve performance, but rather helps the recovery of that performer back to baseline. These effects may be potentially valuable for the public and the athlete. The most significant effect is the increase in ROM without any subsequent decrease in performance. These results show that a FR may be a useful tool for athletes to use between training sessions or competition to aid recovery and allow optimum training. Having said this, FR cannot replace an active warm-up including sports specific movements and dynamic stretching. There is a lack of evidence with regards to the chronic effect of FR.

Foam rolling can be used in a warm up that includes DS and a sports specific active warm-up to enhance performance, particularly for those sports that require flexibility. Foam Rolling can be used to enhance recovery from EIMD with its effects on shortening time to return to baseline performance, flexibility and PPT evident. It may be more useful to perform FR and SS after a bout of exercise to enhance recovery and allow the athlete to be ready for their next session. The

mechanism by which FR has its effects is still unknown, but it appears FR may have a global effect. It is not advised to use a FR between sets of a workout, specifically resistance training which was the type of exercise taking place in the studies who utilized FR between sets of knee extensions. This may serve as a caution for those who are participating in tournaments, where more than one game may be played in a day, due to the risk of increased fatigue.

It cannot be concluded that FR directly enhances performance, but it appears to be a safe and potentially effective addition to an elite warm-up regime. FR may be more beneficial in the enhancement of recovery with effects on flexibility and PPT. Using harder foam rollers that exert more pressure may play an important role in obtaining positive effects. It appears that FR for too little time doesn't bring about a desired effect, too much diminished any benefit, but the middle is optimal which appeared to be 60-90s. The exact mechanism that FR obtains its benefits from is not clear, however it seems that it may be through modulation of the central nervous system.

Practical Application

1. A slow undulating bout of FR, for 2-3 sets of 45s and 30s respectively, can be done during a warm-up to enhance performance through flexibility. Best combined with a dynamic warm-up and activity specific active warm-up.
2. A slow undulating bout of FR, for 2-3 sets of 45s and 30s respectively, can be used after an exercise bout to enhance recovery from EIMD and the symptoms of DOMS, as well as reduce the feeling of fatigue.
3. Caution: Using a FR between sets may result in an increase of fatigability. Resulting in a decrease of your ability to continually produce force.
4. A multi-level rigid FR may be more effective in obtaining the effects of FR. This is a FR with PVC pipe which is surrounded by neoprene foam.

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FIGURES AND TABLES

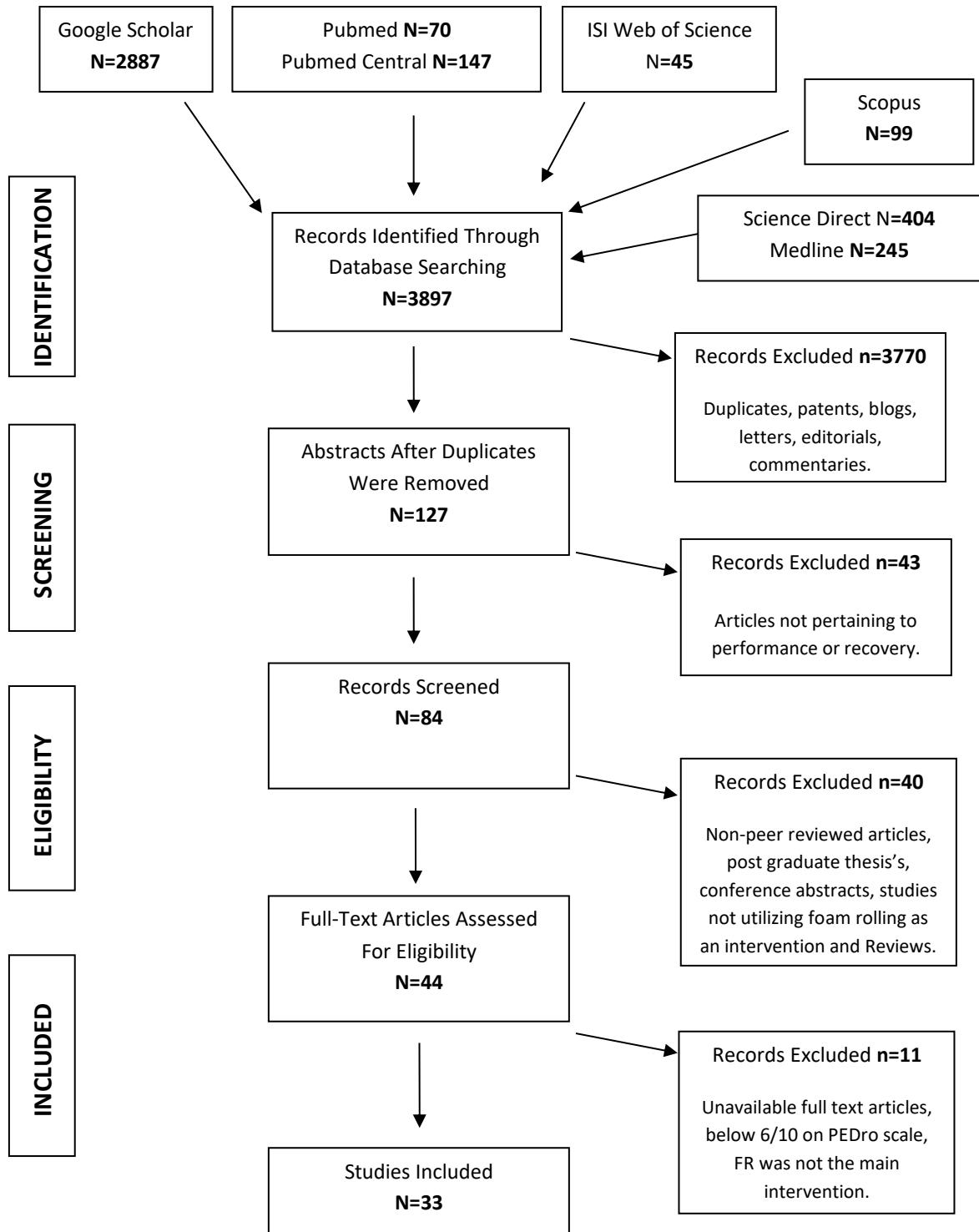


Figure 1: Summary of the study collection process

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.
<ol style="list-style-type: none"> 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 6.² 	<ol style="list-style-type: none"> 1. Date Range: January 2006 – April 2017 2. Language: English 3. Journal Type: Peer Reviewed Journals 4. Study Design: Intervention type study using a foam roller 5. Foam Rolling utilised as a tool to enhance performance and/or recovery

