The evidence of conventional physiotherapeutic interventions after exercise-induced muscle damage: systematic review and meta-analysis.

Abstract

Introduction: Exhaustive and/or unaccustomed exercise, mainly those involving eccentric muscle actions, induces temporary muscle damage, evidenced by Delayed Onset Muscle Soreness. Different strategies to recover the signs and symptoms of this myogenic condition have been studied by researchers, as a result a significant number of articles on this issue have been published.

Purpose: A systematic review was conducted to assess the evidence of the physiotherapeutic interventions of exercise-induced muscle damage.

Methods: The electronic data bases were searched, including MEDLINE (1996-2011), CINHAL (1982-2011), EMBASE (1988-2011), PEDro (1950-2011), and SPORTDiscus (1985-2011). Systematic review was limited to randomized control trials (RCTs) studies, written in English or Portuguese, which included physiotherapeutic interventions, namely massage, cryotherapy, stretching and low-intensity exercise, on adult human subjects (18-60 years old) of either gender. Studies were excluded when the intervention could not be assessed independently. The methodological quality of RCTs was independently assessed with the PEDro Scale by three reviewers.

Results: Thirty-three studies were included in the systematic review; eight analyzed the effects of the massage, ten analyzed the effects of the cryotherapy, eight the effect of stretching and seventeen focused low-intensity exercise intervention.

The results suggest that massage is the most effective intervention and that there is inconclusive evidence to support the use of cryotherapy; whereas the other conventional, namely stretching and low-intensity exercise, there is no evidence to prove their efficacy.

Conclusion: The results allow the conclusion that massage is the physiotherapeutic intervention that demonstrated to be the most effective in the relief of symptoms and signs of exercise-induced muscle damage, as a result, massage should still be used in the muscular recovery after sports activities.

Introduction

Exhaustive and/or unaccustomed exercises (particularly those involving muscle contractions) are known to induced temporary muscle damage (1, 2), evidenced by muscle soreness, reduction in muscle strength, muscle swelling, and a reduced range of motion at involved joints (3-5).The mechanism that explains exercise-induced muscle damage remains unclear. However, the most accepted theories involve the high mechanical tension exerted in the myofibril during eccentric muscle contraction and the metabolic changes imposed by the exercise, such as the accumulation of lactic acid, leading to loss of the cellular homeostasis, particularly in the high intracellular calcium concentration (6, 7). It is suggested that the initial stage of the abnormal functioning of the myofibril and the changes of the structure of the cytoskeleton are caused by the increase of intracellular calcium concentration.

Although the first publication of exercise-induced muscle damage was made in 1902 by Hough (8), this issue remains present, particularly with regard to research into the prevention and treatment of this clinical condition. As a result, several studies have evaluated the effect of conventional physiotherapeutic interventions on the negative effects induced by intense exercise. O´Connor & Hurley (9) in 2003 conducted the first systematic review of the literature on the subject of the effectiveness of physiotherapeutic interventions in the management of delayed onset muscle soreness (DOMS). Since then, a considerable number of studies on this topic have been published, whereby a new summary of research identifying the valid and applicable evidence will be of an important contribution for all professionals involved in sports activities.

The most conventional physiotherapeutic intervention, with the intention of creating analgesia and/or treating soft tissue injuries, has often included therapeutic massage, cryotherapy, stretching and active exercise; however, it is unclear which of these interventions show more scientific evidence of its efficacy in preventing or changing the course of exercise-induced muscle damage (3, 9, 10).

In this sense, the aim of this systematic review and meta-analysis is to analyze the evidence of the physiotherapeutic interventions, particularly those named as conventional interventions such as massage, cryotherapy, stretching and low-intensity exercise, in the signs and symptoms of exercise-induced muscle damage.

Materials and methods

Selection criteria for studies

The systematic review was undertaken with the purpose to identify qualitative studies investigating the effect of physiotherapeutic interventions after exercise-induced muscle damage. Only randomized controlled clinical trials (RCTs), in adult human subjects and written in English or Portuguese, were included. Titles, abstracts, and keywords identified from the results of the search were screened by two researchers and were used as a criterion for inclusion or exclusion (Fig 1). When both reviewers did not reach an agreement, the full text of a reference was obtained and analyzed to establish suitability.

The following criteria were used to select relevant papers for the review:

- ✓ Type of participants: conducted on adult subjects of either gender; age-range 18-60
- ✓ Type of study: randomized controlled trials
- ✓ Methodological quality: only studies with a score of at least three in the PEDro Scale
- ✓ Type of interventions: the use of only physiotherapeutic intervention per group
- ✓ Study purpose: to determine the effectiveness of physiotherapeutic intervention on exercise-induced muscle damage or on delayed onset muscle soreness
- ✓ Language: articles written in English or Portuguese

Databases and search strategy

The electronic search was performed on MEDLINE (1966 to February 2011), CINHAL (1982 to February 2011), EMBASE (1988 to February 2011), PEDro (1950 to February 2011), and SPORTDiscus (1985 to February 2011) and included a combination of the following keywords: “delayed onset muscle soreness”, “DOMS”, “eccentric exercise”, “physiotherapy”, “muscle soreness”, “exercise-induced muscle damage”, “skeletal muscle damage”, “cryotherapy”, “cold water immersion”, “massage”, “stretching”, “low-intensity exercise” and “warm-up”. Additional literature was accumulated by manually searching the bibliographies of the identified papers to ensure that as many as possible appropriate articles were obtained.

Assessment of methodological quality and data collection

The methodological quality of the RCTs was assessed by using the PEDro scale, which is based on the Delphi list developed by Verhagen et al. (11); it is a valid and reliable measure of the methodological quality of clinical trials (12, 13).

Two authors, familiarized with the PEDro Scale, independently assessed the methodology quality of each RCT. Reviewers were not blinded with respect to authors, institutions, or journals. Consensus was used to resolve disagreements, and a third author was consulted if the disagreements persisted.

A study was rated as having “high” methodological quality if it attained six points or more, and this classification was used to grade the strength of the evidence. Only studies receiving a score of at least three were considered in the initial analysis. Data were extracted by one author in a standardized predefined fashion to describe participants, exercise protocol, interventions, outcomes, results, and conclusions, which were then summarized by tabulation.

Quantitative data synthesis

The mean change in muscle soreness, measured on a 100 mm Visual Analogue Scale (VAS), and percentage of change of muscle strength relative to baseline was defined as the outcome and used to assess the difference between treatment group and control group. Means and 95% confidence intervals (Cls) were calculated using standard meta-analysis software (RevMan 5.0. Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2008). Meta-analysis of continuous outcomes (scores for muscle soreness and muscle strength) were calculated with a random effect model using the inverse of the estimated sampling variances as weights. The Chi^2 test and Higgins I^2 test were used to assess heterogeneity. We attempted to assess publication bias using a funnel plot, whereby effect estimates of the common outcome measure were plotted against sample size.

Results

In the totality, thirty-three studies were included in the systematic review; ten analyzed the effects of the cryotherapy (14-23), eight the effect of massage (24-31), eight the effect of stretching (32-39) and seven studies of low-intensity exercise (29, 40-45). Except one study that was published in Portuguese (38) all others were written in English.

The PEDro score achieved for each study is detailed in Table 1. Only those carried out by Sellwood et al. (14), Ascensão et al. (23) Paddon-Joness & Quigley (15), and Dannecker et al. (41) had high methodological quality; lack of blinding is the most evident methodological flaw in the studies. Failure to conceal allocation was another general methodological limitation of the researches.

The meta-analysis was only made in the variables of “muscle soreness” and “muscle strength” due to the fact that they are the only ones that have sufficient detail data in the different studies that compose this review. Due to the same reason, the meta-analysis made in the assessment at 1 hour involving the effect of stretching on “muscle soreness” and “muscle strength”, and the effect of massage on the muscle soreness, was not possible.

Relatively to the effectiveness of massage after exercise-induced muscle damage, eight RCTs were found (Table 2); six of these studies found positive effects on muscle soreness (24, 25, 27, 28, 30, 31). In the muscle function only three demonstrated a positive effect: Farr et al. (24) found positive effects in muscle strength and vertical jump, while Mancinelli et al. (27) and Williems et al. (30) only found this in the latter variable.

