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An evidence-based approach for optimising sports recovery practises following DOMS educing exercise. A systemic review and meta-analysis.

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ABSTRACT

Purpose/Background: During intense exercise, muscles generate and release large quantities of blood lactate during anaerobic and resistance based exercise. As a result of intense periods of exercise and physical activity, blood lactate levels and the perception of muscle soreness increases, resulting in an acute decrease in athlete performance. The experience of an acute decrease in athletic performance and increase in negative physiological characteristics is referred to as delayed onset muscle soreness (DOMS). Since the beginning of sports science research, many researchers have tried to create methods to reduce and mitigate the effects of DOMS post exercise. Some of the most common methods include, stretching, massage, ice massage and cold-water immersion, electrical muscle stimulation, kinesiotaping and low-intensity exercise. However, there is currently little evidence to suggest which recovery intervention is best for treating the effects of DOMS. Subsequently, the aim of this present work is to perform a systematic review and meta-analysis evaluating the impact of different recovery techniques on delayed onset muscle soreness.

Methods: A systematic literature search on articles published up to 20 September 2022 was carried out in the databases PubMed (MEDLINE), Scopus, SPORTDisscus. Additionally, academic search engines Google Scholar and ResearchRabbit were used to find additional studies. A search strategy was developed based on the Pico model to identify high quality literature that met the following inclusion criteria:

(1) articles must have been published between 1940-2022 and written in English; (2) a recovery intervention was used either pre or post DOMS; (3) studies must have used at least one physiological or

biomechanical outcome measure to assess the effect of a particular intervention against a control group (either a separate group of people or an untreated muscle on the same individual); (5) a full-text version of the study had to be publicly available with public access to all data used within the study. Using all of the extracted data from the included studies, this meta-analysis will use blood lactate levels, creatine kinase levels, muscle soreness, counter movement jump, maximal isometric voluntary contraction and range of movement. In order to try and answer the primary research aim of what recovery intervention can best mitigate the effects of DOMS.

Results: A total of 275 studies met the inclusion criteria and were used in the systemic review and meta-analysis. The results show that there were significant differences between all of the individual outcome measures, however, once all the results were averaged together to create an overall recovery score, the differences between the interventions were less significant. The results also suggest that some particular recovery interventions have a more pronounced effect for mitigating certain symptoms of DOMS compared to other recovery interventions. When averaging all the results from all of the outcome measures, the pre-DOMS foam roller intervention had the greatest ability to mitigate the effects of DOMS. The second-best recovery intervention overall was dry needling. Both light pressure instrument assisted soft tissue mobilisation technique and flossing reported an average negative Cohen's D value which was significantly below the baseline value reported by the control group which suggests that light pressure instrument assisted soft tissue mobilisation technique and flossing are not good recovery interventions for dealing with delayed onset muscles soreness. However, cryotherapy was the best recovery method for reducing blood lactate levels post DOMS. For the self-reported muscle soreness outcome measure, the post DOMS foam roller recovery intervention had the largest pronounced effect.

For the CMJ outcome measure, pulsed ultrasound provided the greatest reduction in the effects of DOMS and increased the rate of recovery more than any other recovery intervention. For nearly all the chosen outcome measures within this meta-analysis there was a significant interaction between time and the magnitude of DOMS, meaning that after a single bout of the recovery intervention the magnitude of DOMS decreased at every data collection time point. However, not all recovery protocols were able to increase the rate of recovery more than was observed from the control group for each outcome measure. Future research should aim to explore the role of combined recovery techniques to investigate whether a synergetic phenomenon occurs when treating the effects of DOMS.

Keywords: ***DOMS, Recovery, Muscle Soreness. Athletic Performance***

List of Abbreviations

DOMS - Delayed Onset Muscle Soreness

CMJ - Counter Movement Jump

CK - Creatine Kinase

MIVC - Maximal Isometric Voluntary Contraction

BL - Blood Lactate

ROM - Range Of Motion

CWI - Cold Water Immersion

CWT - Contrast Water Therapy

INTRODUCTION

During intense exercise, muscles produce large quantities of blood lactate (Gladden, 2008) and an increase in creatine kinase is experienced (Koch et al. 2014) which is largely the result of repeated periods of eccentric contractions (Ispirlidis et al., 2008). These adverse effects of exercise inhibit both acute and chronic athletic performance (Brown et al. 2015). Delayed onset muscle soreness (DOMS) was first communicated in the scientific literature by Hough (1902), who classified DOMS as a form of neuromuscular soreness that is typically experienced by untrained muscles. Individuals usually experience DOMS as a result of unaccustomed eccentric exercise or as a result of experiencing an unfamiliar increase in muscular load during resistance training (Cheung et al. 2003; De Gail et al. 1966) which involves an acute chemical and physiological response to exercise including the sensation of pain and stiffness in the muscles and an increase in overall soreness (Cheung et al. 2003; Smith 1992) as well as an acute rise in blood lactate levels (Gleeson et al. 1998; Scott et al. 2003). Extreme cases of intense eccentric exercise can also cause structural damage to myofibers and secondary inflammation resulting from the tearing or damage to tissues (Clarkson & Sayers 1999; Howatson & Van Someren 2008; Peake et al., 2005).

Due to the nature of both resistance exercise (Gentil et al. 2006; Reynolds et al. 1997) and aerobic exercise producing DOMS (Bellezza et al. 2009), many sports scientists and researchers have focused on creating an intervention that will mitigate or reduce the effects of DOMS and increase athletic performance following the intro duction of DOMS. Such interventions are needed to allow for recovery post-exercise and structured training to enable an optimal balance between training and recovery (Barnett 2006; Cheung et al., 2003: Soligard et al., 2016). Without optimal recovery, an individual may be at risk of overtraining and injury (Weerapong et al. 2005). Therefore, when an individual is attempting to reach peak athletic performance optimal recovery from training can have a much greater effect on changing an individual's physiological performance compared to just increasing an individual's training load (Johnson et al. 2011). Several recovery methods have been created with the intent of mitigating or reducing the effects of DOMS. Cowan and Solandt (1937) published the first piece of scientific research which explored the effect of different time durations on recovery post-exercise.

However, Mathews et al. (1969) were the first to explore the concept of purposefully designed recovery strategies for DOMS. However, contemporary research regarding myofascial release and self-administered myofascial release focused on different manual soft tissue mobilisation techniques (Beardsley and Škarabot, 2015). However, in recent years there has been an increase in the development of tools to increase myofascial release. The foam roller was the first tool that was developed to enhance myofascial release (Clark and National Academy of Sports Medicine, 2001). Since the first introduction of foam rollers, several other devices have been developed to increase the amount of self-myofascial release that is experienced by the user. Over the years foam rollers have been iterated and developed by changing the surface material and density of the device (Cheatham and Stull 2018; Rhodes et al. 2022) as well as the depth and layout of the textured external surface of the foam roller (Cheatham and Stull 2019).

Vibration foam rollers have also become a popular recovery strategy in recent years. Ahmed and Akter (2019) reported that the use of a vibrating foam roller has a positive impact on hamstring range of motion. Several other studies have explored the use of vibration foam rolling on quadriceps (Lim et al., 2019), knees (Cheatham and Stull, 2018) and other body parts (Cheatham and Stull, 2018; García-Gutiérrez et al., 2018; Wilke et al., 2020). These studies reported an acute increase in range of motion following the use of a vibrating foam roller. On the other hand, Thompson et al. (2014) discovered that using a vibrating foam roller is a safe method to increase bone density.

Despite many post-exercise recovery treatments, only a few are considered effective. Some examples of the methods used for improving recovery include stretching, massage, ice massage and cold-water immersion, electrical stimulation muscle stimulation, Kinesio taping and low-intensity exercise (Crowther et al. 2017; Dupuy et al. 2018; Peake 2019) Most of them are based on improving blood flow, which can be done by different methods of stimulation (e.g., temperature, mechanical impact, muscular movements). Adamczyk et al., (2020) have been the most recent research group to assess the effect of different types of foam rollers on their ability to reduce the effects of DOMS. The results from Adamczyk et al., (2020) suggest that foam rolling is an effective method for enhancing lactate clearance and reducing the effects of DOMS, but the type of foam roller does not seem to influence the recovery rate.

However, when it comes to assessing multiple recovery interventions in a single research study there is currently only one peer-reviewed study that has attempted to determine the best DOMS recovery intervention. A systematic review conducted in 2018 by Dupuy (2018) compared some of the mainstream methods that are commonly used to mitigate the effects of DOMS. Dupuy (2018) compared the effects of Active recovery, massage, compression garments, immersion, contrast water therapy, and cryotherapy for treating the magnitude of DOMS and fatigue. However, they did not directly assess multiple recovery interventions for their effect on reducing blood lactate levels and improving athletic performance. Therefore, the purpose of this systematic review and meta-analysis is to search the current literature and identify studies that have analysed the effects of different recovery interventions either pre- or post-DOMS. Then all the included recovery interventions will be compared to identify which is the best recovery method. Three separate outcome measures will be analysed including acute blood lactate levels, self-reported muscle soreness, creatine kinase activity, range of motion, maximal isometric voluntary contraction and countermovement jump height.

General knowledge and understanding of the dose-response relationship between different exercise training methods and their impact on muscular fatigue, muscle damage and the introduction of DOMS has significantly improved for most of the primary recovery interventions and there are several low-quality recommendations based on anecdotal evidence available for athletes, coaches, and support staff to use. However, to this date, there is a very limited number of high-quality research studies that have compared the effect of several different DOMS recovery interventions together in the same study. To date, there is only one published study that has explored the impact of multiple different recovery strategies. Despite the work by Dupuy (2018), there remains the question of which DOMS recovery intervention has the best capability of restoring athletic performance post DOMS inducing exercise. Therefore, the purpose of this systemic review and meta-analysis is to compare the effects of various recovery interventions that have been designed to mitigate the effects of DOMS, muscle soreness, perception of fatigue and the time needed for individual to return to their baseline level of sporting performance following a period of intense exercise.

METHOD

Search Strategy

A systematic literature search on articles published up to 20 September 2022 was carried out in the databases PubMed (MEDLINE), Scopus, and SPORTDisscus. Additionally, the two academic search engines Google Scholar and Research-Rabbit were used to locate additional studies that met the inclusion criteria.

A search strategy was developed based on the Pico model (Santos et al. 2007; Eriksen & Frandsen, 2018). The Pico model is an evidence-based protocol used for framing a research question or hypothesis. The Pico model focuses on identifying a problem then creating an intervention, comparing pre-and post-intervention, and measuring the outcome of interest. To identify studies that might match the inclusion criteria the Boolean operators 'AND' and 'OR' were used to search the following terms: "massage gun", "massage therapy or massage therapies", and "myofascial release techniques or myofascial release" as well as "delayed onset muscle soreness" and "recovery from exercise".

However, the Research Rabbit software does not support the use of Boolean operators when searching for articles. Research Rabbit is an online platform that uses database information and machine learning to identify published articles relating to each other. Instead of using Boolean operators, key search terms including ‘massage therapy’, ‘myofascial release techniques’ and ‘delayed onset muscle soreness were used. The literature search on Research Rabbit was the final part of the systematic literature search. Subsequently, research study titles that matched the inclusion criteria from other databases were inputted into the research rabbit software. Then research rabbits' artificial intelligence software searched for new articles with similar methodology and research aims. Once all the possible matches were listed on research rabbit, they were saved as a secure excel file to keep a record of all the studies that matched the focus of the research question.