² 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 scores)

Study Author(s)	1	2	3	4	5	6	7	8	9	10	11	Total
1. Behara & Jacobson 2017	1	1	0	1	0	0	0	1	1	1	1	7
2. Cavanaugh et al 2016	1	1	0	1	0	0	0	1	1	1	1	7
3. Cheatham et al 2017a	1	1	0	1	1	1	1	1	1	1	1	10
4. Cheatham et al 2017b	1	0	0	1	1	0	0	1	1	1	1	7
5. Couture et al 2015	1	1	1	1	0	0	0	1	1	1	1	8
6. Griefahn et al 2016	1	1	1	0	1	1	1	1	1	1	1	10
7. Hansen et al 2016	1	1	0	1	1	0	0	1	1	1	0	7
8. Healey et al 2014	1	1	0	1	0	0	0	1	1	1	1	7
9. Hotfiel et al 2017	1	0	0	1	0	0	1	1	1	1	1	7
10. Jones et al 2015	1	1	0	1	0	0	0	1	1	1	1	7
11. Junker & Stoggl 2015	1	1	0	1	0	0	0	1	0	1	1	6
12. Kelly & Beardsley 2016	1	1	0	1	0	0	0	1	1	1	1	7
13. Kim et al 2014	0	1	0	1	0	0	0	1	1	1	1	6
14. Macdonald et al 2013	0	1	0	1	0	0	0	1	1	1	1	6
15. Macdonald et al 2014	0	1	0	1	0	0	0	1	1	1	1	6
16. Martinez-Cabrero & Núñez-sánchez 2016	1	0	0	1	0	0	0	1	1	1	1	6
17. Mohr et al 2014	1	1	0	1	0	0	0	1	1	1	1	7
18. Monteiro 2016	1	1	0	1	0	0	0	1	1	1	1	7
19. Monteiro et al 2017a	1	1	0	1	0	0	0	1	1	1	1	7
20. Monteiro et al 2017b	1	1	1	1	0	0	0	1	1	1	1	8
21. Monteiro et al 2017c	1	1	0	1	0	0	0	1	1	1	1	7
22. Morales-Artacho et al 2016	1	1	0	1	0	0	0	1	1	1	1	7
23. Murray et al 2016	1	1	1	0	1	0	0	1	1	1	1	8
24. Okamoto et al 2013	0	1	0	1	0	0	0	1	1	1	1	6
25. Peacock et al 2014	0	1	0	1	0	0	0	1	1	1	1	6
26. Peacock et al 2015	0	1	0	1	0	0	0	1	1	1	1	6
27. Pearcey et al 2015	0	1	0	1	0	0	0	1	1	1	1	6
28. Roylance et al 2013	1	1	0	1	0	0	0	1	1	0	1	6
29. Sagiroglu et al 2017	1	1	0	1	0	0	0	1	1	1	0	6

Study Author(s)	1	2	3	4	5	6	7	8	9	10	11	Total
30. Skarabot et al 2015	1	1	1	1	1	0	0	1	1	1	1	9
31. Su et al 2017	1	1	0	1	0	0	0	1	1	1	1	7
32. Vaughn & McLaughlin 2014	1	0	0	1	0	0	0	1	1	1	1	6
33. Zorko et al 2017	1	1	0	1	1	0	0	1	1	1	1	8

Table 4.1: Acute short term effects of FR on performance measures

Author	Change?	Recommend FR
Behara & Jacobson 2017	No, only increased hip flexion ROM	Yes, for warm-up as substitute for SS
Cavanaugh et al 2016	Yes, decrease	
Hansen et al 2016	No	No
Healey et al 2014	No, only post exercise fatigue	Yes, not for performance
Jones et al 2015	No	No
Macdonald et al 2013	No, only knee ROM	Yes, maintain contraction and increase ROM
Martinez-Cabrera & Núñez-sánchez 2016	No	Yes, maintain muscle stiffness and contraction time
Monteiro et al 2017a	Yes	Yes
Monteiro et al 2017b	No	No, not during inter-sets
Monteiro et al 2017c	No	No, not during inter-sets
Monteiro 2016	No, not more than 90s	No, but helps fatigue index
Morales-Artacho et al 2017	Yes	Yes, combined warm-up routine
Peacock et al 2014	Yes	Yes, combined warm-up routine
Peacock et al 2015	Yes	Yes
Sagiroglu et al 2017	No	No
Su et al 2017	Yes	Yes, combined warm-up routine

Table 4.2: Acute short term effects of FR on components of recovery

Author	Change?	Recommend FR
Cheatham et al 2017a PPT	Yes	Yes, for PPT and flexibility
Cheatham et al 2017b PPT	Yes	Yes
Couture et al 2015 Flexibility	No	No
Griefahn et al 2016 Flexibility	Yes	Yes
Hotfiel et al 2017 Other	Yes	Yes
Junker & Stoggl 2015 Flexibility	Yes	Yes
Kelly & Beardsley 2016 Flexibility	Yes	Yes
Kim et al 2014 Other	No	No
Macdonald et al 2014. DOMS	Yes	Yes
Mohr et al 2014 Flexibility	Yes	Yes, combined with static stretching protocol
Murray et al 2016 Flexibility	Yes	Yes
Okamoto et al 2013 Other	Yes	Yes
Pearcey et al 2015 DOMS	Yes	Yes
Royslance et al 2013. Flexibility	Yes	Yes, combination of static stretching or postural exercise
Skarabot et al 2015 Flexibility	Yes	Yes, combined with static stretching more effective
Vaughn & McLaughlin 2014 PPT	Yes	Yes
Zorko et al 2017 DOMS	No	No