Only three RTCs (24, 25, 30) studying the effect of massage (total sample size 24) have sufficient data to make a meta-analysis at 24 hours (Fig 2A); its results demonstrated that massage post-exercise attenuates soreness; the overall effects suggest a significant positive effect (p=0.01) with a mean difference on a 100 mm VAS of -0.33 mm (95% CI – 0.59, -0.07). The result of heterogeneity indicated that the observed differences between trials results were unlikely to have been caused by chance (Chi^2 = 0.38; I^2 = 0%).

Only two studies permitted to make a meta-analysis of effect of massage on muscle soreness at 48 (25, 30) and 72 (24, 30) hours (Fig 2A); the overall effect of massage in the attenuation of muscle soreness was not statistically significant (p = 0.14 and 0.32 to 48 and 72 hours, respectively). Although, the heterogeneity between the studies (I^2 = 73% and 38% to 48 and 72 hours, respectively) made it difficult to clarify the true effect of massage after exercise-induced muscle damage at 48 and 72 hours, i.e., whether the massage is effective or not effective in the attenuation of soreness.

At 1 hour, only one study with sufficient data was found (24), not being enough to make the meta-analysis; therefore, the acute effect of massage on muscle soreness has not been studied much. Nevertheless, the results of this study suggest a positive effect immediately after its application.

Relatively to the effect of massage post-exercise on the muscle strength (Fig 2B), the meta-analysis demonstrated significant overall effect at 1, 24 and 72 hours with mean difference of 1.87 (95% CI 0.30, 3.44), 3.42 (95% CI -0.36, 7.18) and 2.29 (95% CI -0.15, 6.76) percent, respectively. Therefore, only the assessment made at 48 hours had no significant overall effect (p=0.95). The low heterogeneity (I^2 less than 20%) verified between studies, at all assessed moments, suggests that every variability in effect size estimated is due to error sampling within studies (46).

It should be noted that the positive effect in favour of the control group, shown in figure 2A and 2B, means that the control group showed less ability to produce muscle strength post-exercise than the experimental group, thus it should be viewed as a positive effect of massage post-exercise.

Ten RCTs (14-23) were found evaluating the effectiveness of cryotherapy (Table 3). Only one research examined the effect of ice massage (22); the others studied the effect of cold-water immersion; no study was found to analyze the effect of spray or ice packs in muscle soreness.

The evidence presented in this review does not support the use of cryotherapy intervention; indeed, only four RCTs found positive effects for cryotherapy (16, 20, 21, 23), contrasting with another six studies whose results demonstrated no effect in all assessed variables (14, 15, 17-19, 22). The analysis of trials that assessed muscle soreness using a visual analogue scale (Fig 3A) showed no statistically significant overall effect at 1 and 24 hours, with a mean difference of -0.43 mm (95% CI -1.95, 1.10), -1.22 mm (95% CI -3.31, 0.88). At 48 and 72 hours, although the overall effect was statistically significant, and the mean difference was -1.22 mm (95% CI -1.60, -0.84) and -2.11 mm (95% CI -3.77, -0.45), respectively, these data should be considered unreliable for the reason that it was verified a significant statistical heterogeneity among the trials in each of the assessed moments (I^2 = 95%, 98%, 39% and 88% to 1, 24, 48 and 72 hours, respectively).

On muscle strength, the cryotherapy post-exercise was statistically significant ($p < 0.01$) only at 24 hours; however, this trial could not be pooled due to the methodological heterogeneity (I^2 = 65%), i.e., 65% of variations in the data can be attributed to heterogeneity (Fig 3B).

At 1 hour, it was found no effect (p = 0.29) of cryotherapy on muscle strength and the low heterogeneity found between studies indicated that the mean difference of -2.56% (95% CI -7.32, 2.19) between trial results was unlikely to have been by chance (Chi^2 = 0.27; I^2 = 0%). While at 48 and 72 hours, although was also found no significant effect of cryotherapy (p = 0.16 and p = 0.39, respectively), the high heterogeneity found (I^2 65% and I^2 69%) do not provide with the same certainty the ineffectiveness of its intervention.

With the exception of the study conducted by Bailey et al. (21) the application of a single session of cold-water immersion immediately after exercise had no effects in the different indirect markers of muscle damage. In fact, the studies carried out by Howatson et al. (17) and Jakeman et al. (19), found no difference with a single 12-min (at 15°C) and 10-min (at 10°C) cold-water immersion. Similar results were found by Sellwood et al. (14); these authors examined the effects of three 1-min immersions in ice water at 5(±1)°C and also found no difference with respect to the control group, which was immersed in tepid water at 24°C. On Contrary, Bailey et al. examined the effect of a 10-min cold-water immersion at 10 (±0.5)°C and demonstrated positive effects in muscle soreness, muscle strength, and myoglobin blood concentration after induced muscle damage with a 90-min intermittent shuttle run.

Regarding the effect of repeated cryotherapy, four studies were found (16, 18, 20, 22). Two studies suggest that cryotherapy applied repeatedly over time may contribute to muscle recovery, particularly in the reduction of muscle stiffness. Indeed, Eston & Peters (16) immerged the upper limb 15 min immediately post-exercise and at 12, 24, 36, 48, and 72 hours while Skurvydas et al. (20) performed two 15-min immersions immediately and at 4, 8, and 24 hours post-exercise and both studies found some positive effects. However, Goodal & Howatson (18) and Howatson et al. (22) do not corroborate these findings. Goodal & Howatson administered 12 min of cold water immersion immediately and at 24, 48, and 72 hours post-exercise, and Howatson et al. applied 15 min of ice massage immediately and at 24 and 48 hours post-exercise, finding no difference in muscle strength, soreness, limb girth, range of motion, plasmatic creatine kinase activity (18, 22), and myoglobin blood concentration (22).

Relating the effects of muscle stretching after exercise-induced muscle damage, eight RCTs (32-39) were found (Table 4) and, in general, these interventions failed to reduce the occurrence or magnitude of muscle damage.

There are different protocols in the researches with respect to the timing of stretching relatively to exercise: single stretching program before exercise (34, 39); single stretching program after exercise (33, 37, 39); single stretching program before and repeated stretching program after exercise (33); and a repeated stretching program after exercise (32, 36). Therefore, the effect of stretching in the recovery of muscle function seems to fail regardless of when it is applied.

The mean difference on muscle soreness and muscle strength had no statistically significant overall effect at 24, 48 and 72 hours ($p > 0.05$). The failure of this intervention becomes more likely by the fact that there is a low ($I^2 = 0\%$) heterogeneity between studies, except the assessment of muscle soreness at 24 hours ($I^2 = 38\%$) (Fig 4A and Fig 4B).

Finally, evaluating the effect of low-intensity exercise, only three of the seven researches (Table 5) carried out by Zainuddin et al. (45), Saxton & Donnely (44), and Hasson et al. (43) detected temporary relief in muscle soreness. Regarding the positive effects in the other variables, the results demonstrated only a reduction in plasmatic creatine kinase activity (CK) in two studies (42, 44). Meta-analysis showed no statistically significant overall effect ($p < 0.05$) on muscle soreness (Fig 5A) and muscle strength (Fig 5B) at 1, 24, 48 and 72 hours post-exercise. Moreover, the inconsistency of the results of the studies (moderate or high heterogeneity) reduces the recommendation of low-intensity exercise intervention.

Discussion:

In a general way, the data reviewed in this meta-analysis correspond to a moderate quality of evidence from randomized controlled trials. The participants evaluated are representative of healthy young adult (mean age 23 years old) population, consequently the applicability of findings for this population to children and to older adults is uncertain.

All outcomes were summarized and presented in tables; muscle soreness and muscle strength were the outcomes most frequently used to analyze the effect of conventional interventions after exercise-induced muscle damage. For this reason, the meta-analysis was only possible in two of the variables (muscle soreness and muscle strength), not only by the fact that they were the most frequently used but mainly due to the fact that they have the same method of quantification and data reported with sufficient detail, i.e., the muscle soreness was assessed regularly with a Visual Analogue Scale and muscle strength expressed in torque (N.m). Nevertheless, “muscle soreness” and “muscle strength” are two relevant markers of muscle damage (47, 48); therefore, the true effect of the conventional physiotherapeutic interventions can be assessed with confidence through them. However, other indirect markers of muscle damage are also used in this area under discussion, namely limb girth, range of motion, creatine kinase and the pressure pain threshold.