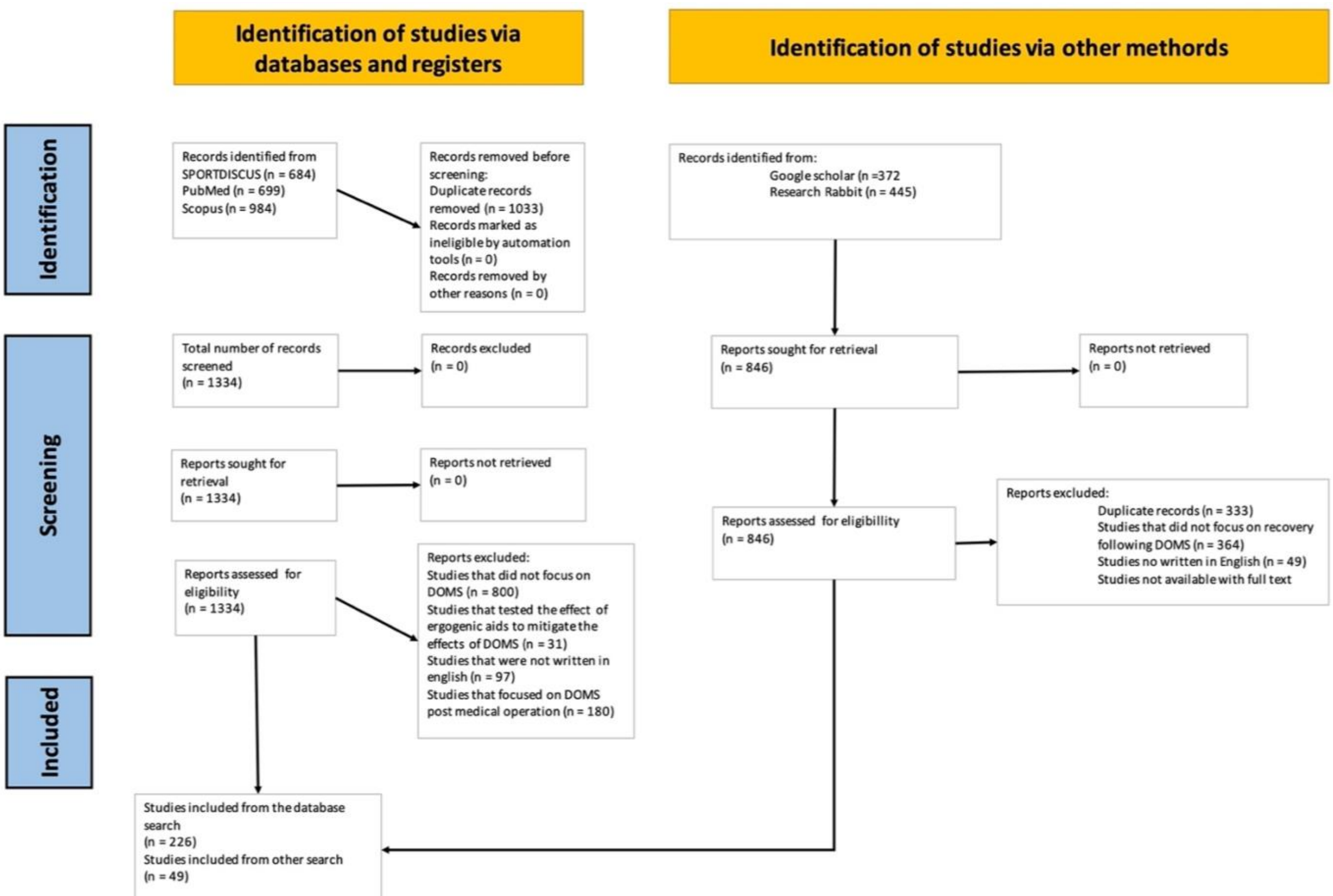

Figure one: Prisma flow diagram

Selection criteria

The previously specified search strategy yielded a net result of 3213 articles. After removing duplicate studies, this came to a total of 1845 titles. Titles and abstracts were reviewed to determine whether the studies fulfilled the selection criteria. Studies were eligible for inclusion if they met the following criteria: (1) articles must be written in English and must have been published between 1940 and 2022; (2) a recovery intervention was used either pre or post-DOMS that was induced by exercise (aerobic or resistance); (3) studies needed to measure muscle soreness and at least one aspect of athletic performance (e.g.) countermovement jump (CMJ); (5) a full-text version of the study had to be publicly available with public access to all data used within the study. Subsequently, the studies selected were based on the Prisma checklist constructed by Moher et al. (2010). Articles were only included in the full-text review if it was deemed that their title and abstract met the fundamental demands of the inclusion criteria. After the final selection, the total number of possible articles came to 298. All eligible papers were then screened by analysing the full text. At this stage, several articles were removed due to data not being in the public domain, despite efforts attempting to contact the authors. Once manuscripts without public data were removed the total number of manuscripts that met the inclusion criteria was 275.

Quality assessment and risk of bias

After analysing all 3184 identified articles and narrowing down the selection at each stage of reviewing the articles, a total of 275 were included due to them meeting all of the components of the inclusion criteria (as reported in Figure 1). Using a modified version of the 11-step Pedro scale (Eriksen and Frandsen, 2018; Moher et al. 2010) the studies were assessed for any possible risk of biases and overall quality. Study quality and reporting were assessed using the validated TESTEX scale (Smart et al., 2015). This scale consists of a validated 15-point scale, which evaluates the randomised-control trial elements of the study (total 5 points available for this section), and the quality of data and information reporting within the study (total 10 points available for this section). A study with a TESTEX quality score of less than 10 was deemed to be low quality. A separate process was also carried out to assess for selection bias, performance bias, detection bias, attrition bias, reporting bias and incomplete outcome data in order to determine if any element of research bias were present within the included studies.

All of the included studies were also assessed to identify if they had reported random sequence generation for the process of dividing participants into different experimental or control groups. Additionally, studies were assessed to determine if allocation concealment was reported within the methodology of each included study. Allocation concealment referred to if the participants knew which experimental or control group they were in. This was especially important for studies that were randomised control trials or had randomised elements within their methodology and equally for studies that were attempting to compare the effect of two or more recovery interventions. Blinding referred to if the primary researchers knew which participants were in each experiment or control group. Incomplete outcome data referred to any participants that failed to complete all of the study and as such their individual data was missing for a particular part of the experimental process. This was specifically in relation to raw data from each stage of the experimental process and from the results section of each stage of the experiment. It is good research practice to exclude any participants that had incomplete data.

As such studies which included participants with only partial experimental data were considered to be of low study quality.

Data extraction and statistical analysis

For all the articles that met the initial inclusion criteria, basic information and data were extracted into a standardised Excel spreadsheet, which included: Manuscript title, Author name, Year of publication, Journal Name, Total sample size, Male sample size, Female sample size, Intervention group Sample size, Control group sample size, Control group mean age (years), Control group mean weight (KG), Control group mean height (cm), Intervention group mean age (years), Intervention group mean weight (KG), Intervention group mean height (cm), Study design type, A list of the recovery intervention that were tested, Primary outcome measures for each study and the type of data that was extracted from the study.

Additionally, an enhanced data-extraction process occurred to conduct a meta-analysis. The data fields for this included: all usable data regarding the perceived muscle soreness pre and post-intervention using either the visual-analogue scale (a one-to-ten scale of self-reported pain) or pain-pressure-threshold data (1-10 scale of self-determined pain). Raw pre- and post-data for countermovement jump height were used. The raw data from pre-intervention testing and post-intervention testing were included. In cases where multiple studies reported data for the same recovery intervention, the data was combined into one overall intervention group. The meta-analysis was conducted by exporting all accessible raw data for all outcome measures into a customised Excel spreadsheet and then importing the data into SPSS (statistics software version 23).

Within the SPSS software package, effect sizes were calculated for each subgroup for each of the predetermined outcome measures using Cohen's D effect sizes (Cohen 2013). During the initial concept and planning for this meta-analysis, it was decided that a random-effects model would be used because the effect of a recovery intervention might differ depending on the type of exhausting exercise or sport that was used to introduce DOMS into the participants and also the training status, age and sex of the participants. Cohen's criteria was used to interpret the magnitude of the effect sizes: < .50: small; 0.50| to 0.80: moderate; and >.81: large (Cohen 2013). For outcome measures where DOMS increased the value, a negative effect size was considered to suggest an increase in exercise performance and recovery from DOMS. Conversely, for outcome measures where DOMS decreased the value a positive effect size was considered to suggest an increase in exercise performance and recovery from DOMS. In order to calculate the total magnitude of recovery that was experienced as a result of each of the different recovery interventions, the average effect sizes for each of the six outcome measures were averaged to provide an effect size value for total recovery.

Results

The inclusion criteria produced a total of 275 included studies containing a total of 64 randomised control trials, 22 repeated measures design studies, three counterbalanced design studies, nine randomised cross over studies, three quasi-experimental cross over design studies, one laboratory control study, 1 five arm randomised control study, one randomised sham-control study, one arm-to-arm comparison model with 2 independent variables study, one randomised pretest-posttest control group design, one double-blind, placebo-controlled study, one randomised, masked comparison design study, one double-blinded randomised controlled trial, one mixed-subjects experimental design study, one examiner-blind randomised controlled trial, one randomised double-blind controlled study, one experimental method with a one way crossover design pretest-posttest approach study, one randomised blinded repeated measures design study, one double-blind randomised control design study, one single-blind randomised control trial and one randomised, parallel arm open-label comparative study.

Figures two-five shows a list of all the included studies and which recovery method they tested. From the total of 275 studies there was a total of 48 studies tested the effects of a foam roller-based intervention to mitigate the effects of DOMS, four studies implemented vibrating foam rollers post-DOMS whilst eight studies explored the effects of cold-water immersion post-DOMS. Two studies explored the effects of dry needling with seven different studies testing the effects of compression clothing to reduce DOMS. A total of nine studies investigated the effect of active recovery, whilst nine other studies focused on the effects of pulsed ultrasound. 17 studies tested the effect of instrument-assisted soft tissue manipulation post-DOMS and nine other studies tested the effects of percussion therapy after DOMS. Nine studies used a method of electrical stimulation and 18 studies utilised massage post-DOMS. Only one study tested the effects of flotation-restricted environmental stimulation therapy for mitigating the effects of DOMS whilst two different studies used laser therapy post-DOMS. Two studies used Soft tissue oscillation therapy post-DOMS, one study used Tissue Flossing post-DOMS, one study used Kinesio-Taping post-DOMS, one study used Cryotherapy post-DOMS, two studies used Whole-body vibration Therapy post-DOMS, one study used the Graston technique post-DOMS and one study used far-infrared emitting ceramic materials during night time sleep post-DOMS.

All the included studies were published in the period from 1984-2022. The sample sizes from the included studies ranged from six to 113 with all participants being completely informed of what was involved in their respective studies. The total sample size was n = 5982 with 3977 (66%) being reported as male and 1511 (25%) being reported as female and a further 494 (8%) of participants who were not categorised by either gender. The mean age for the entire sample was 24.47 ± 10.24 (years), the mean weight for the whole sample was 73.76 ± 11.43 (KG) and the mean height for the entire sample was 175.32 ± 8.26 (cm). An individual breakdown of the sample characteristics can be viewed in table 19. Participants sporting habits were classified as either healthy recreational individuals or healthy well-trained individuals competing in endurance sports such as triathlons and marathons.

Table One: Participant characteristics

The total sample characteristics are displayed in the table below; as well as a breakdown of participants who reported to be in either the control group or the intervention group. The mean age (years) for the total sample size was 24.47 ± 10.24, the mean weight (KG) was 73.76 ± 11.43 and the mean height (CM) for the entire sample was 175.32 ± 8.26.

	Total Sample Size n = 5982				Control Group Sample size n = 3604				Intervnetion Group Sample size n = 3681		
	AGE	WEIGHT (KG)	HEIGHT (CM)		AGE	WEIGHT (KG)	HEIGHT (CM)		AGE	WEIGHT (KG)	HEIGHT (CM)
Mean	*24.47*	*73.76*	*175.32*		*24.03*	*73.92*	*175.71*		*24.12*	*73.33*	*175.58*
SD	*10.24*	*11.43*	*8.26*		*5.30*	*10.63*	*6.05*		*5.49*	*10.14*	*6.24*

Figure Two:

Due to the total number of studies included in this review and the level of information within the scoping table. The table is too big to display within this document. A full PDF copy of the scoping table is available to read on the open science framework page for this manuscript. Please see the following link to see a scalable easy to read photo of the scoping table. https://osf.io/qrd5e/

Foam Roller Studies	Multiple Intervention Studies	Active Recovery Studies	Vibrating Foam Roller Studies	Mechanical Vibration Studies
Adamczyk 2020	Akinci 2019	Tufano 2012	Alonso-Calvete 2021	Aminian-Far 2011
Ali 2021	Andersen 2013	Andersson 2008	De Benito 2019	Chwała 2021
Beier 2019	Bielik 2010	Suzuki 2004	Lai 2020	Gordon 2018
Casanova 2018	Crowther 2017	Zainuddin 2006	Romero-Moraleda 2019	Lau 2011
D'Amico 2019	Fechtelkotter 2017	Akbar 2021		Rhea 2009
D'Amico 2020	García-Sillero 2021	Taoutaou 1996		Wheeler 2013
Drinkwater 2019	Kalén 2017	High 1989		Couture 2017
Fleckenstein 2017b	Maior 2020	Tessitore 2008		Bakhtiary 2007
Jo 2018	Maloon 2017	Lund 1998		
Juache 2019	Monedero 2000	Buroker 1989		
Laffaye 2019	Nazarudin 2021			
Lam 2018	Özsu 2018			
Lee 2020	Putri 2021			
Lennon 2018	Rasooli 2012			
MacDonald 2013	Rey 2012			
Martins 2016	Vaidya 2021			
Medeiros 2020	Weber1994			
Monteiro 2019	Gill 2006			
Mustafa 2021	Leal Junior 2011			
Naderi 2020	Stacey 2010			
Nakamura 2021	Weber 1994			
Pearcey 2015	Yarar 2021			
Phillips 2021	Hausswirth 2011			
Pożarowszczyk 2018	Wilson 2019			
Rey 2019	Getto 2013			
Rivera 2020	King 2009			
Schroeder 2019	Kinugasa 2009			
Scudamore 2021	Robey 2009			
Shu 2021	Montgomery 2008			
West 2020	Argus 2013			
Yanaoka 2021	Schmidt 2021			
Rahimi 2020	Şahin 2021			
Shalfawi 2019	Imtiyaz 2014			
Takuma and Norikazu 2020	Coffey 2004			
Zuraimy and Muhammad 2021	Delextrat 2013			
	Heyman 2009			
	Webb 2011			
	Dawson 2005			
	Lane 2004			
	Tessitore 2007			
	Isabell 1992			
	Martin 1998			
	Thiriet 1993			

Figure Two: List of included studies for the intervention methods subgroups: Foam roller, Multiple recovery methods, Active recovery, Vibrating Foam Roller, and Mechanical vibration.