Table 5.1: Summary of studies on the effects of FR on performance

Author	PEDro Score (LOE)	Aim	N	Subjects/ Population	Protocol	Outcome Measures	Findings
Behara & Jacobson 2017	7/11	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	<p>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.</p> <p>FR: rolling each extremity unilaterally (hamstrings, quadriceps, gluteus maximus, and gasrocnemius). 8min in total.</p> <p>DS: done on the same muscle groups co-ordinated to reflect the same time as FR. Total 8min.</p> <p>Instruction: Did not mention instructions with regard to pressure applied on FR.</p> <p>Foam roller: The Rumble Roller equipped with raised nodules</p>	<p>VJ power (Watts) and Velocity (m·s⁻¹) recorded with Tendo® Speed Analyzer</p> <p>Knee Isometric torque- quadriceps and hamstring – Biodex System 4 Pro® dynamometer.</p> <p>Hip flexion ROM with Baseline® Bubble Inclinometer</p>	<p>FR neither benefited or deterred maximal isometric strength or velocity.</p> <p>Appears to enhance ROM</p> <p>May be an appropriate substitute for SS as a warm up due to SS potential interference with strength and power</p>
Cavanaugh et al 2016	7/11	Foam Rolling of the quadriceps decreases biceps femoris activation	18	Recreationally active men (10) and women (8)	<p>4 randomised experimental conditions separated by 24-48 hours included rolling of the 1) Hamstrings, 2) quadriceps, 3) both muscle groups and 4) a control session.</p> <p>Warm up of 5-minutes of lower body cycling, highest of 3 vertical jumps 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.</p> <p>FR: 4 sets of 45s with 15s rest in between at a cadence of 40bpm.</p> <p>Control: sit for 4 minutes</p> <p>Instruction: Apply as much pressure as possible on the FR.</p> <p>Foam roller: closed cell expanded polypropylene pro foam Roller</p>	<p>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</p> <p>Perceived pain on VAS scale</p>	<p>FR a muscle group may alter antagonist muscle activity</p> <p>Changes in activation are likely a result of reciprocal inhibition due to increased agonist pain perception</p> <p>Men and women respond similarly</p>

Hansen et al 2016	7/11	To determine a dose-response relationship between MR and anaerobic power output in active college-aged males	19	College-aged males, classified as healthy and physically active	<p>Baseline Wingate test was done. Immediately following completion of the FR treatment, participants began a 3-min self-paced warm-up using 1kg 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.</p> <p>Four different pre-exercise conditions were performed: Control, 30s, 60s, and 90s of SMR. Participants completed 30s Wingate tests following each pre-exercise condition to assess anaerobic power. Each condition was completed on non-consecutive days.</p> <p>FR: Quadriceps, hamstrings, iliotibial band, hip adductors, gluteus maximus, hip flexors, gastrocnemius and soleus.</p> <p>Instruction: Participants applied self-selected pressure on the FR.</p> <p>Foam Roller: 92 x 15 cm high-density foam roller</p>	<p>Wingate test on Monark 894E Peak Bike and Monark Anaerobic Test software version 3.3.0.0</p> <p>Variables measured: peak power output, average power output, percent power drop, and minimum power output.</p>	<p>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.</p>
Healey et al 2014	7/11	To determine whether the use of FR before athletic tests can enhance performance	26	Healthy college aged individuals who were recreationally active. 13 men and 13 women.	<p>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 foam rolling in the first trial, and the other half performed planking in the first trial. The groups changed over to either planking or foam rolling in the second trial, depending on what they had done in the first trial.</p> <p>Participants completed 4 athletic tests post-intervention.</p> <p>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).</p> <p>Planking: 5x30 sec. Same amount of time as FR protocol</p> <p>FR: 30 sec on each muscle- quadriceps, hamstrings, calves, latissimus dorsi, and the rhomboids.</p> <p>Instruction: No pressure specified</p> <p>Foam Roller: non-uniform cylinder consisting of a hollow polyvinyl chloride inner core.</p>	<p>Likert scale.</p> <p>Isometric force via isometric squat.</p> <p>Vertical jump measurements (height and power).</p> <p>Pro agility using the 5-10-5 yard shuttle run.</p>	<p>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.</p>

Jones et al 2015	6/11	To determine the effects of FR on VJ performance	20	Recreationally trained males. Kinesiology students.	<p>Participants underwent 3 days of testing separated by at least 24 hours. 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 hours.</p> <p>Warm-up: High knee pulls, Frankenstein's, and forward gate swings for 20 meters each.</p> <p>CON: 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 repetitions.</p> <p>FR: 30s bout for each muscle group: gastrocnemii, quadriceps, hamstrings, glutei, in that order. Both sides were rolled simultaneously.</p> <p>Instruction: No mention of pressure applied.</p> <p>Foam Roller: 36 inch high-density foam roller</p>	VJ height on a force plate using a vanes device. Jump height, impulse and relative ground reaction force were measured.	30 second bouts of lower body FR do not improve VJ performance
Macdonald et al 2013	6/11	To determine the effect of SMR via FR application on knee extensor force and activation and knee joint ROM.	11	Healthy males, University population, recreationally resistance-trained.	<p>4 sessions with 24-48hr interval between sessions. Variables measured Pre-condition, 2 and 10 minutes' Post-condition.</p> <p>Warm up= 5min Monark cycle ergometer.</p> <p>Control received no SMR.</p> <p>FR: quadriceps for 2x1min bouts with 30sec interval.</p> <p>Instruction: place as much of their body mass as possible onto the foam roller</p> <p>Foam Roller: Hollow PVC pipe surrounded by 1-inch of neoprene foam</p>	Knee extensor force (extension table). Rate of force development. Muscle activation (Knee extension isometric contractions). Modified kneeling lunge (knee ROM).	An acute bout of slow undulating FR of the quadriceps increases ROM, but had no significant impact on knee extensor force or activation.
Martinez-Cabrera & Núñez-sánchez 2016	(6/11)	To determine the acute effect of a foam roller on the mechanical properties of the rectus femoris based on tensiomyography in soccer players	17	Male professional soccer players	<p>8 min cycling warm up. TMG assessment. FR protocol (2sets). TMG assessment. FR protocol (2 sets)</p> <p>TMG measurements were performed at rest after warm-up, after two sets of FR, and after four sets of FR. Only on the dominant leg.</p> <p>FR: 4 sets of FR with a duration of 15s using the FR on the dominant leg at 30 beats per min with 2min of rest</p> <p>Foam roller: PVC pipe with neoprene foam surrounding</p>	TMG with parameters of stiffness (Dm) and contraction time (Tc).	Use of a FR in slowly executed small sets maintains the muscle stiffness and the contraction time of the RF.