In a general way, the results suggest that massage is the most effective intervention, while the cryotherapy intervention has little evidence to continue its use. The other conventional interventions, such as stretching or low-intensity exercise, have no scientific evidence to sustain their validity.

Indeed, massage is a widely used therapy in the treatment of athletic muscle soreness and micro-injury. Many athletes are convinced of its potential to alleviate muscle soreness (49). It has been established that massage might have a number of physiological and psychological effects, particularly by increasing blood circulation and lymphatic flow, decreasing edema production and reduction of muscular tone, and contributing to the repair of damaged muscle and pain modulation.

In fact, this review confirms that massage has positive effects after exercise-induced muscle damage; the evidence shows that muscle massage lasting 20 to 30 minutes administered immediately or up to 2 hours post-exercise relieves muscle soreness at 24 hours; however, the effect beyond this period is not shown. Related with this positive effect could be involved the stimulation of sensitive fibers of type Ia, Ib, and II due to the massage, leading to an interference in the pain sensation “transported” by type III and IV (6). In other words, pain fibers are constantly balanced against tactile signals, each of them is capable of inhibiting the other; thus, the excessive tactile stimulation can suppress pain transmission but have temporary effect.

Regarding the effect of its application on muscle strength, massage may have a positive and longer effect on muscle recovery; indeed, with the exception of the assessment at 48 hours, massage had a significant contribution to recuperate the strength loss induced by the intense exercise.

In other variables related to inflammatory response, which could be theoretically changed, such as the “limb girth” or “neutrophils,” the results were contradictory. The study conducted by Lightfoot et al.

(26), using different techniques of massage for 10 min, had positive effects in limb girth, while the study by Zainuddin et al. (31), although using only "petrissage" and applying the same length of time (10 min), found no changes. Similar analysis could be made for the neutrophils' count, where two conflicting studies were found; Smith et al. (28) applied a 30-min massage two hours after exercise and observed a decrease in the neutrophils, whereas the 20-min massage performed in the study carried out by Hilbert et al. (25) did not create changes in this variable.

Relatively to the intervention with cryotherapy, its used is known in the initial treatment of traumatic soft tissue injuries (3) and in the recovery from sport activities, particularly with the aim to minimize DOMS (14, 19, 50, 51). Although the underlying mechanism of DOMS remains uncertain, it is generally accepted that muscle soreness is caused by inflammation of the damaged muscle and/or connective tissues and the efflux of substances to the extra cellular space that sensitizes type III and IV free nerve endings to mechanical, chemical or thermal stimulation (3, 6). The superficial application of cold results in changes in skin, subcutaneous, intramuscular, and joint temperatures; consequently, this decrease in tissue temperature stimulates cutaneous receptors, leading to excitation of the sympathetic adrenergic fibers, causing the constriction of local arterioles and venules, and diminishing the inflammation (3, 14). In this sense, a reduction in perceived pain and/or in limb girth could be expected as a result of the intervention in the local inflammation. However, the goal to determine the effectiveness of cryotherapy becomes difficult due to the fact that studies have varied tremendously in their interventions, particularly with respect to the number, timing, and duration.

In fact, although the results have demonstrated at 48 and 72 hours a significant positive overall effect, the inconsistency of studies' results reduces the recommendation of this intervention; the moderate to high I^2 values show that most of the variability across studies is due to heterogeneity rather than chance (46). These findings, suggesting little evidence of cryotherapy intervention, corroborate those obtained by Burguess and Lambert (52); these authors carried out a systematic review composed of 13 articles of any primary research, which found inconclusive evidence to support the use of cryotherapy modalities in recovery from exercise-induced muscle damage.

Regarding to the application of stretching, it has been related to changes in both mechanical and neural factors, leading to the recovery of muscle function after exercise-induced muscle damage. DeVries (53) in 1966 argued that muscle stretches might reduce muscle spasms after intense exercise, thus recommending its use. Subsequently, the results found by McGlynn et al. (36) equally demonstrated a decrease in the electromyography activity after stretching the musculature involved in intense exercise, thereby reducing muscle spasm. More recently, Torres et al. (37), using a substantially different methodology, discovered reduction in muscle stiffness and suggested that some effects of stretching on the reflex activity might involve changes in the muscle spindle function. Despite these findings, all other researches with static stretching, that comprised this systematic review, had no differences in any of the variables collected (32-35, 39).

Moreover, in general the stretching meta-analysis have low heterogeneity between studies (I^2 = 0%); this little variability between studies indicates that the lack of effect of stretching after exercise-induced muscle damage cannot be by chance; thus nothing suggests that we should continue to recommend the its use with the aim to alleviate the signs and symptoms of exercise-induced muscle damage. Although researching only muscle soreness, Herbert and Gabriel (54), in a systematic review composed of five studies conducted in 2002, found that stretching before and after exercising does not confer protection from muscle soreness, confirming our findings.

Lastly, another conventional intervention that has been suggested to increase the recovery of the signs and symptoms after exercise-induced muscle damage is low-intensity exercise (3, 6). It is postulated that the increase of blood circulation caused by light exercise may facilitate the removal of toxic products and promote the release of endorphins, leading to an analgesic effect. Moreover, the reduction of pain sensation could have the same explanation given by the effect of massage; in both there is a rise in the stimulation of sensitive fibers of type Ia, Ib, and II, which may lead to an interference in the pain sensation "transported" by type III and IV (55).

However, the findings of this systematic review are contradictory and cannot support the idea that low-intensity exercise is effective in the management of the signs and symptoms of exercise induced muscle damage, particularly in muscle soreness, as theoretically expected. Indeed, only three of the seven researches (Table 5) carried out by Zainuddin et al. (45), Saxton & Donnely (44), and Hasson et al. (43) detected temporary relief in muscle soreness. Moreover, overall, the meta-analysis demonstrated no significant effects of low-intensity exercise on muscle soreness after exercise-induced muscle damage, particularly at 24, 48 and 72 hours ($p>0.05$). In a similar way, regarding muscle function, nothing suggests that low-intensity exercise might aid the recovery of the damaged muscle (Fig 5A and 5B).

Concerning the positive effects in the other variables, the results demonstrated only a reduction in plasmatic creatine kinase activity (CK) in two studies (42, 44); therefore, it is unclear whether low-intensity exercise has a role in improving the functioning of the cell membrane..

This systematic review's main concern was to have a high rigour in terms of searching literature, as well as the inclusion and exclusion criteria and the data assessment. Nevertheless, it only includes studies written in English or Portuguese, which could be seen as a limitation of the study.

Although the analyses of data from randomized controlled trials have yielded robust indication effects on the outcomes, clinical heterogeneity showed differences in the conditions which caused muscle damage and in the duration and frequency of the interventions, which may lead to lack of accuracy in the final results. Moreover, the PEDro score showed deficits in the methodological quality of some of the studies, mainly with respect to the lack of blinding and small sample size, which should be taken into account in future research. Therefore, further researches are still required considering the long-term effects of interventions on recovery.

Conclusions

This systematic review and meta-analysis, undertaken with the purpose to assess the evidence of conventional physiotherapeutic interventions after exercise-induced muscle damage, demonstrated that therapeutic massage intervention is the one that presents more scientific evidence. Relatively to the other interventions, there is inconclusive evidence to support the use of cryotherapy while stretching or low-intensity exercises no scientific evidence supporting their use.