There was a total of 35 studies that were included in the foam roller subgroup and a further 43 studies that were included in the multiple interventions subgroup. Ten manuscripts attempted to assess the ability of Active recovery to reduce the effects of DOMS. However, there were only four included studies in the Vibrating foam roller subgroup and eight manuscripts that formed the Mechanical vibration subgroup.

Massage Studies	Floatation Studies	Electrical Stimulation Studies	Instrument Assisted Massage Studies	Laser Therapy Studies
Arroyo-Morales 2008	Broderick 2019	Butterfield 1997	Cheatham 2019	Craig 1996a
Bitchell 2015		Craig 1996b	Kitsuksan 2021	Douris 2006
Cè 2013		Dover 2005	Son 2018	Kobordo 2015
Dawson 2004		Ferguson 2014		Tomazoni 2019
Farr 2002		Rocha 2012		
Guest 2010		Tourville 2006		
Hart 2005		Bieuzen 2014a		
Henry 2015		Denegar 1992		
Hilbert 2003		Fleckenstein 2017a		
Iehl 2010				
Jay 2014				
Kargarfard 2016				
Kong 2018				
Law 2008				
Mancinelli 2006				
Micklewright 2009				
Smith 1994				
Willems 2009				
Zainuddin 2005				
Bakar 2015				
Crane 2012				
Delextrat 2014				
Lightfoot 1997				
Tiidus 1995				
Robertson 2004				
Howatson 2005				
Hemmings 2000				
Yackzan 1984				
Howatson 2003				

Figure Three: List of included studies for the recovery subgroups Massage, Floatation recovery, Electrical Stimulation, Instrument Assisted Massage, and Laser Therapy.

A total of 29 manuscripts were included in the Massage subgroup, whilst only one study was included in the Floatation recovery subgroup. Nine manuscripts were included in the Electrical stimulation subgroup. A total of three studies formed the Instrument Assisted Massage subgroup and another four manuscripts formed the Laser Therapy subgroup.

Compression Studies	Dry Needling Studies	Cryotherapy Studies	Acupuncture Studies	Pulsed Ultra Sound Studies
Cranston 2020	Cushman 2021	Ferreira-Junior 2015	Fleckenstein 2016	Hasson 1990
Jakeman 2010a		Moradi 2020		Ketcham 2018
Nguyen 2019		Fonda 2013		Shankar 2006
Steers 2017		Guilhem 2013		
Bieuzen 2014b		Vieira 2015		
Hill 2017		Wozniak 2007		
Kraemer 2001a		Qu 2020		
Kraemer 2010		Costello 2012		
Pruscino 2013		Paddon-Jones 1997		
Rimaud 2010		Clifford 2018		
Ali 2007		Santos 2012		
Armstrong 2015		Hohenauer 2016		
Born 2014				
Duffield 2008				
Duffield 2010				
Hill 2014				
Rugg 2013				
Carling 1995				
Cerqueira 2015				
Goto 2014				
Jakeman 2010b				
Kraemer 2001b				
Martorelli 2015				
de Glanville 2012				
Driller 2013				
Ehrström 2018				
Hettchen 2019				
Upton 2017				
Atkins 2020				
Brown 2022				
Martínez-Navarro 2021				
Hotfiel 2021				
Brown 2021				
Oliver 2021				
Lee 2019				
Höger 2021				
Atkins 2019				
Driller 2021				
Brophy-Williams 2018				
Bastos 2012				
Berry 1987				
Ali 2011				
Kemmler 2009				
Lovell 2011				
Rivas 2017				
Treseler 2016				
Marques-Jimenez 2017				
Marqués-Jiménez 2018				
Overmayer 2018				
Lea 2016				
Gallaher 2012a				
Gallaher 2012b				
Brophy-Williams et al 2017				
Brophy-Williams et al 2019				

Figure Four: List of included studies for the recovery subgroups Compression garments, Dry Needling, Cryotherapy, Acupuncture, and Pulsed Ultrasound.

54 manuscripts made up the compression garments subgroup whilst only one manuscript was included in the Dry needling subgroup. A total of 12 manuscripts formed the cryotherapy subgroup. A

single manuscript made up the Acupuncture subgroup whilst a further three formed the Pulsed ultrasound subgroup.

Kinesio Tape Studies	Hydrotherapy and Cold Water Immersion Studies	Infrared light-emitting diode irradiation Studies	Cupping Studies
Hung 2021	JUNAIDI 2021	Nunes 2020	Smith 2018
	Lêdo 2018	Vinck 2006	Liao 2021
	Tseng 2013		
	Eston 1999		
	Goodall 2008		
	Roberts 2015		
	Rowsell 2011		
	Barber 2020		
	Elias 2013a		
	Higgins 2013a		
	Pointon 2012		
	Takeda 2014		
	Tavares 2019		
	Brophy-Williams 2011		
	Elias 2012		
	Stanley 2012		
	Bailey 2007		
	Leeder 2015		
	Jakeman 2009		
	Crystal 2013		
	Vaile 2008a		
	Vaile 2007		
	French 2008		
	Ingram 2009		
	Pournot 2011		
	Versey 2011		
	Versey 2012		
	Higgins 2013b		
	Sánchez-Ureña		
	Chaiyakul 2021		
	Hamlin 2007		
	Ascensão 2011		
	Crowe 2007		
	Howatson 2009		
	Rowsell 2009		
	Rupp 2012		
	Sellwood 2007		
	Stanley 2013		
	Vaile 2008b		
	Fronseace 2016		
	Koekemoer 2010		
	Elias 2013b		
	Vieira 2016		
	Cuesta-Vargas 2013		
	Higgins 2011		
	Viitasalo 1995		
	Alshoweir 2016		
	Broatch 2014		
	Parouty 2010		
	Iswahyudi 2021		

Figure Five: List of included studies for the recovery subgroups Kinesio Tape, Hydrotherapy and Cold-Water Immersion, Infrared light-emitting diode irradiation and Cupping.

A single study formed the Kinesio Taping subgroup, whilst a total of 50 manuscripts were included in the Hydrotherapy and Cold-water Immersion subgroup. Both the Infrared Light-emitting diode irradiation and Cupping studies subgroups had two included.

The inclusion criteria for this systematic review and meta-analysis produced a total of 275 studies. All the studies were grouped into different categories depending on what recovery strategy was being tested in relation to its potential to reduce the effects of DOMS. There was a total of 19 groups. Every included study was selected for one of the following groups: Foam Roller Studies (n = 35), Multiple Intervention Studies (n = 43). Active Recovery Studies (n = 10), Vibrating Foam Roller Studies (n = 4), Mechanical Vibration Studies (n = 8). Massage Studies (n = 29). Floatation Studies (n = 1). Electrical Stimulation Studies (n = 9). Instrument Assisted Massage Studies (n = 3), Laser Therapy Studies (n = 4), Compression Studies (n = 54), Dry Needling Studies (n = 1), Cryotherapy Studies (n = 12). Acupuncture Studies (n = 1), Pulsed Ultrasound Studies (n = 3), Kinesio Taping Studies (n = 1), Hydrotherapy Studies (this group included both cold water immersion and contrast water immersion studies) (n = 50), Infrared Light-emitting Diode Irradiation Studies (n = 2) and Cupping Studies (n = 2).

Testex study quality data

Due to the extensive amount of data that is stored within the Testex study quality data table, it is not possible to show a clear and detailed version of this document. To see a fully scalable and readable version of the Testex study quality data table please use the link below. https://osf.io/ebwjt

The effect of different types of recovery intervention post DOMS on blood lactate values

The effect of specific DOMS recovery interventions on post-exercise blood lactate values (figure two). Ten recovery interventions were tested to assess their impact on blood lactate levels post-DOMS. A number of the selected manuscripts presented data across multiple time points after the introduction of DOMS or the admission of the intervention (e.g. 1 hour, 24 hours, 48 hours and 72 hours). Subsequently, a total of 28 subgroups presented data in figure two.

Blood lactate values were collected directly post the introduction of DOMS, three minutes post-intervention, six minutes post-intervention, nine minutes post-intervention, one-hour post-intervention, 24 hours post-intervention, 48 hours post-intervention and 72 hours post-intervention. All of the recovery methods that presented data for multiple time points showed a significant interaction between time and the effect on blood lactate. Consequently. the data presented suggests that there is a significant interaction between the time duration of the intervention and the magnitude of the desired effect of reducing the impact of DOMS.

Only one of the included recovery interventions presented a statistically significant difference compared to the baseline measurement of blood lactate that was taken directly after the introduction of DOMS but before any recovery intervention had been administered. The cryotherapy post-intervention group reported a Cohen's D effect size of -0.78. This negative effect size shows that Cryotherapy significantly decreases blood lactate levels (mmol/L) after the introduction of DOMS via either resistance or aerobic-based exercise.

Several of the recovery interventions only reported an increase in blood lactate levels. The vibration foam roller subgroup nine minutes post-intervention reported the greatest positive effect size at 0.99. This effect size shows that the use of vibration foam rollers has a significant acute increase on blood lactate (mmol/L).

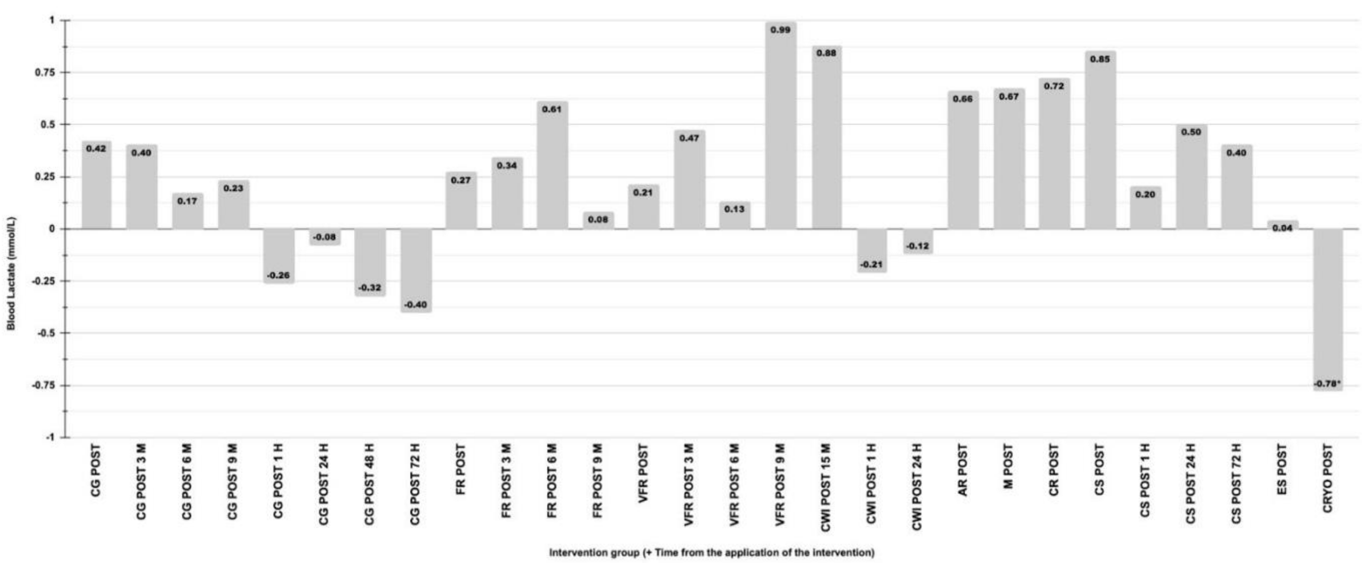

Figure Two: The effect of different recovery interventions on Blood Lactate levels (mmol/L)

A total of 28 subgroups from 10 different recovery strategies reported Cohen's D effect size values for blood lactate (figure 2). For the control group (passive recovery), a reduction in blood lactate was observed after six minutes. However, there was a negative effect size which was reported one hour following the intervention. Both the foam roller and Vibration foam roller groups did not report a negative effect size for any of the time points. However, both the foam roller groups, and the vibration foam roller group did report an interaction between time and a decrease in blood lactate levels.

CG = Control group (Passive recovery), FR = Foam roller, VFR = Vibrating foam roller, CWI = Cold Water Immersion, AR = Active Recovery, M = Massage, CR = Combined Recovery, CS = Compression Socks (Or compression garments), ES = Electrical Stimulation, CRYO = Cryotherapy

The effect of different types of recovery intervention post DOMS on self-reported muscle soreness

Figure three shows the effect of different DOMS recovery interventions on muscle soreness. A total of 21 unique recovery interventions reported data regarding muscle soreness using either a 0-10 Borg scale or the 0-100 VAS scale). Muscle soreness data was collected at multiple time points including directly after the introduction of DOMS, directly after the recovery intervention had been applied for the first time, one post-intervention, 24 hours post-intervention, 48 hours post-intervention, 78 hours post-intervention, 96 hours post-intervention.