					Instructions: to place all of their body mass over the leg and using their arm to make the movement		FR is useful for activating muscle and can be used in programs aimed to maintain the level of muscle stiffness
Monteiro et al 2017a	7/11	To determine the acute effects of different SM volumes on the FMS overhead deep squat performance	20	Recreationally active, resistance-trained females	<p>2 experiments were conducted, roughly separated by 2-3 months. 4 sessions, session 1 & 2 consisted of baseline testing, session 3 consisted of SM to the lateral thigh, and session 4 consisted of SM applied to the torso and plantar fascia. SM was done either with a FR or a tennis ball.</p> <p>Experiment 1- FR performed to the both lateral thighs unilaterally- 4 different single set SM with FR protocols P30, P60, P90, P120 per side. 15min intervals between each protocol.</p> <p>Experiment 2- FR was used to roll the lateral side of the trunk while the plantar surface of the foot was rolled over a tennis ball. During 3rd and 4th visit, single-set SM protocols P30, P60, P90, P120 were performed. After each protocol, participants were scored on their performance of the overhead deep squat. 60 minutes between protocols.</p> <p>Instruction: Participants were instructed to exert as much pressure as possible.</p> <p>Foam Roller: The Grid Foam Roll</p>	FMS overhead deep squat score	SM appears to be an effective modality for inducing acute improvements in the performance of the FMS overhead deep squat in all conditions tested.
Monteiro et al 2017b	8/11	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	<p>10 RM testing and retesting using the knee extension machine. Warm-up 2 sets of 15 repetitions at 50% of normal training load.</p> <p>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 foam rolling volumes (FR60 and FR120) were randomized in a randomized, counterbalanced fashion. For both conditions, three sets were performed with four minutes of rest between each set. There was a 10min break between FR protocols to avoid fatigue.</p>	6 sets of 10 RM Knee extensions to concentric failure.	The results suggest that more inter-set foam rolling applied to the antagonist muscle group is detrimental to the ability to continually produce force. Decreases in maximum

					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		repetition performance has implications for FR prescription and implementation, in both rehabilitation and athletic populations
Monteiro et al 2017c	7/11	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 hours 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 repetitions completed	Interest 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 2016	7/11	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 CONT. 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. Each interest Rolling was done on different occasions. As well as a visit for CONT, which consisted of a 4min passive rest. Instructions: No mention with regard to pressure applied. Foam roller: The Grid Foam Roller	10 RM testing Fatigue index (%)	The FR fatigue index declined (less fatigue resistant) compared to the CONT condition. FR for more than 90s could be detrimental to the ability to continually produce force.

Morales- Artacho et al 2017	7/11	Comparing the effects of a cycling warm-up and a FR warm-up on hamstring stiffness	14	Physically active (recreationally active) males.	<p>4 separate testing sessions. Each session included a warm-up condition: Control, Cycling, Foam Rolling, or Cycling plus FR (mixed). Conducted in random order 3 days apart. Start of each session participant lay in relaxed lying position for 30min. Pre-tests done, then post-tests 5 and 30min after warm up condition.</p> <p>Control- 15min period in a lying position on a padded bench</p> <p>Cycling protocol- 5min cycling at 40%, 5min at 60% of maximum power followed by 5x 6s all out sprints every minute for 6 minutes.</p> <p>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 30-second rest between sets. Metronome controlled at 27 bpm.</p> <p>Mixed protocol: first cycling warm up protocol followed by FR protocol, separated by 2min rest. Total duration was a 30min warm-up</p> <p>Instruction: No instruction given with regard to pressure applied</p> <p>Foam Roller: The Grid foam roller</p>	<p>5 min incremental cycling test for maximal aerobic power output</p> <p>Passive Hip flexion ROM measured with dynamometer</p> <p>Shear modulus measured with an ultrasound scanner as an index of stiffness</p> <p>Muscle contractility via surface EMG</p>	<p>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</p> <p>Performing passive tasks (FR) at the start of a warm-up routine (before active tasks) may help maximise reductions in muscle stiffness. Evidence is not conclusive.</p>
Peacock et al 2014	6/11	To determine if an acute bout of FR SMR in addition to a dynamic warm-up could influence performance	11	Athletically trained males	<p>Subjects participated in 2 separate experimental trial conditions, separated by a 7-day recovery period. The first trial consisted of a 5min general warm up (jogged 1000m), followed by a 5min range of dynamic warm up techniques (each technique followed a 2sets of 10reps scheme). The second trial began with the same general warm up for 5min, followed by a SMR routine utilizing a FR, then followed by the same 5min dynamic warm up routine as performed in the first trial.</p> <p>FR: 6 muscle groups were rolled and each group was rolled with 5 strokes in 30s. Muscle groups: Thoracic/Lumbar, gluteals, hamstrings, calves, pectorals, and quadriceps.</p> <p>Instruction: No instruction given with regard to pressure applied</p>	<p>Performance tests were S&R, VJ, standing long jump, indirect 1 RM bench press, and a 37m sprint. 4min rest intervals were used between each measure.</p>	<p>A warm-up routine consisting of both a dynamic and foam rolling routines resulted in overall improvements in athletic performance testing.</p>

					Foam Roller: Conventional foam roller, High Density Moulded Foam Roller – 6” x 12” Round.		
Peacock et al 2015	6/11	To investigate differences in FR progressions	16	Athletically trained males	All subjects underwent two common FR progressions in regard to performance testing. The two conditions included FR progression targeting the mediolateral (ml) axis of the body, and FR progression targeting the anteroposterior (ap) axis (5 rolls per 30sec). 7 days separated each condition. FRml: inferior spine region, the medial gluteal region, the hamstring region, the posterior calf region, the pectoral region and the quadriceps region. FRap: latissimus dorsi, obliques, side hip, iliotibial band, side calves, and adductors. Instructions: No mention of pressure applied. Foam Roller: Conventional foam roller, High Density Moulded Foam Roller – 6” x 12” Round.	Performance testing: VJ, broad jump, shuttle run, bench press, S&R, ratings of perceived exertion and preference.	FR in targeting the ml axis of the body was effective at improving stability when compared to FR targeting the ap axes. No other differences were found between progressions. Athletes preferred FRml over FRap.
Sagiroglu et al 2017	(6/11)	Residual effects of SS and SMR exercises on flexibility and lower body explosive strength in well-trained combat athletes	16	Well-trained male combat athletes	5 min light running, 3 sub-maximal CMJ's with 10s rest between the two, pre-tests, 2 min of passive rest, then SMR or SS. SS: 4 stretching exercises, 2x 30s with 10s of passive rest for each side. 30s rest between each exercise. Muscles stretched were the hamstrings, quadriceps, glutei, and gastrocnemius. FR: 5 rolls per 30s with as much pressure as possible. Applied to hamstrings, quadriceps, glutes, and gastrocnemius. 2x 30s with 10s of passive rest. 30s of rest between exercises. Instruction: Apply as much pressure as possible Foam Roller: Grid foam roller cylinder	S&R test with S&R testing box. CMJ with Myotest Pro System.	SMR may have a detrimental effect on CMJ and S&R performance. a) SMR presents no advantage over AR or SS in terms of enhancing flexibility, b) no statistically significant inhibitory effect of SMR on the CMJ was detected, and c) SS appeared to have an inhibitory effect on CMJ for approximately 15 minutes.