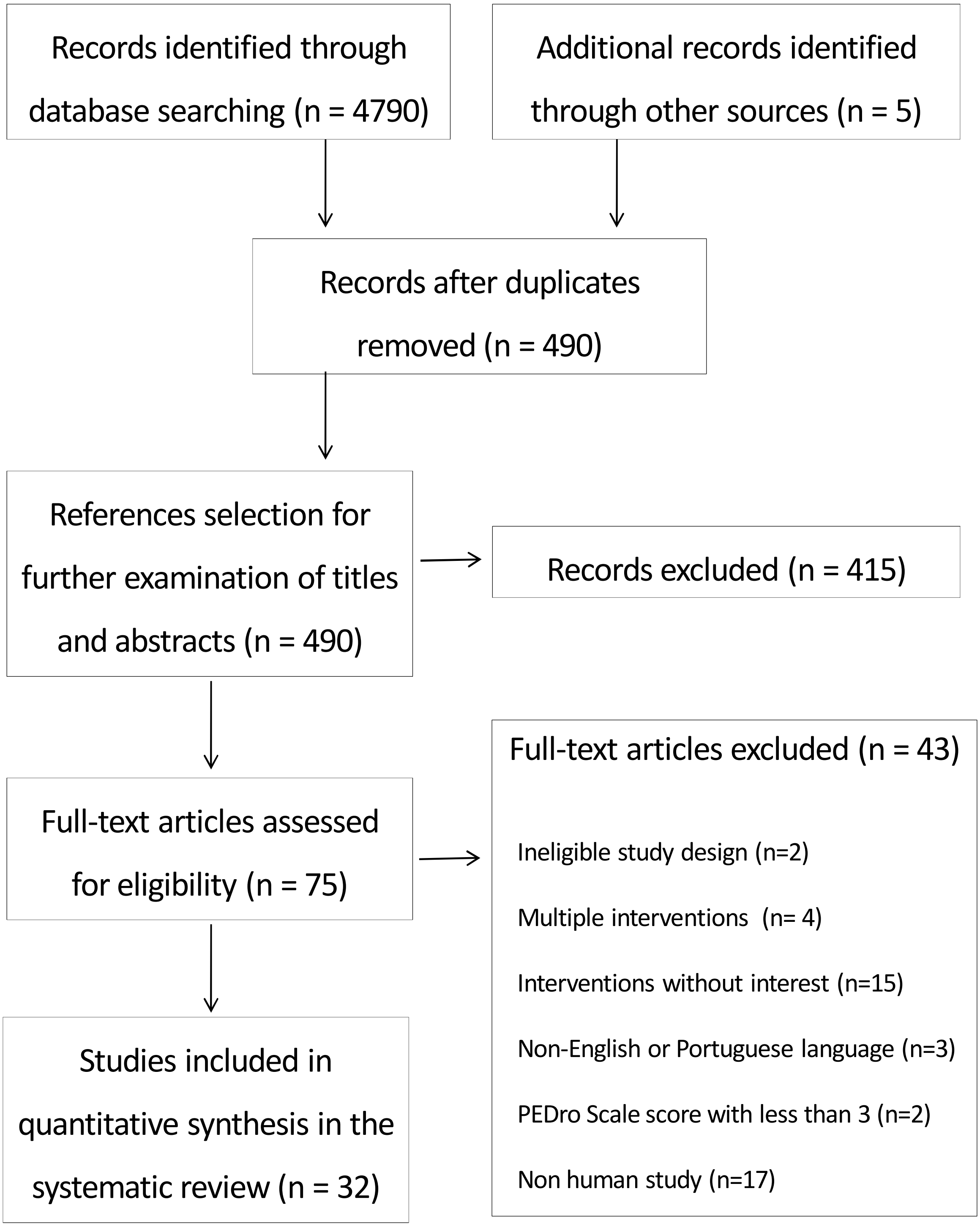
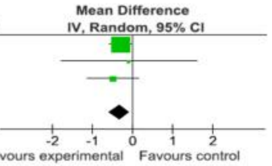


Figure 1 – Flow chart of inclusion process of articles used in the systematic review

24 hours

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
Farr 2002	2.1	0.3	8	2.4	0.3	8	80.5%	-0.30 [-0.59, -0.01]
Hilbert 2003	5.5	1.2	9	5.6	2.3	9	2.4%	-0.10 [-1.79, 1.59]
Williems 2009	3.2	0.5	7	3.7	0.7	7	17.1%	-0.50 [-1.14, 0.14]
Total (95% CI)			**24**			**24**	**100.0%**	**-0.33 [-0.59, -0.07]**

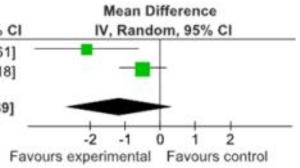
Heterogeneity: Tau² = 0.00; Chi² = 0.38, df = 2 (P = 0.83); I² = 0%
Test for overall effect: Z = 2.45 (P = 0.01)



48 hours

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
Hilbert 2003	5.1	1.8	9	7.2	1.4	9	41.1%	-2.10 [-3.59, -0.61]
Williems 2009	3.3	0.7	7	3.8	0.6	7	58.9%	-0.50 [-1.18, 0.18]
Total (95% CI)			**16**			**16**	**100.0%**	**-1.16 [-2.70, 0.39]**

Heterogeneity: Tau² = 0.93; Chi² = 3.66, df = 1 (P = 0.06); I² = 73%
Test for overall effect: Z = 1.47 (P = 0.14)



72 hours

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
Farr 2002	1.85	0.46	8	1.9	0.46	8	37.7%	-0.05 [-0.50, 0.40]
Williems 2009	2.4	0.3	11	2.1	0.4	11	62.3%	0.30 [0.00, 0.60]
Total (95% CI)			**19**			**19**	**100.0%**	**0.17 [-0.16, 0.50]**

Heterogeneity: Tau² = 0.02; Chi² = 1.62, df = 1 (P = 0.20); I² = 38%
Test for overall effect: Z = 0.99 (P = 0.32)

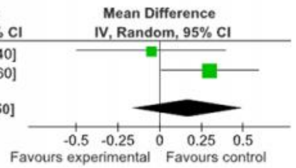


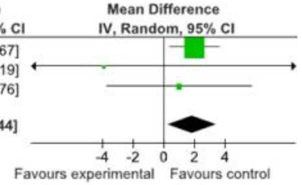
Fig 2A – Effects of massage <u>on delayed onset muscle soreness</u> at 24, 48 and 72 hours (Visual Analogue Scale)

Fig 2B – Effects of massage on <u>muscle strength</u> at 1, 24, 48 and 72 hours (Percentage of change)

1 hour

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
Farr 2002	93	1.7	8	91	1.7	8	88.7%	2.00 [0.33, 3.67]
Hilbert 2003	83.1	26.4	9	87	27.9	9	0.4%	-3.90 [-28.99, 21.19]
Zainudin 2005	63	4.8	10	62	6	10	10.9%	1.00 [-3.76, 5.76]
Total (95% CI)			**27**			**27**	**100.0%**	**1.87 [0.30, 3.44]**

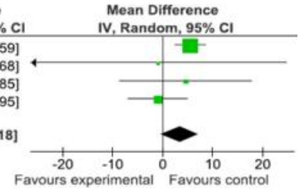
Heterogeneity: Tau² = 0.00; Chi² = 0.35, df = 2 (P = 0.84); I² = 0%
Test for overall effect: Z = 2.33 (P = 0.02)



24 hours

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
Farr 2002	98	3.7	8	92.5	2.5	8	61.3%	5.50 [2.41, 8.59]
Hilbert 2003	76.2	25.4	9	77.2	30	9	2.1%	-1.00 [-26.68, 24.68]
Weber 1994	72.2	18.5	10	67.6	10.7	10	7.5%	4.60 [-8.65, 17.85]
Zainudin 2005	63	6	10	64	7.5	10	29.0%	-1.00 [-6.95, 4.95]
Total (95% CI)			**37**			**37**	**100.0%**	**3.41 [-0.36, 7.18]**

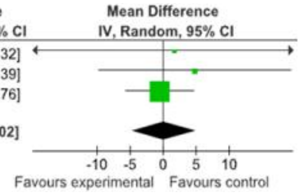
Heterogeneity: Tau² = 3.55; Chi² = 3.76, df = 3 (P = 0.29); I² = 20%
Test for overall effect: Z = 1.77 (P = 0.08)



48 hours

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
Hilbert 2003	80	26.4	9	78.3	29	9	3.6%	1.70 [-23.92, 27.32]
Weber 1994	73.6	17.8	10	68.8	15.4	10	11.1%	4.80 [-9.79, 19.39]
Zainudin 2005	64	6	10	64.5	6	10	85.3%	-0.50 [-5.76, 4.76]
Total (95% CI)			**29**			**29**	**100.0%**	**0.17 [-4.69, 5.02]**

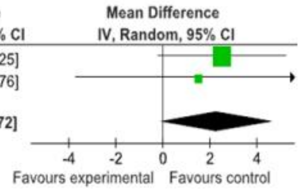
Heterogeneity: Tau² = 0.00; Chi² = 0.46, df = 2 (P = 0.79); I² = 0%
Test for overall effect: Z = 0.07 (P = 0.95)



72 hours

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
Farr 2002	102.5	2.2	8	100	3.3	8	78.5%	2.50 [-0.25, 5.25]
Zainudin 2005	74	6	10	72.5	6	10	21.5%	1.50 [-3.76, 6.76]
Total (95% CI)			**18**			**18**	**100.0%**	**2.29 [-0.15, 4.72]**