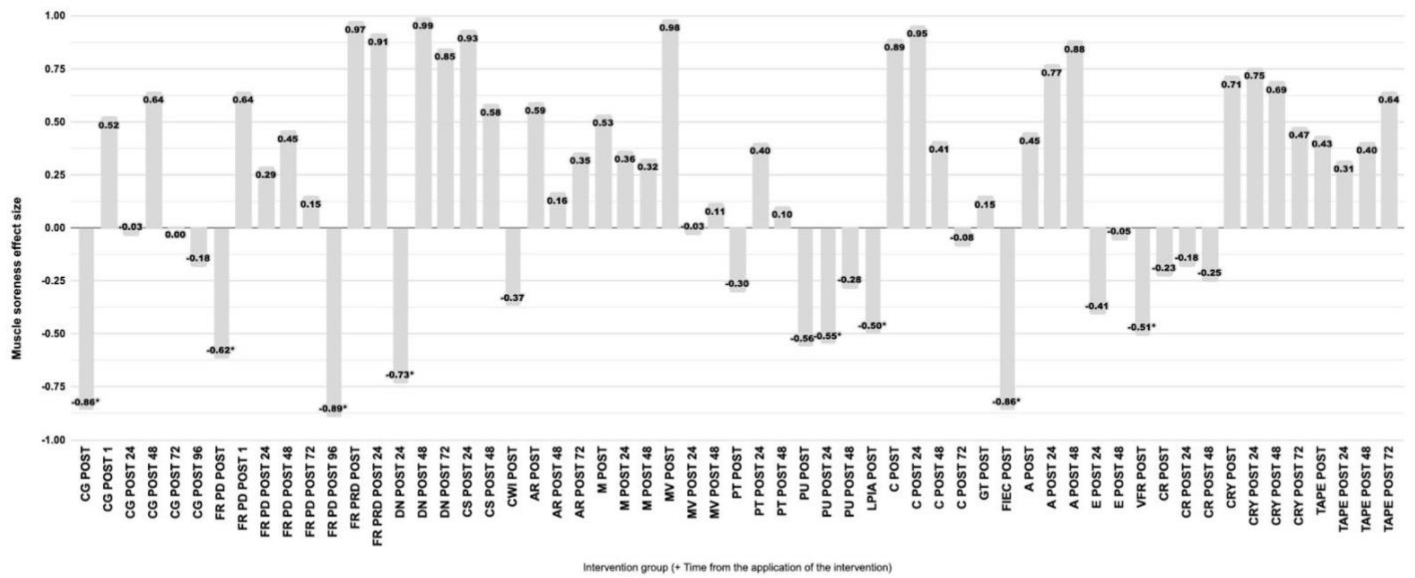

Figure three: Mean self-reported muscle soreness values for post different DOMS recovery interventions

A total of 59 subgroups from 21 different recovery interventions reported data for muscle soreness. Eight of the 59 subgroups reported a negative effect size that was considered statistically significant. The post-intervention effect size for the control group reported a Cohen's D effect size of -0.86. However, following this time point all the control group effect sizes reported a significant increase in muscle soreness. Subsequently, the control group (passive recovery) failed to reduce the perception of DOMS past an acute period. The use of a foam roller post-DOMS reported two negative effect sizes at the post-intervention and post-96-hour time points. The Dry needling 48 hours post group reported the greatest positive effect size (0.99) suggesting that using dry needling as a recovery technique significantly increases the perception of DOMS. The mechanical vibration post group also reported a significant positive effect size of 0.98. This effect size suggests that mechanical vibration increases the perception of muscle soreness following the introduction of DOMS.

There was a lack of interaction between time and the perception of muscle soreness which suggests that there is no direct correlation between time duration and an increase or decrease in muscle soreness.

CG = Control group (Passive recovery), FR PD = Foam Roller Post DOMS, FR PRD = Foam Roller Pre DOMS, DN = Dry Needling, CS = Compression garments, CWI = Cold water immersion, AR = Active Recovery, M = Massage, MV = Mechanical Vibration, PT = Percussion Therapy, PU = Pulsed Ultrasound, LPIA = Light pressure instrument assisted soft tissue mobilisation technique, C = Cupping, GT = Graston Technique, FIEC = Far-Infrared Emitting Ceramic Materials during night time sleep, A = Acupuncture, E = Electrical Stimulation, VFR = Vibrating Foam Roller, CR = Combined Recovery, CRY = Cryotherapy, TAPE = Kinesio taping.

The effect of different types of recovery intervention post DOMS on counter movement jump height

The ability of different DOMS recovery interventions in relation to CMJ performance was asses in figure four. Figure four included data from 12 different recovery interventions in the analysis, resulting in a total of 35 subgroups.

Six of the 35 subgroups reported a statically significant positive effect sizes, indicating that following these particular recovery interventions were able to reduce the negative physiological and neuromuscular effects of DOMS. The subgroup which provided the greatest positive effect size was the pulsed ultrasound post-72 hours group. 72 hours after the first application of a pulsed ultrasound treatment this subgroup reported a Cohen's D effect size of 0.92 which was considered to be statically significant. This effect size suggests that the after a period of 72 hours the pulsed ultrasound treatment dramatically reduced the effects of DOMS and restored CMJ performance close to its baseline level before the introduction of DOMS. This suggests that daily pulsed ultrasound treatments administered 72 hours after the onset of DOMS may be effective in improving CMJ performance.

The second greatest statically significant positive effect size was reported by the compression garments post-72-hour subgroup, with an effect size of 0.82. This suggests that wearing compression garments for 72 hours after the onset of DOMS may also be effective in improving CMJ performance. Three of the six statistically significant positive effect sizes came from post-72-hour groups, while the other three came from the final time point for each recovery intervention (all time points were 24 hours). This suggests that the greatest amount of recovery may be observed following a significant period of time after the initial application of the recovery method, although there was no clear interaction between time and the magnitude of the effect from any of the reported recovery interventions.

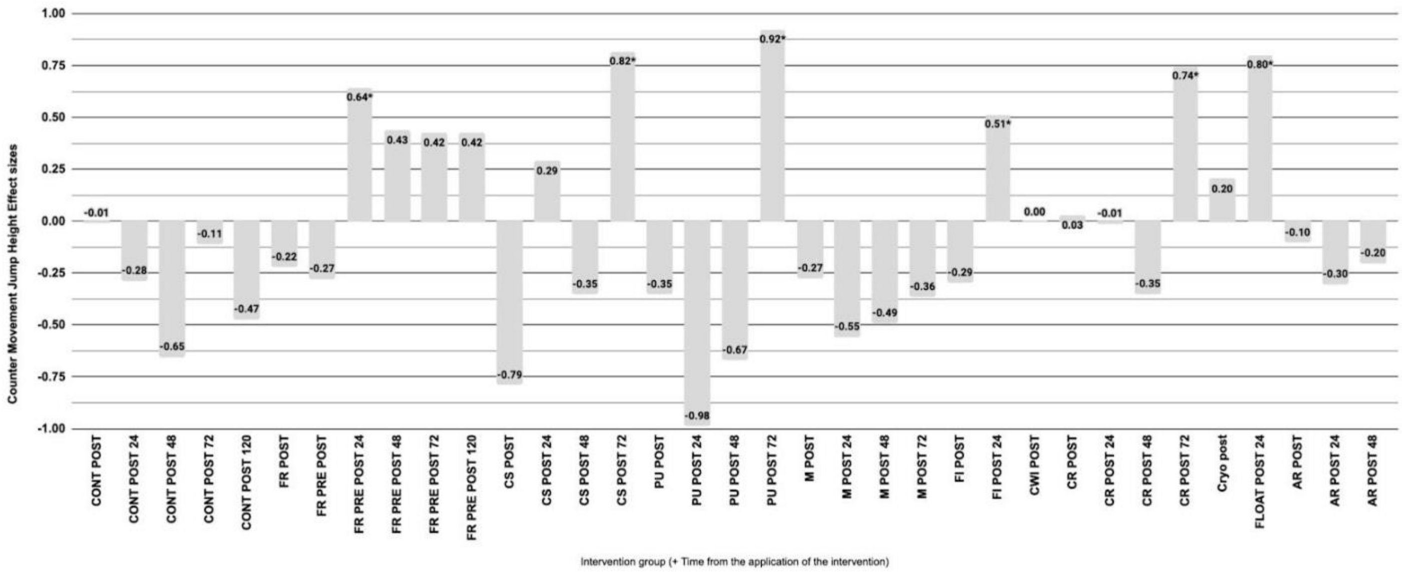

Figure four: Mean counter movement jump values post different DOMS recovery interventions

A total of 12 different recovery interventions reported data for their effect on counter-movement performance following the introduction of DOMS. However, some recovery groups presented data for multiple time points, which resulted in 35 subgroups. Six of the 35 subgroups reported positive effect sizes. The pulsed ultrasound post-72 hours group reported the largest positive effect size, suggesting that daily pulsed ultrasound repeated for 72 hours is the best method for restoring vertical jump performance following the introduction of DOMS. Whilst the largest positive effect size occurred 72 hours after the first intervention, there was no clear interaction between time and the magnitude of the effect from any of the reported recovery interventions. Due to the lack of interaction between intervention time and the magnitude of DOMS recovery, the data presented in figure four suggests that the recovery rate for vertical jump performance does not occur linearly.

The reported Cohen's D effect size for the pulsed ultrasound post-72-hour group was 0.92. The compression garments post-72-hour subgroup reported an effect size of 0.82, which was the second-largest positive effect size. Three of the six statistically significant positive effect sizes came from post-72-hour groups. The other three statistically significant positive effect sizes came from the final time point for each recovery intervention (all time points were 24 hours). Subsequently, whilst there was no linear interaction between time and the magnitude of recovery from each intervention. The greatest amount of recovery was observed following a significant period of time after the initial application of the recovery method.

Five out of the 35 subgroups reported a significant negative effect size demonstrating that they are unable to mitigate the effects of DOMS regarding CMJ performance. The pulsed ultrasound 24-hour group reported the greatest negative effect size of -0.98, whilst the second greatest negative effect size was reported by the compression sock group directly after the first application of the recovery method reported an effect size of -0.79.

Cont = Control group (Passive recovery), FR = Foam roller post-DOMS, FR PRE = Foam Roller Pre DOMS, CS = Compression Socks (or any type of compression garments), PU = Pulsed Ultrasound, M = Massage, FI = Far-Infrared Emitting Ceramic Materials during night time sleep, CWI = Cold water immersion, CR = Combined recovery (Active aerobic recovery and one method of myofascial release therapy), Cryo = Cryotherapy, Float = Floatation therapy, AR = Active recovery.

Figure five shows the effects of various recovery interventions on maximal isometric voluntary contractions (MIVCs) following the onset of delayed onset muscle soreness (DOMS). MIVCs refer to the maximum force that a muscle can generate during an isometric contraction, or a contraction in which the muscle does not change length.

A total of 44 subgroups from 14 different recovery interventions were included in the analysis and reported data on their effects on MIVCs. The reported effect sizes do not show a clear linear relationship between time and recovery from DOMS, meaning that the effectiveness of the recovery interventions did not consistently increase or decrease over time.

Of the 44 subgroups, 5 reported a statistically significant positive effect size, which means that these interventions were associated with improvements in MIVCs following DOMS. The subgroup with the greatest positive effect size was the acupuncture post-72 hours group, with an effect size of 0.90. This suggests that acupuncture treatment administered 72 hours after the onset of DOMS may be effective in improving MIVCs. The second greatest positive effect size was reported by the 24-hour control group, with an effect size of 0.86. This suggests that MIVCs may naturally improve on their own within 24 hours following the onset of DOMS, even without any intervention. Other subgroups with statistically significant positive effect sizes included the massage post group (0.79), Electronic stimulation post group (0.73), and the combined recovery group (0.70). These results suggest that these interventions may also be effective in improving MIVCs following DOMS.

On the other hand, 9 out of the 44 subgroups reported a statistically significant negative effect size, indicating that these interventions were unable to mitigate the negative effects of DOMS on MIVCs. This means that these interventions were associated with a decrease in MIVCs following DOMS. It is not clear from the paragraph what the specific interventions were or what the magnitude of their negative effect sizes was.