Su et al 2017	7/11	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	<p>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.</p> <p>FR: 2x 30s on anterior thigh bilaterally, then 2x 30s on posterior thigh. Repeat 3 times (Roughly 6 min duration)</p> <p>SS: Stretch to mild discomfort. Bilateral quadriceps and hamstrings stretched 3x 30s each (Roughly 6 min duration).</p> <p>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.</p> <p>Instructions: place as much body weight as possible.</p> <p>Foam Roller: PVC pipe with EVO foam surrounding.</p>	<p>Isokinetic peak torque of knee extensor and flexor</p> <p>Biodex isokinetic dynamometer</p> <p>Flexibility of quadriceps measured by Thomas test</p> <p>Flexibility of hamstring by S&R test.</p>	<p>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.</p>
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FR- Foam Rolling; **SS-** Static stretching ; **ROM-** Range of Motion; **SMR-** Self Myofascial Release; **PWV-** Pulse wave velocity; **NO-** Nitric Oxide; **GH-** Growth Hormone; **RM-** Repetition Maximum; **SJ-** Squat Jump; **CMJ-** Countermovement Jump; **VJ-** Vertical jump; **DJ-** Depth Jump; **reps-** Repetitions; **min-** Minutes; **s-** Seconds; **BFR-**Bio-Foam Roller; **MRR-** Multilevel rigid roller; **m-** meters; **n-** Number; **LOE-** Level of Evidence; **SLR-** Straight Leg Raise; **TMG-** Tensomyography; **SM-** Self-Massage; **FMS-** Functional Movement Screen; **RM-** Repetition Maximum; **ml-** mediolateral; **ap-** anteroposterior; **S&R-** Sit-and-Reach; **EMG-** Electromyography; **CONT-** Control

Table 5.2: Summary of studies on the effects of FR on recovery

Author	PEDro Score (LOE)	Aim	N	Subjects/ Population	Protocol	Outcome Measures	Findings
Cheatham et al 2017a PPT	10/11	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 second, followed by 4 knee bends to 90 degrees. 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 et al 2017b PPT	7/11	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 second. Then the participants were instructed to stop at the one of the zones and perform 4 knee bends to 90 degrees. The sequence was repeated for 2 minutes. 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 minute FR intervention with a rigid foam roller
Couture et al 2015 Flexibility	8/11	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 degrees. Measured with goniometer Pressure exerted – digital scale.	Self-Administered FR for a total up to 2min is not adequate to induce improvements in knee joint flexibility.

Griefahn et al 2016 Flexibility	10/11	To determine if exercises with FR have a short-term impact on the thoracolumbar fascia	38	Healthy athletic men (13) and women (25)	Measurements were executed before the intervention and exactly 10min after the treatment. 3 treatment groups: Control group, placebo group and a foam roll group. CON: 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. Foam roller: not mentioned	Mobility of TLF-determined using a sonographic measurement. Lumbar flexion-Modified Schober test. Mechanosensitivity-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	7/11	To determine the acute effects of lateral thigh FR on arterial tissue perfusion determined by spectral Doppler and power Doppler ultrasound	21	Healthy participants from the medical and sports faculty. 12 male students and 9 female students.	Baseline Doppler examinations were done under resting conditions. Then participants were re-examined directly after (1min) and 30 minutes after prescribed FR intervention. FR: 3 sets of 45s of FR on the lateral thigh. 20s rest between each set. Instructed to place as much pressure as tolerable. 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. The advantages of enhanced blood flow are relevant for warm-up and recovery. These changes could still be detected at 30min post intervention.
Junker & Stoggl 2015 Flexibility	(6/11)	To determine the effect of a 4-week training period of the foam roll method on hamstring flexibility	47	Recreationally active male participants	5-10 min of light jogging warm –up. Measurements done before and after intervention period of 4 weeks. The intervention period consisted of 3 training sessions per week for 4 weeks. 3 intervention groups, a FR group, a PNF group and a CON group. FR- Rolled hamstrings unilaterally for 30-40 seconds (10 times back and forth). This was repeated on both legs for 3 sets in 1 session.	Stand and reach test done on a box (cm)	The Foam Roll can be seen as an effective tool to increase hamstring flexibility within 4 weeks. The effects are comparable with

					PNF- Performed 3 separate PNF stretches at approximately 25% of their maximal voluntary isometric contraction with each leg. Used a rope or towel for assistance, a 6s contraction was held, then muscle relaxed and stretched into next barrier for 10s. This was repeated 3 times equal to 1 set. 3 sets were performed. Both legs were stretched alternately. CON- no intervention. Only tests were done. Advised to maintain normal training routine. Instruction: roll within PPT Foam Roller: not mentioned		scientifically proven contract-relax PNF stretching method.
Kelly & Beardsley 2016 Flexibility	7/11	To determine the specific and cross-over effects of FR on ankle DF ROM	26	16 male and 10 female recreationally active university students.	Warm-up of 10 double-leg heel raises to the floor. Baseline DF ROM for both ipsilateral and contralateral legs at 0, 5, 10, 15, and 20min following the CON protocol or the FR protocol. CON- 2 min long sitting rest position FR- 3 sets of 30 s FR of the plantar flexors on the dominant leg. 10 s rest between sets. Total time of 2min. 1 st set focus on lateral aspect, 2 nd set focus on middle aspect, 3 rd 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	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.
Kim et al 2014 Other	6/11	To examine the effect of SMR induced with a FR on the reduction of stress by measuring the serum concentration of cortisol	24	Healthy females in their 20's	Walk 30min on treadmill, 10ml blood was collected after the 30 minute walk, and blood collected from the subjects after 30 minutes of the SMR program or after the 30 minutes of rest. CON: 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 minutes. During the 30-min SMR program, pressure was applied on a single spot for 30 seconds using the subject's body weight in order to stimulate the corresponding muscle over a period of 3 to 6 minutes as a means of alleviating muscle tension in the spine and areas around the 4 limbs Instructions: no pressure instructions mentioned Foam Roller: Not mentioned	Serum cortisol levels	SMR induced with a FR did not significantly affect the reduction of stress.