Heterogeneity: Tau² = 0.00; Chi² = 0.11, df = 1 (P = 0.74); I² = 0%
Test for overall effect: Z = 1.84 (P = 0.07)



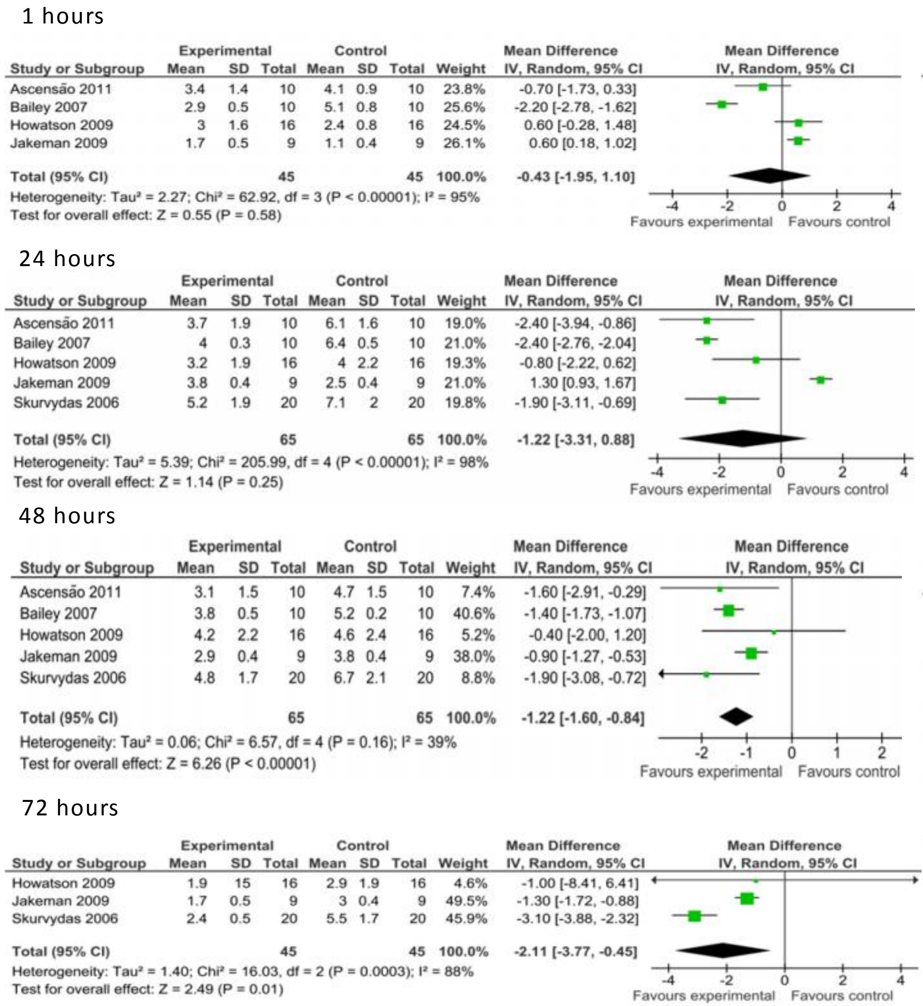


Fig 3A – Effects of cryotherapy on delayed onset muscle soreness at 1, 24, 48 and 72 hours (Visual Analogue Scale)

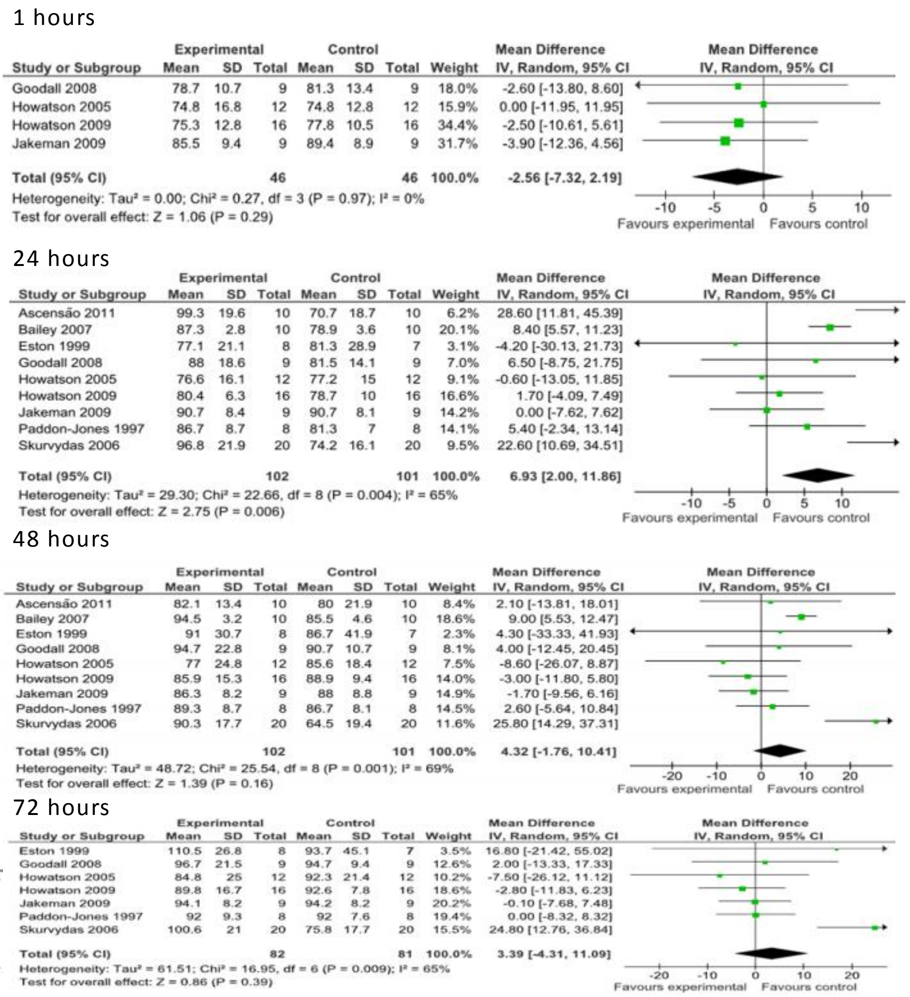


Fig 3B – Effects of cryotherapy on muscle strength at 1, 24, 48 and 72 hours (Percentage of change)

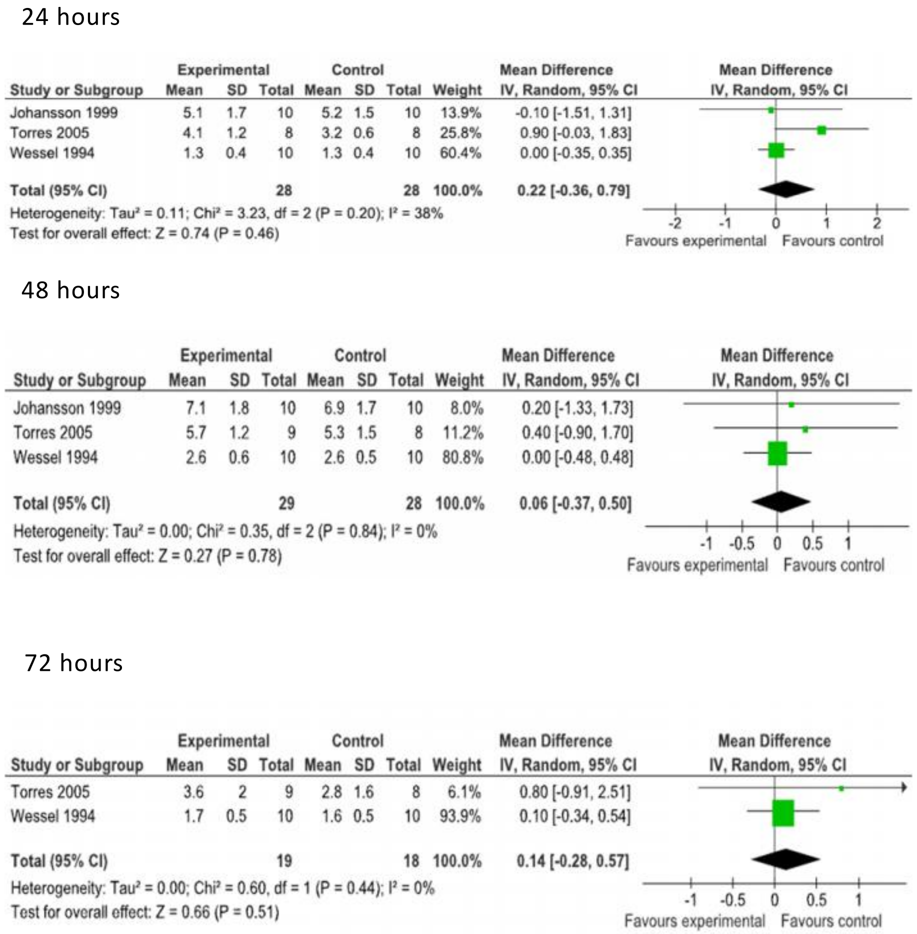


Fig 4A – Effects of stretching on <u>delayed onset muscle soreness</u> at 24, 48 and 72 hours (Visual Analogue Scale)