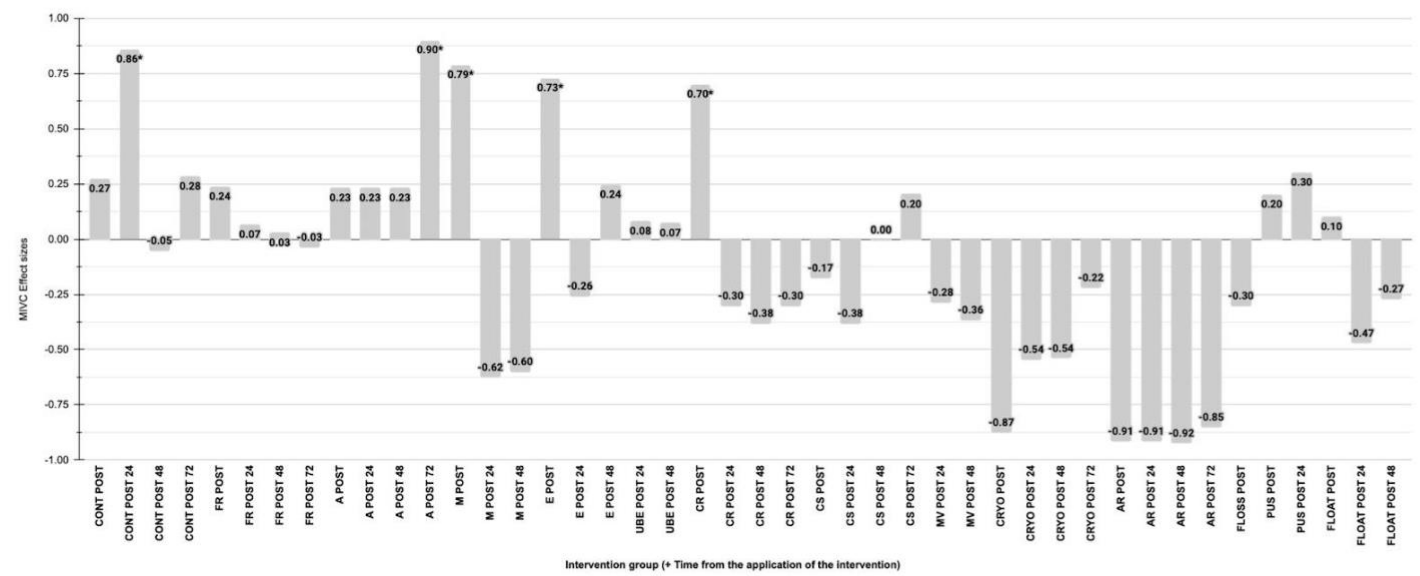

Figure five: Mean maximal isometric voluntary contraction values post different DOMS recovery interventions

A total of 44 subgroups from 14 different recovery interventions reported data for their effect on maximal isometric voluntary contractions following the introduction of DOMS. The reported effect sizes do not support the concept of a linear relationship between time and recovery from DOMS. Five of the 44 subgroups reported a statistically significant positive effect size. The greatest positive effect size came from the acupuncture post-72 hours group (0.90). However, the second greatest positive effect size was reported by the 24-hour control group (0.86). The other three statistically significant positive effect sizes were reported by the massage post group (0.79), Electronic stimulation post group (0.73) and the combined recovery group (0.70). Nine out of the 44 subgroups reported a statistically significant negative effect size which suggests that those specific subgroups were unable to mitigate the negative effects of DOMS regarding maximal isometric voluntary contraction.

Cont = Control group (Passive recovery), FR = Foam roller post-DOMS, A Post = Acupuncture, M = Massage, E = Electrical stimulation, UBE = Upper Body Ergometry, CR = Combined Recovery, CS = Compression garments, MV = Mechanical vibration, AR = Active recovery, Floss = Tissue flossing, Float = Flotation therapy.

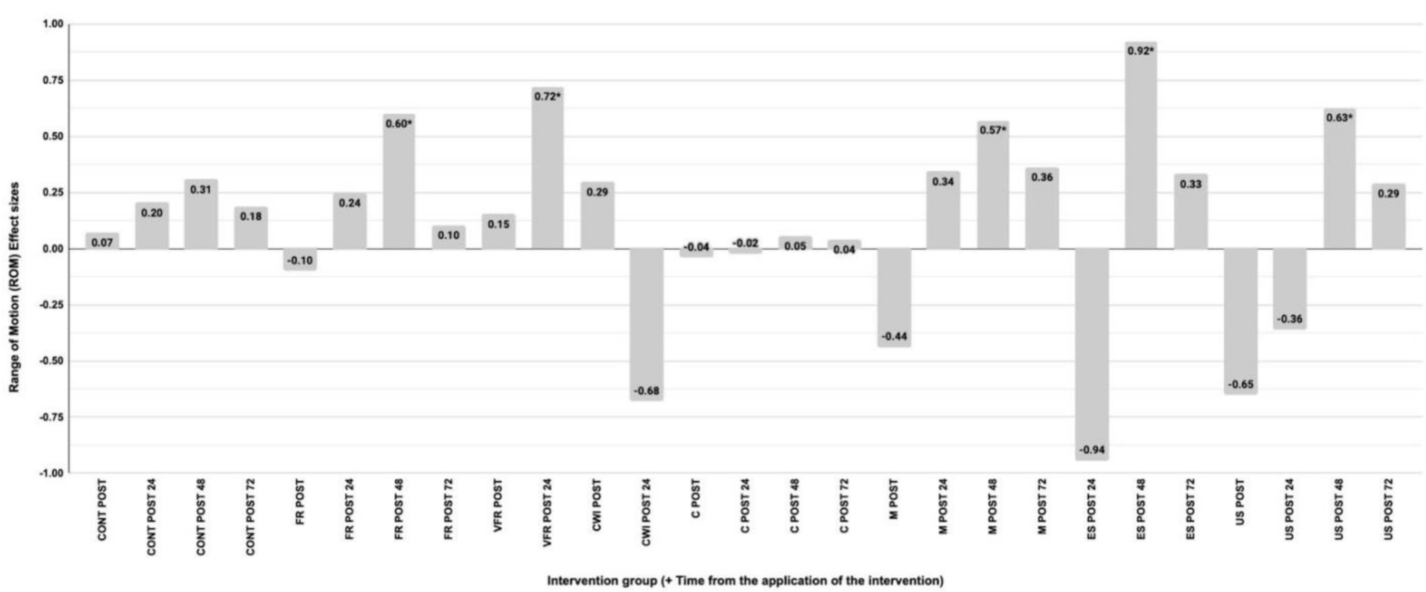

Figure 6 Mean range of motion (°) values post different DOMS recovery interventions

For the outcome measures of range of motion, there were 27 subgroups from eight different recovery intervention methods. There was no observed linear relationship between time and the magnitude of recovery. However, four out of five statistically significant positive effect sizes were reported 48 hours following the first application of the recovery intervention. The electronic stimulation 48-hour subgroup reported the largest positive effect size with a value of 0.92. The vibrating foam roller group reported the second largest positive effect size with an effect size of 0.60 after 24 hours.

Cont = Control group (Passive recovery), FR = Foam roller post-DOMS, VFR = Vibrating foam roller, CWI = Cold water immersion and Cold-water therapy, C = Cupping, M = Massage, ES = Electrical stimulation, US = Ultrasound.

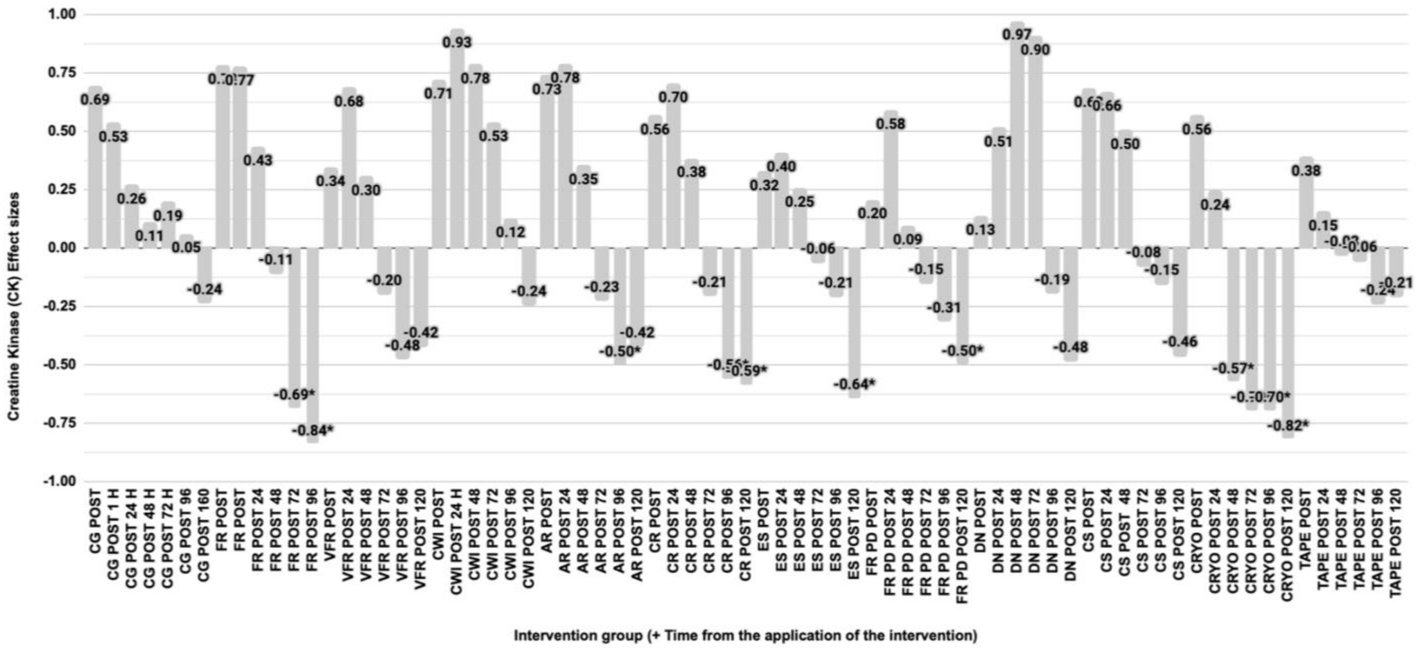

Figure 7 Mean creatine kinase effect size values post different DOMS recovery interventions

A total of 12 recovery interventions reported data within figure seven but owing to some recovery interventions reporting over multiple time points there was a total of 73 subgroups. There was a clear interaction between time and the creatine Kinase activity for all the reported recovery interventions. Meaning that all of the recovery interventions which reported data in figure seven demonstrated that as time progressed following the introduction of DOMS the amount of creatine kinase activity decreased. The final data point reported by the control group was a Cohen's D value of -0.24 which was not considered to be statistically significant. In total 11 out of the 73 subgroups reported results that were considered statically significant. The greatest reduction in creatine kinase activity was reported by the foam roller post 96-hour subgroup which reported a Cohen's D value of -0.84, within the foam roller intervention group both the post 72- and 96-hour subgroups reported a statically significant decrease in creatine kinase activity.

The second greatest reduction in creatine kinase activity was reported by the cryotherapy post 120-hour subgroup, which reported a Cohen's D value of -0.82. However, the value reported by the cryotherapy 96-hour sub group was only a Cohen's D value of -0.70 which was 0.14 less than the value for the same time point from the foam roller group. This suggest that the foam roller recovery intervention was the best at reducing the amount of creatine kinase activity post DOMS.

CG = Control group (passive recovery), FR = Foam roller post DOMS, VFR = Vibrating Foam Roller, CWI = Cold Water Immersion, AR = Active Recovery, CR = Combined Recovery, ES = Electrical Stimulation, FR PD = Foam Roller Pre DOMS, DN = Dry Needling, CS = Compression Socks, CRYO = Cryotherapy, TAPE = Kineso Tape

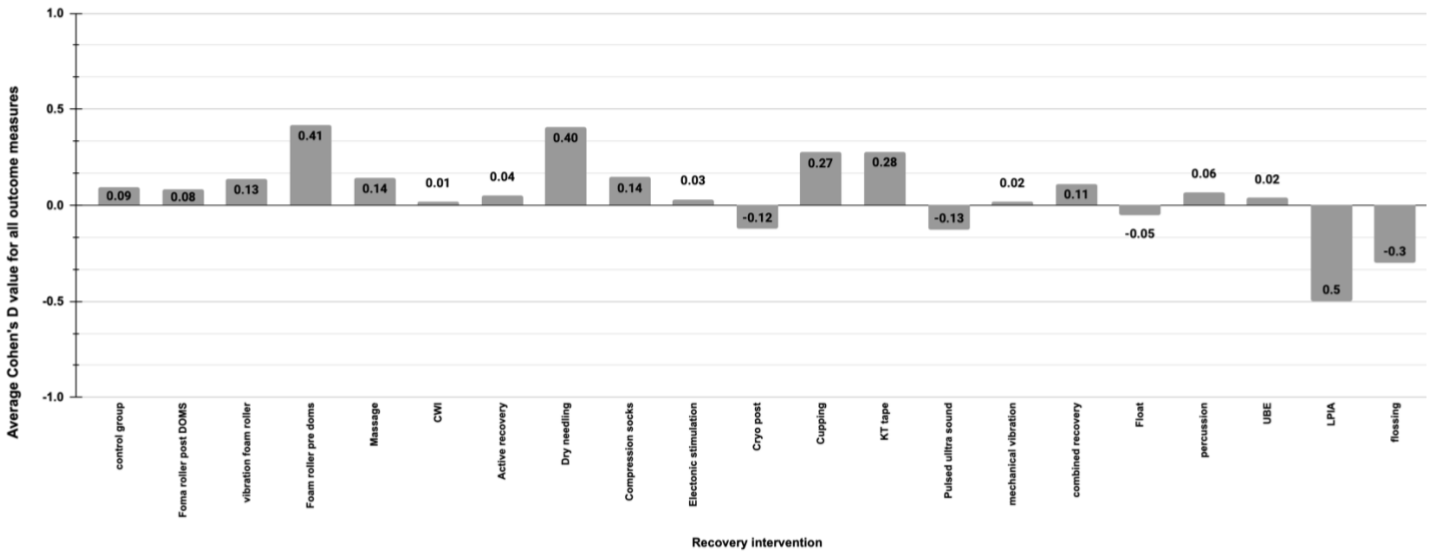

Figure eight reports the average Cohen's D value for all the of the outcome's measures for each of the recovery interventions.