Macdonald et al 2014. DOMS	6/11	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, foam rolling. This is repeat post-24-hrs, post-48-hrs, and post-72-hrs. Each session was separated by 24h. Except session 1 & 2 separated by 96h. DOMS inducing protocol- 10 x 10 back squats, 60% the participants 1 RM. CON: 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 degrees. VJ height.	Decreased muscle soreness while improving VJ height, muscle activation, and passive and dynamic ROM. Negatively affected several evoked contractile properties of the muscle
Mohr et al 2014 Flexibility	7/11	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	6 sessions (separated by 48 hours each) where passive hip flexion was measured before and immediately after SS, FR and SS, FR, or nothing. SS: held for 1 minute and rest for 30s (x3). FR: from ischial tuberosity to popliteus fossa (1sec down and 1sec up) 3x 1-minute repetitions with a 30sec break in between. Instructions: allow as much pressure as possible Foam Roller: Cando EVA foam roller	Passive SLR ROM measured with a baseline bubble inclinometer.	Results support the use of a FR combined with static stretching protocol. However, there was an increase in ROM across all treatment groups.
Murray et al 2016 Flexibility	8/11	Sixty seconds of FR does not affect functional flexibility or change muscle temperature in adolescent athletes	12	Male adolescent squash players from an elite sports school	Testing on 2 separate occasions separated by 7-12 days. One occasion was treatment, other was a control. Tests done 0, 5, 10, 15 and 30 min post intervention. Control: Prone lying for same duration as FR protocol. Treatment: FR of 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	Single 60s bout of FR to the quadriceps induces small significant change in flexibility. Muscle contractility and temperature remain unchanged.

						TMG assessment for muscle contractility	
Okamoto et al 2013 Other	6/11	To determine the acute effect of FR on arterial stiffness and vascular endothelial function.	10	Healthy individuals. 7 men and 3 women.	Control and experimental went on different days, 3 days apart. Tested before and 30min after both trials. Each session= 15min. CON: rested in supine for the same amount as the FR treatment time FR: 20 reps on each muscle group with a 1min interval. Muscles: Adductors, Hamstrings, Quadriceps, ITB and Trapezius. Instructions: No mention of pressure applied Foam Roller: 15 x 91-cm uniform polystyrene roller	S&R, Brachial-ankle PWV, an index of arterial stiffness, and plasma NO concentration.	SMR using a FR reduces arterial stiffness and improves vascular endothelial function.
Pearcey et al 2015 DOMS	6/11	To examine the effects of FR as a recovery tool after and intense exercise protocol	8	Healthy physically active males	Testing session 1 (consisting of baseline measurements and the DOMS protocol) commenced 24 to 48 hours after the control or foam-rolling orientation session. Testing sessions 2, 3, and 4 were conducted at 24, 48, and 72 hours. Participants performed 2 conditions, separated by 4 weeks, involving 10 sets of 10 repetitions of back squats at 60% of their 1-RM, followed by either no FR or 20min of FR immediately, 24, and 48 hours post-exercise. FR: performed for 45s with 15s break for each muscle group at a cadence of 50 beats per minute (ie, 1 rolling motion per 1.2 seconds). Foam. This resulted in 15min of Foam rolling and 5min of rest. Muscles: Quadriceps, Hip adductors, hamstrings, iliotibial band, and gluteals. Instructions: place as much body mass as tolerable on the foam roller at all times Foam Roller: custom-made with a hollow polyvinylchloride pipe (10.16-cm outer diameter and 0.5-cm thickness) and was surrounded by neoprene foam (1-cm thickness)	PPT (Algometer), sprint speed (30m sprint time), power (broad-jump distance), change of direction (T test), and dynamic strength-endurance (Barbell back squats at 35% of 1 RM).	FR effectively reduced DOMS and associated decrements in most dynamic performance measures
Roylance et al 2013. Flexibility	6/11	To compare the acute effect of SMR, postural alignment exercises and SS on joint ROM	27	University students. 14 males and 13 females.	Participants completed three S&R tests pre and post intervention and two treatments during each testing session. Completed 2 sessions with a 24 -48h gap in between. 2 groups performing FR & SS or FR & postural exercises.	S&R test via sit and reach box.	Acute treatment of FR increased joint ROM when combined with

					<p>Session 1 (30-40min): S&R test, FR treatment (10min), S&R test, postural exercise or SS (10 min) treatment, S&R test.</p> <p>Session2 (30-40min): same test sequence with postural exercise or SS done first and then FR treatment after.</p> <p>FR: total of 10 min rolling the lower back, upper back, Gluteus Maximus and Piriformis, Hamstrings and Gastrocnemius.</p> <p>Instructions: no instructions with regard to pressure provided</p> <p>Foam Roller: Cylindrical foam roller made of densely packed foam</p>		either postural alignment exercises or SS.
Skarabot et al 2015	9/11	Comparing the effects of SMR with SS on ankle ROM in adolescent athletes	11	Resistance trained adolescent swimmers. 5 females and 6 males.	<p>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.</p> <p>SS: Single plantarflexion stretch, 3 sets of 30s. 15s rest in between. Standing with leg on edge of bench.</p> <p>FR: 3x 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.</p> <p>FR and SS combined both protocols</p> <p>Instructions: to exert as much pressure on the foam roller as possible</p> <p>Foam Roller: The Grid Foam Roller</p>	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 minutes.
Vaughn & McLaughlin 2014	6/11	To investigate the effect on the PPT following the application of a foam roller to the ITB of asymptomatic participants	18	Student population of the Victoria University Osteopathic Medicine University	<p>3 points on the participants ITB of the right leg were marked. Measurements were taken pre-intervention, post-intervention and five minutes post-intervention. Participants completed a single 3-minute bout on the foam roller.</p> <p>FR:</p> <p>Instructions: no instruction with regards to pressure</p> <p>Foam Roller: Comffit Pilates foam roller, with medium density foam</p>	Pressure pain threshold using a Pressure algometer	FR the ITB produces an immediate increase in the PPT of the lower thigh in asymptomatic participants. The immediate increased PPT was ameliorated 5 minutes later.

Zorko et al 2017 DOMS	8/11	The acute effect of SM on the short-term recovery of muscle contractile function	10	Recreationally active college aged individuals (18-24 years old). 9 males and 1 female	2 visits, 48 hours 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. Then a maximal voluntary contraction done for peak torque analysis, then direct muscle stimulation to determine single twitch of the quadriceps in a relaxed position. 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	Maximal Voluntary Isometric Contraction Direct muscle stimulation through electrodes and biphasic electrical current of the quadriceps.	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
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FR- Foam Rolling; **SS-** Static stretching ; **ROM-** Range of Motion; **SMR-** Self Myofascial Release; **PWV-** Pulse wave velocity; **NO-** Nitric Oxide; **GH-** Growth Hormone; **RM-** Repetition Maximum; **SJ-** Squat Jump; **CMJ-** Countermovement Jump; **DJ-** Depth Jump; **reps-** Repetitions; **s-** Seconds; **h-** Hours; **min-** Minutes; **BFR-**Bio-Foam Roller; **MRR-** Multilevel rigid roller; **n-** Number; **LOE-** Level of Evidence; **SLR-** Straight Leg Raise; **ITB-** Illio-tibial Band; **PPT-** Pressure Pain Threshold; **TLF-** Thoracolumbar Fascia; **PNF-** Proprioceptive Neuromuscular Facilitation; **DF-** Dorsiflexion; **ml-** Millilitres; **DOMS-** Delayed Onset of Muscle Soreness; **S&R-** Sit-and-Reach; **TMG-** Tensomyography; **SM-** Self-Massage

APPENDICES

Appendix A:

The Journal of Bodyworks and Movement Guidelines

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Single quotation are used to express a quote marks (Matthews (1989) suggests, 'The best type of?') while double quotation marks are used for a quote within a quote or to emphasise a word within a quote.