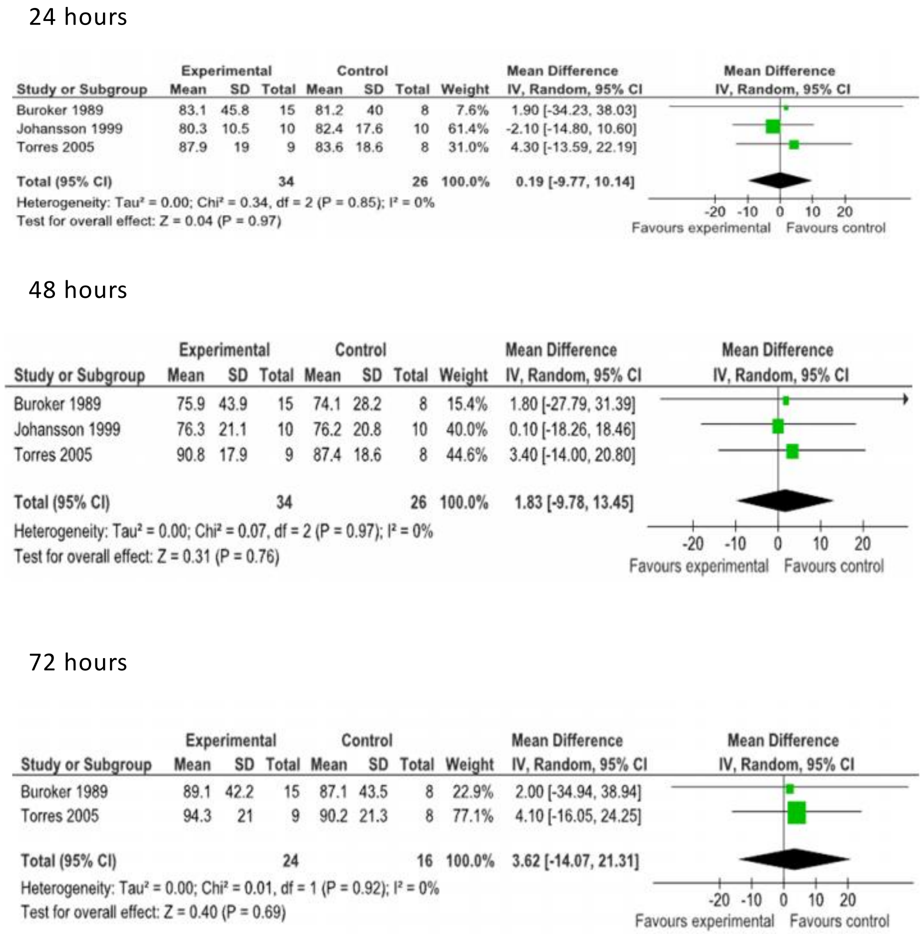
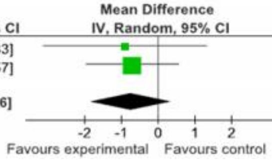


Fig 4B – Effects of stretching <u>on muscle strength</u> at 24, 48 and 72 hours (Percentage of change)

1 hour

Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
Chen 2008	3.5	2	10	4.4	3	10	24.4%	-0.90 [-3.13, 1.33]
Dannecker 2002	3.9	2.5	23	4.6	2	27	75.6%	-0.70 [-1.97, 0.57]
Total (95% CI)			**33**			**37**	**100.0%**	**-0.75 [-1.85, 0.36]**

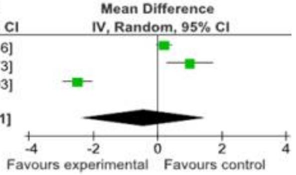
Heterogeneity: Tau² = 0.00; Chi² = 0.02, df = 1 (P = 0.88); I² = 0%
Test for overall effect: Z = 1.33 (P = 0.18)



24 hours

Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
Chen 2008	6.9	0.3	10	6.7	0.3	10	33.9%	0.20 [-0.06, 0.46]
Donnelly 1992	4.9	1	9	3.9	0.5	9	32.6%	1.00 [0.27, 1.73]
Zainuddin 2006	2.1	0.4	14	4.6	0.8	14	33.5%	-2.50 [-2.97, -2.03]
Total (95% CI)			**33**			**33**	**100.0%**	**-0.44 [-2.40, 1.51]**

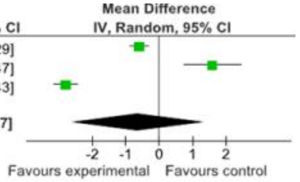
Heterogeneity: Tau² = 2.91; Chi² = 110.73, df = 2 (P < 0.00001); I² = 98%
Test for overall effect: Z = 0.44 (P = 0.66)



48 hours

Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
Chen 2008	6.1	0.3	10	6.7	0.4	10	34.0%	-0.60 [-0.91, -0.29]
Donnelly 1992	6.1	1.3	9	4.5	0.3	9	32.2%	1.60 [0.73, 2.47]
Zainuddin 2006	2.3	0.5	14	5.1	0.5	14	33.9%	-2.80 [-3.17, -2.43]
Total (95% CI)			**33**			**33**	**100.0%**	**-0.64 [-2.65, 1.37]**

Heterogeneity: Tau² = 3.07; Chi² = 125.12, df = 2 (P < 0.00001); I² = 98%
Test for overall effect: Z = 0.62 (P = 0.53)



72 hours

Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
Chen 2008	3.6	0.3	10	3.7	0.4	10	34.9%	-0.10 [-0.41, 0.21]
Donnelly 1992	3.2	0.6	9	4.3	0.5	9	32.4%	-1.10 [-1.61, -0.59]
Zainuddin 2006	3.1	0.6	14	4.5	0.7	14	32.8%	-1.40 [-1.88, -0.92]
Total (95% CI)			**33**			**33**	**100.0%**	**-0.85 [-1.71, 0.01]**

Heterogeneity: Tau² = 0.53; Chi² = 24.23, df = 2 (P < 0.00001); I² = 92%
Test for overall effect: Z = 1.93 (P = 0.05)

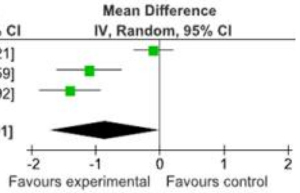
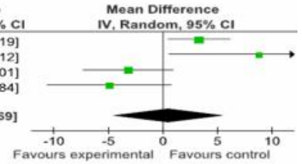


Fig 5A – Effects of low-intensity exercise <u>on delayed onset muscle soreness</u> at 1, 24, 48 and 72 hours (Visual Analogue Scale)

1 hour

Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
Chen 2008	80	3.3	10	76.7	3.3	10	30.6%	3.30 [0.41, 6.19]
Donnelly 1992	46.3	7.5	9	37.5	10.3	9	18.0%	8.80 [0.48, 17.12]
Saxton 1995	68.5	4.3	8	71.7	4.3	8	27.6%	-3.20 [-7.41, 1.01]
Zainuddin 2006	49.5	4.9	14	54.4	9.8	14	23.8%	-4.90 [-10.64, 0.84]
Total (95% CI)			**41**			**41**	**100.0%**	**0.54 [-4.61, 5.69]**