A total of 21 recovery interventions reported an average Cohen's D value which is displayed within figure eight. A positive Cohen's D value showed that the recovery intervention was able to mitigate the effects of DOMS and increase the rate of recovery. A negative Cohen's D value showed that the recovery intervention was unable to mitigate the effects of DOMS and could not influence the rate of recovery following DOMS. None of the 21 groups reported a Cohen's D value that was considered statically significant.

The control group reported a Cohen's D value of 0.09. Using the baseline value of 0.09 reported by the control group figure 8 shows that 13 recovery interventions failed to mitigate the effects of DOMS more than the control group (passive recovery). The foam roller group reported a value of 0.08 which was slightly lower than the control group value of 0.09, therefore, it can be suggested that foam roller post DOMS is not a good recovery intervention regarding the effects of DOMS. The CWI group reported a value of 0.01 which was a lower Cohen's D value than the control group value of 0.09 which shows that cold water immersion is not a successful recovery method for dealing with DOMS. The activity recovery group reported a Cohen's D value of 0.04 which was 0.05 below the value reported by the control group. Subsequently it can be suggested that the active recovery method should not be used as a method for dealing with DOMS. Additionally, the electronic stimulation group reported a Cohen's D value of 0.03 which was 0.06 below the value reported by the control group suggesting that electronic stimulation is not an optimal way to mitigate the effects of DOMS or influence the rate of recovery following DOMS.

The cryotherapy group reported a value of -0.12 which was significantly lower than the control group demonstrating that cryotherapy is not capable of mitigating the effects of DOMS nor is it capable of increasing the rate of recovery following DOMS. Similarly, the pulsed ultrasound group reported a Cohen's D value of -0.13. Furthermore, the mechanical vibration recovery group reported a Cohen's D value of 0.02 which was lower value that the control group (0.09), this shows that mechanical vibration is not a good recovery intervention for mitigating the effects of DOMS. Flotation therapy reported a Cohen's D value of -0.05 which was significantly lower than the value reported by the control group. The negative Cohen's D value shows that flotation therapy was not successful in mitigating the effects of DOMS and it failed to positivity increase the rate of recovery after the introduction of DOMS and should not be used as a recovery method.

The next recovery intervention displayed in figure eight is percussion recovery this group which included all types of percussion devices, such as massage guns, reported a Cohen's D value of 0.06 which was not considered statically significant. The value of 0.06 was only marginally lower than the control group and whilst it was not a negative Cohen's D value, the results from figure eight suggest that percussion is not the best method for mitigating the effects of DOMS. The upper body ergometry group reported a Cohen's D value of 0.02 which was statically significant and was also lower than the Cohen's D value reported by the control group. This suggests that using upper body ergometry is not an optimal way to recovery from the impacts of DOMS or intense exercise.

The lowest Cohen's D value was reported by the LPIA (Light pressure instrument assisted soft tissue mobilisation technique) group which reported a value of -0.50 which suggests that using LPIA is not a good way to mitigate the effects of DOMS or increase the rate of recovery post DOMS. The final recovery intervention from figure eight was the flossing group which also reported the second lowest Cohen's D value of -0.30 which shows that flossing is not a good recovery technique for mitigating the effects of DOMS.

There was no group that reported a Cohen's D value that considered to be statically significant, however, some of the reported positive values were far greater than the 0.09 baseline value reported by the control group. The foam roller pre-DOMS recovery intervention reported a result of 0.41 which was the great positive value. Whilst the value of 0.41 was not statically significant, it was far greater than the control group value of 0.09 and shows that using a foam roller before intense exercise is the best way to mitigate the effects of DOMS.

The second greatest Cohen's D value was reported by the dry needling intervention group which reported a value of 0.40. The value of 0.40 was not considered to be statically significant however, it was far greater than the value reported by the control group which suggests that dry needling after the introduction of DOMS is a good way to mitigate the effects of DOMS and increase the rate of recovery from DOMS. Both the cupping and KT tape groups reported similar positive Cohen's D value of 0.27 and 0.28 respectively. Both values were not statically significant however, they were greater than the baseline value of 0.09 reported by the control group and therefore the use of either cupping or KT tape can be recommended as a way to recover from DOMS. The vibration foam roller group, massage group and compression socks group all reported similar Cohens D values, 0.13, 0.14 and 0.14 respectively. None of these three values were considered statically significant and were only marginally greater than the control group value of 0.09. Whilst the vibration foam roller group, massage group and compression socks group did all report results greater than the control group there use as a recovery technique for dealing with the effects of DOMS cannot be recommended as there was several other groups who reported much greater Cohen's D values. Similarly, the combined recovery group reported a Cohen's D value of 0.11 which was not statically significant and only slightly greater than the control group. Therefore, the use of a combined recovery approach cannot be recommended for mitigating the effects of DOMS as figure eight shows there was other recovery methods that were able to decrease the magnitude of DOMS to a greater extent than what was possible by using combined recovery.

Whilst there were no groups who reported a statically significant positive Cohen's D value, there were significant differences in results that shows that some recovery techniques are more successful at mitigating the effects of DOMS compared to other recovery interventions.

Control group = Control group (passive recovery), Foam roller post DOMS = foam roller post DOMS, Vibration foam roller = vibration foam roller, Foam roller pre DOMS = Foam roller pre DOMS, Massage = Massage, CWI = Cold Water Immersion, Active recovery = Active recovery, Dry needling = Dry needling, Compression socks = Compression socks, Electrical stimulation = Electrical stimulation, Cryo post = Cryotherapy post DOMS, Cupping = Cupping, KT tape = Kineso tape, Pulsed ultra sound = pulsed ultra sound, Mechanical vibration = Mechanical vibration, Combined recovery = Combined recovery, Float = Floatation therapy, Percussion, = Percussion therapy, UBE = Upper body ergometry, LPIA = Light pressure instrument assisted soft tissue mobilisation technique, Flossing = Flossing

Discussion

This meta-analysis aimed to search the current literature for research articles that assessed the effect of a particular device or method for reducing the effects of DOMS and increasing physiological or biomechanical performance. A total of 275 studies met the predefined inclusion criteria. A total of 19 different recovery techniques and methods were analysed in a meta-analysis to determine if they could mitigate the effects of DOMS using the outcomes measures: Blood lactate, perceived muscle soreness, countermovement jump height, maximal isometric voluntary contraction performance, range of motion, creatine kinase activity and the total amount of recovery that was experienced (determine by calculating the average Cohen's D effect size of each of the previous outcome measures). The different recovery techniques that were investigated are as follows: Foam roller post-DOMS, Foam roller pre-DOMS, Active recovery, Vibrating Foam roller, mechanical vibration, Massage, Floatation, Electronic stimulation, Instrument assisted soft tissue massage, Laser therapy, compression garments, Dry needling, cryotherapy, Acupuncture, pulsed ultrasound, Kinesio taping, Cold water immersion, contrast water therapy, generic hydrotherapy, infrared light emitting diode irradiation and cupping.

The results from the included studies contain several different recovery interventions aimed at reducing the effects of DOMS. Compared to the only other previous study that has compared multiple recovery interventions together (Dupuy et al. 2018), this current systematic review and meta-analysis compared a total of 22 recovery interventions against each other for three different primary outcome measures. The results show that there are many different ways to measure recovery post-DOMS. Each method of assessing recovery resulted in a different intervention having the greatest impact on DOMS. When using blood lactate values to measure recovery, the cryotherapy group reported an effect size of (-0.76) which was the most statistically significant decrease in blood lactate values. However, the self-reported muscle soreness outcome measure reported that a combined recovery approach using 3 minutes of foam rolling on the affected muscle group with 15-20 minutes of light aerobic exercise at <50% of vo2max immediately post-exercise is the most effective method of mitigating DOMS and reducing muscle soreness. However, for CMJ performance (cm), the best recovery intervention was pulsed ultrasound, which after 72 hours reported an effect size of 0.92.

The cryotherapy intervention group reported the best average effect sizes for all the outcome measures tested in the meta-analysis. Therefore, cryotherapy should be the recovery method of choice when attempting to mitigate the effects of DOMS.

The historical development of DOMS Recovery interventions and strategies

Some previous research has shown the positive effects of myofascial release in relation to its ability to reduce the perception of fatigue and general muscle soreness. However, contemporary research regarding myofascial release and self-administered myofascial release focused on different manual soft tissue mobilisation techniques (Beardsley and Škarabot, 2015). However, in recent years there has been an increase in the development of tools to increase myofascial release. The foam roller was the original tool developed to enhance myofascial release (Clark and National Academy of Sports Medicine, 2001). Since the first introduction of foam rollers, several other devices aim to increase the self-myofascial release experience.

Foam rollers combined with a vibration element have gained increased popularity in recent years. Ahmed and Lim et al., (2019) reported that the use of a vibrating foam roller has a positive impact on hamstring range of motion. Several other studies have explored the use of vibration foam rolling on quadriceps (Lim et al., 2019), knees (Cheatham and Stull, 2018) and other body parts (Cheatham and Stull, 2018; García-Gutiérrez et al., 2018; Wilke et al., 2020). These studies reported an acute increase in range of motion following the use of a vibrating foam roller. On the other hand, Thompson et al. (2014) discovered that using a vibrating foam roller is a safe method to increase bone density.

The current state of the scientific literature suggests that there has been a significant increase the development of devices and tools aimed to mitigate the effects of DOMS. Most of the new devices or recovery protocols are very different from the first tools designed to mitigate the effects of DOMS such as traditional sports massage or foam rollers. Additionally, in recent years researchers and practitioners have begun to develop increasing complex recovery protocols that are very different compared to the first ever recovery protocols that were created for the treatment of DOMS (Martin 2021). Recovery interventions such as floatation therapy and flossing have not been researched to the same extent as some of the other contemporary recovery methods such as mechanical vibration, pulsed ultrasound and cryotherapy. The current direction of DOMS research suggests that several new tools or protocols will be developed within the next years as the effects of DOMS are so influential on athletic performance and thus, will always be a point of interest.

How recovery is measured and how this impact how different recovery strategies are measured against each other

There are several ways that recovery from intense exercise can be measured in scientific research studies. A variety of physiological, biomechanical and general sports performance markers can be used to assess the impact of different recovery interventions that are designed to mitigate the effects of DOMS following period of intense exercise. Some physiological markers which are commonly included in research are heart rate, blood pressure, blood lactate levels, and creatine kinase. Whilst some performance measures can include running speed, jumping height, or maximal strength. Finally biomechanical markers such as range of motion, muscle flexibility, or muscle activation patterns can be used to asses the impact of different recovery protocols or devices.

Massage

Massage is a very traditional way to improve recovery after physical exercise both in sports and rehabilitation contexts (Best et al., 2008). Sports massage is a type of therapeutic massage which is typically used to help prevent injuries, improve performance, and speed up recovery after intense physical activity (Brummitt, 2008). Sports massage is known to have several beneficial effects on the body. One of the primary benefits is its ability to improve muscle flexibility and range of motion (Yeun, 2017). Tight muscles can limit an athlete's performance and increase the risk of injury, but regular sports massage has been shown to help to loosen and stretch the muscles, improving mobility, range of motion and athletic performance.

Another benefit of sports massage is its ability to reduce muscle soreness and fatigue (Ogai et al., 2008). Research conducted by Ogai et al., (2008) suggests that sports massage can reduce the perception of muscle soreness and fatigue by increasing blood flow to the targeted area and thus, promoting the removal of harmful waste products such as lactate acid. Research carried out by Hidetoshi et al., (2004) showed that sports massage can significantly increase blood flow to the targeted muscles using techniques, such as kneading and stroking. Hidetoshi et al., (2004) also demonstrated that the application of traditional sports massage is far better than passive recovery in regard to promoting a quicker decrease in muscle soreness or pain and also an individual's perception of fatigue.

Additionally, research carried out by Vairo et al., (2009) has shown that manual massage administered a short while after an a period of intense exercise can promote lymphatic drainage which helps to carry waste products away from the DOMS effected muscles promoting recovery and reducing the perception of fatigue.