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Section and topic	Item No	Checklist item
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Title:		
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Update	1b	If the protocol is for an update of a previous systematic review, identify as such
Registration	2	If registered, provide the name of the registry (such as PROSPERO) and registration number
Authors:		
Contact	3a	Provide name, institutional affiliation, e-mail address of all protocol authors; provide physical mailing address of corresponding author
Contributions	3b	Describe contributions of protocol authors and identify the guarantor of the review
Amendments	4	If the protocol represents an amendment of a previously completed or published protocol, identify as such and list changes; otherwise, state plan for documenting important protocol amendments
Support:		
Sources	5a	Indicate sources of financial or other support for the review
Sponsor	5b	Provide name for the review funder and/or sponsor
Role of sponsor or funder	5c	Describe roles of funder(s), sponsor(s), and/or institution(s), if any, in developing the protocol
INTRODUCTION		
Rationale	6	Describe the rationale for the review in the context of what is already known
Objectives	7	Provide an explicit statement of the question(s) the review will address with reference to participants, interventions, comparators, and outcomes (PICO)
METHODS		
Eligibility criteria	8	Specify the study characteristics (such as PICO, study design, setting, time frame) and report characteristics (such as years considered, language, publication status) to be used as criteria for eligibility for the review
Information sources	9	Describe all intended information sources (such as electronic databases, contact with study authors, trial registers or other grey literature sources) with planned dates of coverage
Search strategy	10	Present draft of search strategy to be used for at least one electronic database, including planned limits, such that it could be repeated
Study records:		
Data management	11a	Describe the mechanism(s) that will be used to manage records and data throughout the review
Selection process	11b	State the process that will be used for selecting studies (such as two independent reviewers) through each phase of the review (that is, screening, eligibility and

		inclusion in meta-analysis)
Data collection process	11c	Describe planned method of extracting data from reports (such as piloting forms, done independently, in duplicate), any processes for obtaining and confirming data from investigators
Data items	12	List and define all variables for which data will be sought (such as PICO items, funding sources), any pre-planned data assumptions and simplifications
Outcomes and prioritization	13	List and define all outcomes for which data will be sought, including prioritization of main and additional outcomes, with rationale
Risk of bias in individual studies	14	Describe anticipated methods for assessing risk of bias of individual studies, including whether this will be done at the outcome or study level, or both; state how this information will be used in data synthesis
Data synthesis	15a	Describe criteria under which study data will be quantitatively synthesised
	15b	If data are appropriate for quantitative synthesis, describe planned summary measures, methods of handling data and methods of combining data from studies, including any planned exploration of consistency (such as I^2 , Kendall's τ)
	15c	Describe any proposed additional analyses (such as sensitivity or subgroup analyses, meta-regression)
	15d	If quantitative synthesis is not appropriate, describe the type of summary planned
Meta-bias(es)	16	Specify any planned assessment of meta-bias(es) (such as publication bias across studies, selective reporting within studies)
Confidence in cumulative evidence	17	Describe how the strength of the body of evidence will be assessed (such as GRADE)

*** It is strongly recommended that this checklist be read in conjunction with the PRISMA-P Explanation and Elaboration (cite when available) for important clarification on the items. Amendments to a review protocol should be tracked and dated. The copyright for PRISMA-P (including checklist) is held by the PRISMA-P Group and is distributed under a Creative Commons Attribution Licence 4.0.**

From: Shamseer L, Moher D, Clarke M, Ghersi D, Liberati A, Petticrew M, Shekelle P, Stewart L, PRISMA-P Group. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015: elaboration and explanation. BMJ. 2015 Jan 2;349(jan02 1):g7647.

PART D: SUMMARY AND CONCLUSION

Summary

Foam Rolling has popularised SMR in the last decade, and along with its popularity has come an increase in research. The number of articles available on the subject of SMR and FR have more than doubled since 2015. For example, a systematic review performed on various SMR tools in 2015 only included nine studies in the performance enhancing section (Cheatham et al., 2015). Of those nine, six of the studies involved the use of a FR as a performance enhancing tool. In this Review, there were 16 studies that used FR as a performance enhancing tool. The search for this current review was performed in April 2017 and the numbers are sure to have increased since then. However, to our knowledge, this was the first systematic review investigating the effects of FR on enhancing performance and recovery from EIMD and DOMS. These were the objectives for the review:

1. To identify current knowledge on the effects of Foam Rolling on performance and recovery post EIMD.

Foam Rolling seems to enhance performance through its effects on flexibility without attenuating muscle activation. Thus, FR has been recommended to be used prior to activities which require flexibility integrated into an active warm up. In addition, FR seems to improve recovery from EIMD through attenuating the symptoms of DOMS, such as increased muscle soreness, decreased flexibility and decrease performance decrements. Foam Rolling helped those with EIMD reach their baseline performance scores sooner than control groups.

2. To identify whether a specific Foam Rolling protocol has been found to enhance performance.

There was heterogeneity among the studies in terms of methods used in the application of FR. Few studies controlled the tempo of the FR. It appears that FR applied for 60 to 90 seconds may give optimal results. This could be done as two sets of 45s on each muscle group targeted, before a bout of exercise, at a slow and undulating pace. It cannot be said how much pressure should be applied to the FR, but most of the studies instructed the participants to apply as much weight as possible. This allows pain or discomfort to be the limiting factor for pressure applied.

3. To identify whether a specific Foam Rolling protocol has been found to enhance recovery.

A general protocol has been suggested as above as there were similar variations in protocols across all the study categories. Therefore, two sets of 45s of FR on each muscle group targeted, before a bout of exercise, at a slow and undulating pace at the maximum pressure tolerated.

4. To consider the current research on Foam Rolling and its effects on performance and recovery for training implications and further research recommendations.