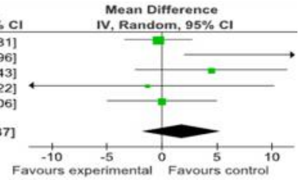
Heterogeneity: Tau² = 20.35; Chi² = 13.66, df = 3 (P = 0.003); I² = 78%
Test for overall effect: Z = 0.21 (P = 0.84)



24 hours

Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
Chen 2008	73	3.6	10	73.3	3.5	10	38.3%	-0.30 [-3.41, 2.81]
Donnelly 1992	60	10	9	47.5	12.5	9	9.6%	12.50 [2.04, 22.96]
Saxton 1995	76.1	6.5	8	71.6	7.6	8	17.9%	4.50 [-2.43, 11.43]
Weber 1994	66.3	15.2	10	67.6	10.7	10	8.2%	-1.30 [-12.82, 10.22]
Zainuddin 2006	50.8	6.2	14	50.8	7.4	14	26.0%	0.00 [-5.06, 5.06]
Total (95% CI)			**51**			**51**	**100.0%**	**1.79 [-1.80, 5.37]**

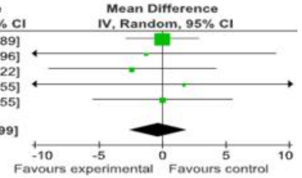
Heterogeneity: Tau² = 6.20; Chi² = 6.60, df = 4 (P = 0.16); I² = 39%
Test for overall effect: Z = 0.98 (P = 0.33)



48 hours

Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
Chen 2008	81.7	3.3	10	81.7	3.3	10	63.1%	0.00 [-2.89, 2.89]
Donnelly 1992	52.5	7.5	9	53.8	13.8	9	5.0%	-1.30 [-11.56, 8.96]
Weber 1994	71.7	7	8	74.1	6.5	8	12.0%	-2.40 [-9.02, 4.22]
Weber 1994	70.5	16.2	10	68.8	15.4	10	2.7%	1.70 [-12.15, 15.55]
Zainuddin 2006	55.7	8.6	14	55.7	6.2	14	17.1%	0.00 [-5.55, 5.55]
Total (95% CI)			**51**			**51**	**100.0%**	**-0.31 [-2.60, 1.99]**

Heterogeneity: Tau² = 0.00; Chi² = 0.56, df = 4 (P = 0.97); I² = 0%
Test for overall effect: Z = 0.26 (P = 0.79)



72 hours

Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
Chen 2008	81.5	3.3	10	81.5	3.3	10	28.7%	0.00 [-2.89, 2.89]
Donnelly 1992	60	11.3	9	50	16.3	9	17.9%	10.00 [-2.96, 22.96]
Saxton 1995	91.3	6.5	8	76.1	1.9	8	27.3%	15.20 [10.51, 19.89]
Zainuddin 2006	55.7	8.6	14	55.7	7.4	14	26.1%	0.00 [-5.94, 5.94]
Total (95% CI)			**41**			**41**	**100.0%**	**5.94 [-2.75, 14.63]**

Heterogeneity: Tau² = 66.27; Chi² = 31.75, df = 3 (P < 0.00001); I² = 91%
Test for overall effect: Z = 1.34 (P = 0.18)

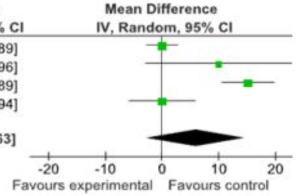


Fig 5B – Effects of low-intensity exercise on <u>muscle strength</u> at 1, 24, 48 and 72 hours (Percentage of change)

Table 1: Pedro scores

Intervention	*Reference*	1	2	3	4	5	6	7	8	9	10	11	Total score
Cryotherapy	Sellwood et al., (2007)	1	1	1	1	0	0	1	1	1	1	1	8/10 *
	Ascensão et al. (2011)	1	1	0	1	0	0	0	1	1	1	1	6/10 *
	Paddon-Jones & Quigley (1997)	1	1	0	1	0	0	0	1	1	1	1	6/10 *
	Eston & Peters (1999)	1	1	0	0	0	0	0	1	1	1	1	5/10
	Howatson et al., (2009)	1	1	0	0	0	0	0	1	1	1	1	5/10
	Goodall & Howatson (2008)	1	1	0	0	0	0	0	0	1	1	1	4/10
	Jakeman et al., (2009)	1	1	1	0	0	0	0	0	0	1	1	4/10
	Skurvydas et al ., (2006)	1	1	1	0	0	0	0	0	0	1	1	4/10
	Bailey et al., (2007)	1	0	1	0	0	0	0	0	0	1	1	3/10
	Howatson et al., (2005)	1	0	1	0	0	0	0	0	0	1	1	3/10
Massage	Weber et al., 1994	1	1	0	1	0	0	0	1	0	1	1	5/10
	Smith et al., 1994	0	1	0	1	0	0	0	1	0	1	1	5/10
	Farr et al., 2002	1	1	0	0	0	0	0	1	1	1	1	5/10
	Mancinelli et al., 2006	1	1	0	1	0	0	1	0	0	1	1	5/10
	Zainuddin et al., 2005	1	0	0	1	0	0	0	1	1	1	1	5/10
	Lightfoot et al., 1997	1	1	0	1	0	0	0	0	0	1	1	4/10
	Willems et al., 2009	1	0	0	1	0	0	0	0	1	1	1	4/10
	Hilbert et al., 2003	0	1	0	0	0	0	0	0	0	1	1	3/10
Stretching	Buroker & Schwane, 1989	1	1	0	0	0	0	0	1	1	1	1	5/10
	Torres et al., 2007	1	1	0	1	0	0	0	1	0	1	1	5/10
	Torres et al., 2005	1	1	0	1	0	0	0	1	0	1	1	5/10
	Johansson et al., 1999	1	1	0	0	0	0	0	1	0	1	1	4/10
	Wessel & Wan, 1994	0	1	0	1	0	0	0	0	0	1	1	4/10
	High & Howley, 1989	0	1	0	0	0	0	0	1	0	1	0	3/10
	Lund et al., 1998	1	0	0	1	0	0	0	0	0	1	1	3/10
	McGlynn et al., 1979	0	1	0	0	0	0	0	0	0	1	1	3/10
Low-intensity exercise	Danneceker, et al., 2002	1	1	0	1	0	0	0	1	1	1	1	6/10 *
	Chen et al., 2008	1	1	0	1	0	0	0	0	1	1	1	5/10
	Saxton & Donnelly, 1995	0	1	0	1	0	0	0	1	0	1	1	5/10
	Hasson et al., 1989	0	1	0	1	0	0	0	1	0	1	1	5/10
	Weber et al., 1994	1	1	0	1	0	0	0	1	0	1	1	5/10
	Donnelly et al., 1992	0	1	0	1	0	0	0	0	0	1	1	4/10
	Zainuddin et al., 2006	0	1	0	0	0	0	0	0	0	1	1	3/10