Alongside the physiological and biomechanical benefits of sports massage that have already been stated, recent research has shown that the application of sports massage can directly increase an individual's mental well-being and their proprioception with the DOMS effected muscles. Brummitt (2008) conducted a literature review assessing the impact of traditional sports massage on an individual's psychological readiness for sport. Brummitt (2008) states that individuals who participate in regular sports massages post exercise experience a significant reduction in cortisol levels and other markers of physiological stress. Equally, individuals reported a statistically significant improvement in profile of mood states questionnaires after a period of sports massage. Correspondingly, the information presented by Brummitt (2008) demonstrates that regular use of sports massage after intense periods of exercise can increase an individual’s psychological readiness and overall mood (Leivadi et al., 1999; Micklewright et al., 2005).

Within this current meta-analysis, massage was unable to mitigate the effects of DOMS in relation to blood lactate. As shown in figure two, massage post DOMS did not result in an increase in blood lactate and therefore, did not promote recovery from DOMS and did not in any way mitigate the effects of DOMS in relation to blood lactate. For the blood lactate outcome measure cryotherapy was a far better recovery intervention than traditional sports massage. For the MIVC outcome measure, the massage group did report one statically significant improvement in torque performance directly after the application of massage but was then unable to improve the rate of recovery after 24 hours. This suggests that whilst massage could change acute muscle force production, but massage cannot increase the rate of recovery from DOMS. Instead figure five suggests that the best recovery intervention for MIVC is acupuncture. The acupuncture post 72-hour sub group reported the greatest increase in MIVC performance after DOMS was educed.

Massage was unable to positively influence self-reported muscle soreness post DOMS. Instead, the foam roller pre DOMS reported the great reduction in muscle soreness. However, the massage subgroups did show a positive interaction between time and the magnitude of DOMS meaning that massage was able to increase the rate of recovery post DOMS.

The results regarding how massage effected range of motion post DOMS show that after 48 hours one single bout of massage significantly increase range of motion (0.57 Cohen's D value) The best recovery intervention for range of motion was electrical stimulation post 48 hour group.

Following an intense period cycling on an ergometer, Ogai et al. (2008) reported that perceived fatigue was more effectively reduced by massage than by passive rest without massage. The results from this systematic review and meta-analysis do not support the results presented by Ogai et al. (2008). The passive recovery subgroup did report a statically significant reduction in muscle soreness (-0.81 Cohens D value). However, a reduction in muscles soreness was only presented by the first and last data collection subgroups (directly after rest and 96 hours post rest). Therefore, the results from figure three show that passive recovery failed to increase the rate of recovery regarding the perception of muscles soreness after the introduction of DOMS. Whereas all of the included massage recovery subgroups reported a small statistically insignificant increase in soreness. Therefore, the data presented within this meta analysis shows that massage failed to increase the rate of recovery after DOMS and in some cases completely failed to increase recovery from DOMS or muscle soreness and passive recovery was a far better method of reducing the perception of DOMS related muscle soreness.

Prior research conducted by Bishop et al., (2008) has suggested that an overserved decrease in CK might correlate with a reduction in muscle damage and an increase in a faster rate of recovery. Furthermore, Torres et al., (2012) demonstrated that the use of traditional sports massage was effective in reducing the symptom's associated with DOMS and that sports massage reduced plasma CK activity after eccentric exercise.

Combining stretching with massage has recently been studied (Delextrat et al., 2014). A significant reduction in fatigue was shown. However, discrepancies in the results were found in males and females, with a faster and shorter reduction in fatigue in females (Delextrat et al., 2014).

Compression garments

Compression garments can be defined as elements of clothing that has been designed to apply continual pressure to a specific area of the body, usually either muscles or joints (Bakken, 2011). Items of compression clothing are commonly used in an attempt to increase the rate of recovery following periods of intense exercise or DOMS educing exercise. Over recent years many researchers have assessed the impact of using compression clothing to reduce the impact of DOMS and to increase the recovery rate following DOMS. Research has mainly focused on the application of lower limb compression garments such as compression socks or tights. A narrative review carried out by Macrae et al., (2011) suggested that the use of compression socks directly worn directly after exercise for a period of 24-48 hours decreased markers of self-reported fatigue and muscles soreness, however, compression socks failed to increase the recovery rate compared to passive recovery for sprint, agility and CMJ performance. Therefore, Macrae et al., (2011) suggested that some individuals may experience more of a phycological benefit rather than a physical performance benefit from adopting the use of compression garments within their post exercise recovery practise.

Meta analysis performed by both Hill et al., (2014) and Marqués-Jiménez et al., (2016) shows that the use of lower limb compression garments after DOMS educing exercise will mitigate the effects of DOMS and may in some cases increase the recovery rate compared to passive recovery. Additionally, the meta-analysis by Marqués-Jiménez et al., (2016) suggested that the use of lower limb compression garments could increase the rate of recovery from DOMS so that an induvial sporting performance would return to baseline after just 96 hours, compared to 144 hours by using passive recovery.

Previous research by Kraemer et al., (2010) showed that wearing a whole body compression garment for a period of 24 hours after intense exercise can significantly reduce the perception of fatigue and muscle soreness. The improved recovery experienced by using compression garments could be explained by a reduction in swelling due to the continual reduction in blood flow space generate by the compression pressure of the item of clothing. Unlike prior research, Kraemer et al., (2010) suggested that individuals should wear compression garments during and after periods of intense exercise if they wish to recovery quicker.

One way that different compression garment protocols can influence the results of studies is by affecting the duration of compression. For example, a study that compares the effects of wearing compression garments for 24 hours per day to not wearing them at all is likely to show different results than a study that compares the effects of wearing compression garments for only a few hours per day.

Due to the varying types of compressions clothing many clothing companies and researchers have developed their own protocols for the use of compression garments. As such, it can be suggested that some of the overserved discrepancies presented in previous literature reviews and meta-analysis may be the result of comparing different application protocols rather than differences in the magnitude of recovery generated using compression garments.

Rimaud et al., (2010) went on to suggest that the observed difference in the effectiveness of compression garments may occur as a result of the different recovery period lengths or the different pressure forces generated by how well the compression garments fitted the participants. This suggests that there is a major limitation to generic "off the shelf" compression garments as they are typically one size fits all items and thus, may provide different levels of compression and pressure to different shapes and sizes of limbs.

Additionally, Bishop et al., (2008) has shown that there is a level of sensitivity to blood flow between individuals wearing the same compression clothing. This suggests that there is some sensitivity regarding where an individual is either a responder or non-responder to compression garments based off how sensitive their changes in blood flow are (Leeder et al., 2012).

Cold water immersion and other hydrotherapy methods of recovery

Scientific work conducted by Ihsan et al., (2016) has attempted to explain the underlying mechanisms that allow CWI to be an effective form of recovery from DOMS. Ihsan et al., (2016) proclaims that CWI is able to reduce fatguie associated with DOMS due to a reduction in post exercise induced inflammation which is what causes the majority of muscle damage created by DOMS. Several other researchers have supported the theory proclaimed by Ihsan et al., (2016), including (Leeder et al., 2012; Sanchez-Ureña et al., 2015). Leader et al., (2012) found that after one bout of CWI post DOMS educing exercise, individuals overserved a significant decrease in the volume of CK compared to using passive recovery.

Building on the concept of reducing post excise induced inflammation, Wilcock et al., (2006) proposed that another mechanisms that allows CWI to be effective at mitigating the effects of DOMS is that the cold temperature of the water may reduce the formation of oedema which contributes to the sensation of pain and a perceived decrease in exercise performance. The cold temperature of the water is also thought to cause a hydrostatic pressure which may facilitate the transport of fluids from the DOMS effected muscles which will therefore eliminate metabolites (Leeder et al., 2012; Willcock et al., 2006).

Bleakley et al., (2012) conducted a systemic review and meta-analysis examining the effects of cold water immersion in regards to its ability as a recovery methods from DOMS. Bleakley et al., (2012).

The aim of the work done by Bleakley et al., (2012) looked to compare the effects of a single bout of cold water immersion with passive recovery regarding mitigating the effects of DOMS and increasing the recovery rate after DOMS had been educed.The results reported by Bleakley et al., (2012) proclaimed that a single bout of CWI post DOMS lowered an individual's rating of fatigue and muscle soreness. Several other research papers have shown that either a single bout or multiple bouts of CWI can improve the rate of recovery both psychotically and physiologically (Delextrat et al., 2014; Rowsell et al., 2011).

Contrast water therapy

Much like cold water immersion, contrast water therapy has been heavily researched regarding the potential for CWT to mitigate the effect of DOMS. Contrast water therapy can be defined by being fully submerged in a cold water bath (5-10°) for 3-5 minutes before being submerged in a hot bath (35-45°) . Hing et al., (2008) published a systemic review and meta-analysis exploring the effects of contrast water therapy in relation to mitigating the effects of exercise induced DOMS, the results show that whilst the topic of contrast water therapy has been assessed by many researchers, it has not been researched to the same degree as traditional cold water immersion protocols. As such there remains some uncertainty regarding the effectiveness of CWT in relation to mitigating the effects of DOMS.

Bieuzen et al., (2013) showed that one single bout of CWT following DOMS educing exercise was able to increase the rate of recovery much greater than was possible by just using passive recovery. The results reported by Bieuzen et al., (2013) also demonstrated that CWT could significantly reduce the perception of pain 24, 48 and 72 hours post introduction of DOMS. Therefore, it can be suggested that CWT is a far better method of mitigating the effects of DOMS compared to just passive recovery only.

Active recovery

Active recovery can be defined a recovery method that focuses on a short duration of low intensity aerobic exercise such as walking, cycling, running or swimming. Querido et al., (2022) completed a systemic review and meta-analysis in which the researchers explored the effects of active recovery after a professional football match. The inclusion criteria used by Querido et al., (2022) included 10 randomised (Abedi et al., 2018; Arabmoneni et al., 2017; Abaidia et al., 2019; Ozsu et al., 2018; Rey et al., 2012; Arazi et al., 2012; Anderson et al., 2010; Anderson et al., 2008; Tessitore et al., 2008 and Suzuki et al., 2004) and 2 nonrandomised control trails (Gill et al., 2006 & Dawson et al., 2005).

In the context of teams sports, active recovery was used immediately postexercise often in terms of a semi structured cooldown after a training or a match or used a structured recovery session 24 hours after a match. The current literature suggests that the practise of active recovery is typically used within team sports particularly football and rugby between 24 and 72-hours post-match. Whilst the use of active recovery has been well documented by researchers and practitioners, most of the current literature reviews suggest that active recovery is not an effective strategy for mitigating the effects of DOMS. A review by Nedelec et al., (2013) reported that active recovery was unable to significantly mitigate the effects of DOMS or increase the recovery rate from DOMS.

Additionally, a meta-analysis carried out by Querido et al., (2022) reported that a single bout of active recovery (<50% vo2max running velocity) had no impact on increasing the recovery rate post DOMS for professional footballers. Querido et al., (2022) instead proclaimed that an active recovery is used post-match within the context of professional football as it can serve the function of socialization and psychological recovery for the athletes in a way that increases team motivation. Therefore, most of the time active recovery is not used because it is best form of recovery from DOMS but because it can theoretically serve many functions at once. Querido et al., (2022) also suggested that when players or athletes are given the freedom to self-select their recovery post work out or match most of them traditionally chose a form of active recovery as that is all they know of.

Cryotherapy

Cryotherapy is a therapeutic treatment that involves exposing the body to extremely cold temperatures, typically in the range of -100 to -160 degrees Celsius, for a short period of time (Banfi et al., 2010). Due to the recent discovery of cryotherapy as a forms of post exercise recovery, there is significantly less research assessing its effectiveness compared to some of the other recovery interventions included within this systemic review and meta-analysis. Some prior research into the effectiveness of cryotherapy has sown that it may promote and increase in the recovery rate post DOMS. It has been proclaimed that cryotherapy may function in a similar way to CWI or CWT regarding the application of a cold substance which in turn reduces inflammation and subsequently reduces muscles soreness and fatigue.

Research by Fonda et al. (2013) reported that a single shirt duration bout of cryotherapy was able to significantly mitigate the effects of DOMS. Just one single 3-minute bout of cryotherapy was able to decrease the physiological and biomechanical impact of DOMS within 24 hours and increase the rate of recovery from DOMS between 24 and 96 hours. However other research into the effects of cryotherapy by Guilhem et al. (2013) and Vieira et al. (2015) did not find the same effects regarding cryotherapies ability to mitigate the effects of DOMS or increase the recovery rate from DOMS. The randomised control trial carried out by Guilhem et al. (2013) had participants performed 3 sets of 20 maximal isokinetic eccentric contractions of the elbow flexors, then over the following 3 days individuals either took part in a passive recovery protocol (labelled as control) or three four-minute bouts at -30°C (labelled as the cryotherapy group). The results from Guilhem et al. (2013) show that the repeated bouts of cryotherapy failed to mitigate the effects of DOMS in relation to maximal isometric torque and could not increase the rate of recovery after the decrease in strength created by DOMS. The reported results by Guilhem et al. (2013) demonstrate that whilst localised and whole-body cryotherapy were able to slightly reduce local inflammation and the formation of edema, cryotherapy could not mitigate the major symptoms of DOMS nor could it increase the recovery rate from DOMS over a period of 24-96 hours.