The current research suggests that the mechanisms underlying the effects of FR may differ to those of SS. When FR and SS are combined, the effects on flexibility were superior to those when either intervention was used alone. There was also a reported cross-over effect to the contra-lateral leg, as well as a global effect on flexibility when one area was rolled. Blood flow seems to increase with FR, but not an associated temperature increase. There are many findings that need to be consolidated by more research exploring the underlying mechanisms.

Understanding of the mechanisms of FR may give us more insight into its benefits and harms. There has not been a focus on the risks of FR which is surprising as the high pressure mechanical loads directly applied to the muscle may have a risk of injury. The only research that demonstrated a possible risk for FR were the three studies by Montero et al (Monteiro, 2016; Monteiro et al, 2017a; Monteiro et al, 2017b; Monteiro et al, 2017c) that showed inter-set FR reduced the number of knee extension repetitions performed. This increased fatigability and hindrance in participants' ability to continue to produce force, may be the first signs of risks for FR.

Future research needs to use similar or the same objectives as those of previous studies to create some homogeneity in the literature. This will allow for a more effective systematic review with the potential for meta-analysis. At present, because of the variations in outcome measures, this review had to take a narrative approach to the topic of FR. Variations in the reviewed studies were in populations, outcome measures, areas foam rolled, the FR tool used and the method of FR application (time and intensity/pressure). Most the studies are limited by small sample sizes and the variation in the population tested. Almost all these studies lacked a true control as both the control groups underwent a warm up to avoid injury to the participants and none of the studies used sham procedures in the control arm.

There are two limitations to this review: the use of the PEDro scale potentially resulting in the exclusion of study types which may have been relevant and the inclusion of studies not directly relating to recovery.

Conclusion

This study has searched and summarized current knowledge around FR. The focus of the review was on the effectiveness of FR on enhancing performance and recovery from EIMD. In addition, insight into mechanisms of action, protocols and risks have been obtained. However, the research is still inconclusive as there is still a paucity of well conducted research with strict protocols and methods which can generate statistically significant data. A lot of research is being done on other SMR modalities such as the Roller Massager, the Stick and various trigger point therapy balls. An updated systematic review on SMR more widely could help generate greater knowledge of FR mechanisms. From the findings of the systematic review, the following practical applications were drawn for the benefit of clinicians:

- A slow undulating bout of FR, for 2-3 sets of 45s and 30s respectively, can be done during a warm-up to enhance performance through flexibility. Best combined with a dynamic warm-up and activity specific active warm-up.
- A slow undulating bout of FR, 2-3 set of 45s and 30s respectively, can be used after an exercise bout to enhance recovery from EIMD and the symptoms of DOMS, as well as reduce the feeling of fatigue.
- Caution: Using a FR between sets may result in an increase of fatigability. Resulting in a decrease ability to continually produce force.
- A multi-level rigid FR may be more effective in obtaining the effects of FR. This is a FR with PVC pipe which is surrounded by neoprene foam.

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Appendices

Appendix A:

The Journal of Bodyworks and Movement Guidelines

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Avoid the use of first person ('I' statements) and second person ('you' statements). Third person, objective reporting is appropriate. In the case of reporting an opinion statement or one that cannot be referenced, the rare use of 'In the author's opinion?' or 'In the author's experience?.' might be appropriate. If in doubt, ask the editor or associate editor for assistance.

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Single quotation are used to express a quote marks (Matthews (1989) suggests, 'The best type of?') while double quotation marks are used for a quote within a quote or to emphasise a word within a quote.

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PRISMA-P (Preferred Reporting Items for Systematic review and Meta-Analysis Protocols) 2015 checklist: recommended items to address in a systematic review protocol*

Section and topic	Item No	Checklist item
ADMINISTRATIVE INFORMATION		
Title:		
Identification	1a	Identify the report as a protocol of a systematic review
Update	1b	If the protocol is for an update of a previous systematic review, identify as such
Registration	2	If registered, provide the name of the registry (such as PROSPERO) and registration number
Authors:		
Contact	3a	Provide name, institutional affiliation, e-mail address of all protocol authors; provide physical mailing address of corresponding author
Contributions	3b	Describe contributions of protocol authors and identify the guarantor of the review
Amendments	4	If the protocol represents an amendment of a previously completed or published protocol, identify as such and list changes; otherwise, state plan for documenting important protocol amendments
Support:		
Sources	5a	Indicate sources of financial or other support for the review
Sponsor	5b	Provide name for the review funder and/or sponsor
Role of sponsor or funder	5c	Describe roles of funder(s), sponsor(s), and/or institution(s), if any, in developing the protocol
INTRODUCTION		
Rationale	6	Describe the rationale for the review in the context of what is already known
Objectives	7	Provide an explicit statement of the question(s) the review will address with reference to participants, interventions, comparators, and outcomes (PICO)
METHODS		
Eligibility criteria	8	Specify the study characteristics (such as PICO, study design, setting, time frame) and report characteristics (such as years considered, language, publication status) to be used as criteria for eligibility for the review
Information sources	9	Describe all intended information sources (such as electronic databases, contact with study authors, trial registers or other grey literature sources) with planned dates of coverage
Search strategy	10	Present draft of search strategy to be used for at least one electronic database, including planned limits, such that it could be repeated
Study records:		
Data management	11a	Describe the mechanism(s) that will be used to manage records and data throughout the review
Selection process	11b	State the process that will be used for selecting studies (such as two independent reviewers) through each phase of the review (that is, screening, eligibility and inclusion in meta-analysis)

Data collection process	11c	Describe planned method of extracting data from reports (such as piloting forms, done independently, in duplicate), any processes for obtaining and confirming data from investigators
Data items	12	List and define all variables for which data will be sought (such as PICO items, funding sources), any pre-planned data assumptions and simplifications
Outcomes and prioritization	13	List and define all outcomes for which data will be sought, including prioritization of main and additional outcomes, with rationale
Risk of bias in individual studies	14	Describe anticipated methods for assessing risk of bias of individual studies, including whether this will be done at the outcome or study level, or both; state how this information will be used in data synthesis
Data synthesis	15a 15b 15c 15d	Describe criteria under which study data will be quantitatively synthesised If data are appropriate for quantitative synthesis, describe planned summary measures, methods of handling data and methods of combining data from studies, including any planned exploration of consistency (such as I^2 , Kendall's τ) Describe any proposed additional analyses (such as sensitivity or subgroup analyses, meta-regression) If quantitative synthesis is not appropriate, describe the type of summary planned
Meta-bias(es)	16	Specify any planned assessment of meta-bias(es) (such as publication bias across studies, selective reporting within studies)
Confidence in cumulative evidence	17	Describe how the strength of the body of evidence will be assessed (such as GRADE)

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