Electrostimulation

There is a limited amount of research exploring the effects of electrical stimulation devices and or protocols regarding supporting the recovery process following the introduction of DOMS. However, amongst the current scientific literature there are several manuscripts which have assessed the impact of electrostimulation on increasing muscle activation and improvising movement patterns and gait post stroke. Vanderthommen et al., (2010) carried out a randomised crossover design study which compared passive recovery, active recovery, and electrostimulation against each other regarding their ability to mitigate the effects of DOMS. Vanderthommen et al., (2010) used 19 healthy individuals who carried out three sets of 25 repetitions of isometric knee extensors contractions. The electrostimulation group performed 25 minutes of continuous and non-tetanic (5Hz) stimulation of the quadriceps. The results show that the interaction between time and the magnitude of DOMS was the same post DOMS for all recovery groups (passive, active and electrostimulation recovery). Vanderthommen et al., (2010) concluded that the use of electrostimulation should not be advised following DOMS.

The results from this current systematic review and meta-analysis show that electrostimulation had no significant impact (0.04 Cohen's D value) on blood lactate immediately post DOMS and 1 hour post DOMS. The Cohen's D value reported by the electrostimulation group was not to different from the value reported by the foam roller 9 minutes group showing that neither group could significantly mitigate the effects of DOMS.

However, for the creatine Kinase outcome measure electrostimulation was able to significantly decrease the amount of creatine Kinase activity after 120 hours (-0.64 Cohen's D value). Whilst this value was statically significant, the value only occurred after 120 hours and two other intervention methods did provide much greater decreases in creatine kinase activity. The foam roller post 96 hours sub group reported a value of -0.84 which was the most significant decrease reported, whilst the cryotherapy 120 hour sub group reported a value of -0.82. Therefore it can be suggested that whilst electrostimulation was able to mitigate some of the effects of DOMS in regards to blood lactate it could not increase the rate of recovery, therefore, utilising either cryotherapy or a foam roller post DOMS is a better way to mitigate the effects of DOMS in relation to blood lactate.

Limitations

There are several limitations regarding the availability of third-party data that have negatively impacted the quality of this dissertation and should therefore be acknowledged. Firstly, there were several studies which only reported either p values or effect sizes for their pre-defined outcome measures. Subsequently despite efforts to contact the authors to get copies of the raw data, it was impossible to include the effect size data in the SPSS comparison of means statistical test or the independent T tests.

The greatest limitation of this current systematic review was the quality assessment of the included studies. Due to a large variety of study types that were included it was impossible to use one study assessment tool that would cater for the characteristics of all the different study designs included in this review. Therefore, the decision was made to use the TESTEX quality assessment tool (Smart et al.,

2015) which is designed to assess randomised control trials as 64 out of the 117 included studies (55%) were reported to be randomised control trials. A total of 26 studies resulted in a TESTEX score of 10/15 which is considered to be of a low study quality score. However, these studies were still included in the systematic review and meta-analysis because of their relation to the overall relation to the objective of this systematic review and meta-analysis. During the planning stages of this manuscript the TESTEX tool was chosen despite its obvious limitations as no other study quality assessment tool exists that can be applied to sports/exercise focused repeated measure design studies and other designs that are not randomised control trials.

Even though both the 11-step Pedro and TESTEX study quality assessment tools both measure binding for both participants and researchers this may not be particularly relevant to research articles comparing recovery methods for DOMS. It would be very difficult or almost impossible to have a completely blind procedure involving the participants and/or assessor for certain recovery interventions that were assessed within this meta-analysis. Therefore, while both of the 11-step Pedro and the TESTEX are popular study quality assessment tools, they do possess significant limitations regarding their application for this particular meta-analysis. Taking this limitation into account for the TESTEX study quality assessment tool, it was possible for some studies to get only 12-15 as a maxim score due to the way that the TESTEX tool measures participant and assessor blinding.

In order to determine if study quality impacted the effect sizes for each subgroup for each of the outcome measures, The effect sizes for each sub group were calculated twice. Once with all data included, from every single study that met the inclusion criteria irrespective of study quality score and once with studies that only met the inclusion criteria and had a high study quality score (a score greater than 10 was considered to be a high score). It was found that the outcome of the both analyses were similar when the studies with lower quality scores were included to calculate effect sizes. Therefore, there is no apparent bias within the results that is created by the quality of the included studies. Additionally, given the practical difficulties of blinding the participants and asses from the recovery modalities, especially for studies that assessed two drastically different recovery methods, the beneficial effect arising from the placebo effect of the recovery interventions could not be eliminated.

Even though this meta-analysis is the first of its kind to use such a wide ranging amount of literature to determine what the best recovery intervention is for DOMS, there are several limitations of the methodology that should be considered. Whilst searching for literature that met the inclusion criteria, both publication and language resitcations bias may have altered the estimates of the effect of each particular recovery technique or method. However, there was significant care. Only one other study to date has attempted to compare different DOMS recovery methods against one another (Dupuy et al. 2018) and this study only included fully peer-reviewed studies and only a very small number of theses and dissertations. Meaning that Duppy et al 2018, had a significant bias against studies that appear within the grey literature. To combat this basis, this present systematic review and meta analysis search an extensive number of grey literature websites and databases and included fully peer-reviewed studies, thesis and dissertation from PhD, Masters and undergraduate level and a small number of preprints that had not been fully peer-reviewed. However, despite including some articles that had been peer-reviewed, each article or study that was included in this meta-analysis went through the same study quality assessment and risk of bias assessment using the 11 step pedro (Eriksen and Frandsen, 2018; Moher et al. 2010) and TESTEX (Smart et al. 2015) quality assessment tools.

One other limitation that is unique and specific to the topic of this meta-analysis is the thoroughness of analysis. One limitation of the data analysis methods was that interactions between certain recovery interventions and outcome measures were able to be assessed. It has previously been shown that the efficiency of some recovery techniques depend on the type of fatigue created by previous exercise. Subsequently, although all of the data regarding the reported training loads of both the experimental and control groups was coded. It was not possible to address the interaction between training load and the magnitude, or total perceived effect, of some particular recovery strategies.

Another significant limitation of this systematic review and meta-analysis is that for some of the newer more novel recovery techniques or interventions, there is only a limited number of studies that have assessed their ability to mitigate the impacts of DOMS. Unlike the meta-analysis conducted by Duppy et al (2018), who chose not to include studies that assessed both laser therapy and mechanical vibration. This present systematic review and meta-analysis included studies that assessed novel recovery methods such as laser therapy, floatation therapy, instrument assisted soft tissue manipulation (e.g. massage guns), cupping and infrared radiation emitting ceramic materials during nightly sleep. Whilst there is still a very low number of studies that have assessed the impact of these recovery interventions regarding their ability to mitigate the effects of DOMS, it was decided that as there is a small number of studies that have proved they work, that they should be included within this meta-analysis. Due to the smaller total number of studies that have assessed to impact of these newly created recovery modalities, their calculated effect sizes may be impacted as a result.

Another limitation that should be addressed and considered is how exactly sports recovery is measured. Historically changes in perceived fatigue and inflammation as well as muscle damage measured by blood lactate or creatine kinase activity have been the primary methods to measure recovery post exercise or DOMS. However, over recent years there have been several new ways to measure aspects of recovery such as heart rate variability (Esco et al. 2010; Javorka et al. 2002).

Recovery from exercise and sports performance as a whole is a complex concept and there are many ways to measure it. In some studies some of the performance tests and measures can be unreliable and make it difficult to compare results between groups or participants. Additionally, nearly all of the studies that used performance tests failed to include the raw performance data and instead only included P values or percentage changes between two or more tests making it impossible to compare the effect of a recovery intervention on physical performance. Therefore, this meta-analysis attempted to determine which recovery intervention of technique could increase recovery after DOMS and not physical performance after DOMS. Hausswirth & Le Meur (2011) suggested that one way to define recovery following DOMS or strenuous exercise is an observed return to homeostasis of the key physiological systems following muscle damage and metabolic and inflammatory changes. Meaning that when an individual can return to their baseline level of physical performance following DOMS or exercise, they have fully recovered.

Whilst all of the previously mentioned methodological limitations should be considered, it is worth mentioning that they do not significantly reduce the overall quality of this systematic review and meta-analysis. This is only the second meta-analysis that has compared multiple DOMS recovery interventions against each other. This meta-analysis also has a far greater number of included studies compared to the only other review paper comparing DOMS recovery interventions. This meta-analysis should provide useful information and data for sports scientists, coaches, medical staff and anyone else looking to increase their recovery following DOMS or strenuous exercise.

Conclusion

In conclusion, the results reported within this systemic review and meta-analysis suggest that there are several recovery techniques that after a single bout of the intervention, can mitigate the effects of DOMS and in some cases increase the rate of recovery after the introduction of DOMS. The results from this meta-analysis suggest that the use of a foam roller before intense exercise or the introduction of DOMS is the best method for mitigating the effects of DOMS. The use of dry needling post DOMS is also an optimal method for reducing the impact of DOMS and increase the rate of recovery following DOMS. There were several other recovery techniques that reported a positive Cohen's D value for all outcome measures compared to the value reported by the control group. The use of cupping and kinesio tape were able to reduce the effects of DOMS and positively influence the rate of recovery from DOMS but with a less pronounced effect. Both light pressure instrument assisted soft tissue mobilisation technique and flossing reported an average negative Cohen's D value which was significantly below the baseline value reported by the control group. The light pressure instrument assisted soft tissue mobilisation technique group reported a Cohen's D value of -0.50 which was the lowest value. This suggests that both light pressure instrument assisted soft tissue mobilisation technique and flossing should not be used a recovery method for treating the effects of DOMS. Cryotherapy was the best recovery method for reducing blood lactate levels post DOMS. For the self-reported muscle soreness outcome measure, the post DOMS foam roller recovery intervention had the largest pronounced effect, however, both the FIEC (Far-Infrared Emitting Ceramic Materials during night-time sleep) group and the control group reported a Cohen's D value that marginally lower than the foam roller post DOMS recovery intervention for the data point immediately following the introduction of DOMS. Therefore, the results of the muscle soreness outcome measure suggest that any recovery protocol may take a significant amount of time to change the magnitude of DOMS. For the CMJ outcome measure, pulsed ultrasound provided the greatest reduction in the effects of DOMS and increased the rate of recovery more than any other recovery intervention. For nearly all the chosen outcome measures within this meta-analysis there was a significant interaction between time and the magnitude of DOMS, meaning that after a single bout of the recovery intervention the magnitude of DOMS decreased at every data collection time point. However, not all recovery protocols were able to increase the rate of recovery more than was observed from the control group for each outcome measure.

Additionally, the results from this meta-analysis show that there was a large discrepancy between most of the intervention methods when looking at each of the outcome measures individually, however, once all the reported Cohen's D values were averaged out to give a measure of total recovery the differences between the recovery interventions were much smaller. Within this meta-analysis, only a single bout of each recovery intervention was examined. Subsequently, further research into the effects of different recovery interventions on DOMS should explore the effect of repeated bouts of each intervention to see how their effect on the magnitude of DOMS. Additionally, some research should aim to explore the role of combined recovery techniques to investigate whether a synergetic phenomenon occurs when treating the effects of DOMS.

Practical applications

The results from this current meta-analysis suggest that there are large differences between some of the recovery interventions for particular ways of measuring recovery, however, there was no statically significant differences between the recovery interventions when all of the Cohen's D effect sizes were averaged across all of the outcome measures. Most, but not all, recovery interventions demonstrated a strong interaction between time and the magnitude of DOMS. Meaning that for all the recovery interventions, the magnitude of DOMS decrease over a period of 24-96 hours after just one bout of the interventions.

There were particularly large differences between all of the included interventions for the self-reported muscle soreness outcome measure and the counter movement jump outcome measure. In contrast, there were less differences between the recovery interventions for the blood lactate outcome measure. Whilst both using a foam roller pre-DOMS and dry needling performed the best overall, there were some other recovery interventions that had a more produced effect on reducing the effects of particular elements of DOMS such as changes in creatine kinase or blood lactate. Therefore, if an individual is solely looking to mitigate one particular symptom of DOMS then they may which to implement the recovery internecion that was best for that symptom (e.g. electronical stimulation was the best intervention for restoring range of motion following DOMS).

However, figure eight shows that whilst some recovery interventions are better than passive recovery, there was no statically significant differences between the best recovery interventions. Therefore, the use of both foam roller pre-DOMS and dry needling can be recommended for the treatment of DOMS. The use of light pressure instrument assisted soft tissue mobilisation technique and flossing cannot be recommended for the treatment of DOMS as they failed to positively influence the rate of recovery post DOMS and could not reduce the symptoms of DOMS.

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