* high methodological quality study

Table 2: Massage in the management of delayed-onset muscle soreness

Reference *(PEDro Score)*	Subjects	Exercise protocol	Intervention	Control	Criterion measures	Results	Conclusions
Farr et al., 2002 (5/10)	8 males [22(3) years]	Downhill treadmill walk [40-min with 10% of their body mass]	30-min of massage (effleurage & petrissage techniques; no deep tissue massage was performed) [at 2h post-exercise]	1. Contra-lateral leg	1. Creatine kinase 2. Muscle soreness 3. Muscle strength 4. Pressure pain threshold 5. Single leg vertical jump weight [before, at 1, 24, 72 & 120h]	Positive for muscle soreness and tenderness. Still positive for isokinetic strength and vertical jump at 1 and 24 hours post-exercise.	Therapeutic massage may attenuate soreness and tenderness associated with DOMS. However, it may not be beneficial in the treatment of strength and functional declines
Hilbert et al., 2003 (3/10)	18 subjects (males & females) [20.4(1.0) years]	Maximal eccentric knee flexors contractions [6 x 10 repetitions + 5]	20-min of massage (5-min effleurage, 1-min percussion, 12-min petrissage, 2-min effleurage) [at 2h post-exercise]	1. Control group without treatment (n=9)	1. Muscle soreness 3.Muscle strength [at 2, 6, 24 & 48h] 4.Neutrophils count [at 6 & 24h] 5.Range of motion [at 6, 24 & 48h]	Positive for muscle soreness at 48 hours post-exercise; No significant differences between groups for muscle soreness, range of motion and neutrophils.	Massage did not improve hamstrings function but did reduce the intensity of soreness 48h after muscle insult.
Lightfoot et al., 1997 (4/10)	12 males & 19 females [college age]	Heel drop exercise [4 x 15 repetitions with 100% of their body weight]	10-min of petrissage [immediately & 24h post-exercise]	1. Group light stretch (n=10) 2. Control group (n=11)	1. Creatine kinase 2. Limb girth 3. Muscle soreness [at 0, 24 & 48h]	No significant differences between groups for all assessed measures	Petrissage does not prevent or attenuate DOMS
Mancinelli et al., 2006 (5/10)	22 trained females [20(0.9) years]	Pre-season training routine for 4 days	17-min of massage to each thigh, (4-min effleurage, 8-min petrissage, 2-min vibration, 3-min effleurage) [on the day of predicted peak soreness]	1. Control group without treatment (n=11)	1.Pressure pain threshold 2.Quadriceps femoris length 3.Time shuttle run 4.Vertical jumps [at days 2 and 4]	Positive for muscle soreness, vertical jumps displacement and algometer reading.	The use of massage decreases muscle soreness and improves vertical jump.
Smith et al., 1994 (5/10)	14 males [18-21 years]	Maximal eccentric flexors/extensors muscles of the elbow [5 x 35 repetitions]	30-min of athletic massage (effleurage, shaking, petrissage, wringing and cross-fiber massage) [at 2h post-exercise]	1. Control group (n=7)	1. Creatine kinase 2. Muscle soreness 3. Neutrophils count [before, at 8, 24, 48, 72, 96 & 120h]	Positive for muscle soreness, creatine kinase activity and neutrophils count.	Sports massage reduces DOMS and creatine kinase activity when administered 2 hours after exercise-induced muscle damage
Weber et al., 1994 (5/10)	40 females [18-35 years]	Maximal eccentric elbow flexors contractions [until exhaustion]	8-min of massage (2-min effleurage, 5-min petrissage, 1-min effleurage) [at 0 & 24h post-exercise]	1. Microcurrent electrical stimulation (n=10) 2. Upper-body ergometry (n=10) 3. Control group, no intervention (n=10)	1. Muscle soreness 2. Muscle strength [before, at 24 & 48h]	No significant differences between groups for all assessed measures	Post-exercise massage did not alleviate DOMS or muscle strength
Williems et al., 2009 (4/10)	7 females [19(1) years]	Downhill walk [20-min with 10% of their body mass; speed: 6.4 km/; gradient: -25%]	25-min of massage (5-min effleurage, 10-min petrissage & tapotement, 10-min effleurage) [immediately post-exercise]	1. Contra-lateral leg	1. Muscle soreness 2. One-legged vertical jump height [before, at 24, & 72h]	Positive for muscle-specific soreness and one-leg vertical jump height	The use of massage decreases muscle-specific soreness and improve vertical jump.
Zainuddin et al., 2005 (5/10)	5 males & 5 females [23.0(1.3) years]	Maximal eccentric elbow flexors contractions [10 x 6 repetitions]	10-min of massage (2.5-min effleurage, 1-min petrissage, 2-min friction, 2-min petrissage & 2.5-min effleurage) [at 3h post-exercise]	1. Contra-lateral arm	1. Limb girth 2. Muscle soreness 3. Muscle strength 4. Range of motion [before, at 30-min, 1- 4, 7, 10 & 14 days post-exercise]	Positive for muscle soreness and limb girth; No significant differences for muscle strength and range of motion	Massage was effective in alleviating DOMS and reducing swelling, but it had no effect on muscle function.

Table 3: Cryotherapy in the management of delayed-onset muscle soreness

Reference *(PEDro Score)*	Subjects	Exercise protocol	Intervention	Control	Criterion measures	Results	Conclusions
Ascensão et al. 2011 (6/10)	20 athletes males [18(1) years]	Soccer match	10-min cold-water immersion at 10 °C [immediately post-exercise]	1.Control group (n=10) ; 10-min of thermo neutral water (35 °C)	1. C-reactive protein 2. Creatine kinase 3. Muscle strength 4. Muscle soreness 5. Myoglobin 6. Performance tests [before , at 30-min, 24 & 48h]	Positive for muscle soreness, creatina kinase, mioglobin, C-reactive protein and muscle strength	Cryotherapy after soccer match is effective in reducing some biochemical, functional, and perceptual markers of muscle damage
Bailey et al., 2007 (4/10)	20 males [22.3(3.3) years]	Shuttle run [90-min intermittent]	10-min cold-water immersion at 10 (±0.5) ° [immediately post-exercise]	1.Control group (n=10)	1. Creatine kinase 2. Myoglobin 3. Muscle strength 4. Muscle soreness [before , at 0, 1, 24, 48 & 168h]	Positive for muscle soreness (at 1,24 & 48h), muscle strength of the knee flexors (at 24 & 48h) and myoglobin (at 1h post-exercise)	Cold-water immersion immediately after prolonged shuttle running reduces some indices of exercise-induced muscle damage
Eston & Peters, 1999 (5/10)	15 females [22.0(2.0) years]	Maximal eccentric/concentric elbow flexor contractions [8 x 5 repetitions]	7 x 15-min cold-water immersion at 15(±1)°C [immediately & 12, 24, 36, 48, 60, 72h post-exercise]	1.Control group (n=7)	1. Creatine kinase 2. Limb girth 3. Muscle strength 4. Pressure pain threshold 5. Range of motion [before, at 24, 48 & 72h]	Positive for creatine kinase and range of motion	Cold-water immersion may reduce muscle stiffness
Goodall & Howatson, 2008 (4/10)	18 males [24(5) years]	Drop Jumps [5 x 20 repetitions]	12-min cold water immersion at 15(±1)°C [immediately & 24, 48, 72h post-exercise]	1.Control group (n=9)	1. Creatine kinase 2. Limb girth 3. Muscle strength 4. Muscle Soreness 5. Range of motion [before, at 24, 48, 72 & 96h]	No significant differences between groups for all assessed measures	Cold-water immersion at 15°C for 12-min demonstrates no effect
Howatson et al., 2005 (3/10)	12 males [24.8(5.3) years]	Maximal eccentric elbow flexor contractions [3 x 10 repetitions at 30°/s performed in the dynamometer]	15-min of ice massage directly on the skin [immediately & 24, 48h post-exercise]	1.Cross-over design: treatment group and placebo group	1. Creatine kinase 2. Limb girth 3. Myoglobin 4. Muscle strength 5. Muscle soreness 6. Range of motion [before, at 0, 24, 48, 72 & 96h]	No significant differences between groups for all assessed measures	Ice massage has no benefit to recovery from exercise-induced muscle damage
Howatson et al., 2009 (5/10)	16 males [23(3) years]	Drop jumps [5 x 20 repetitions]	12-min cold-water immersion at 15 (±1) °C [immediately post-exercise]	1.Cross-over design: treatment group and control group	1. Creatine kinase 2. Limb girth 3. Muscle strength 4. Muscle soreness 5. Range of motion [before, at 0, 24, 48, 72 & 96h]	No significant differences between groups for all assessed measures	Cold-water immersion at 15°C for 12-min demonstrates no effect
Jakeman et al., 2009 (4/10)	18 athletes males [19.9(1.0) years]	Counter- movement jumps [10 x 10 repetitions]	10-min cold-water immersion at 10 (±1) °C [immediately post-exercise]	1.Control group (n=9)	1. Creatine kinase 2. Muscle strength 3. Muscle soreness [before, at 1, 24, 48, 72 & 96h]	No significant differences between groups for all assessed measures	Cold-water immersion at 10°C for 10-min demonstrates no effect
Paddon-Jones & Quigley, 1997 (6/10)	8 trained males [23.0(2.5) years]	Eccentric elbow flexor contractions of both arms [8 x 8 repetitions with 110% of the 1-RM]	5 x 20-min (60-min rest period) cold-water immersion at 5(±1)°C [post-exercise]	1.Contra-lateral arm	1. Limb girth 2. Muscle strength 3. Muscle soreness [before, at 0, 24, 48, 72, 96, 120 & 144h]	No significant differences between groups for all assessed measures	Cold-water immersion 5 x 20-min at 5°C demonstrates no effect
Sellwood et al., 2007 (8/10)	11 males & 29 females [control group 21(3); intervention group 21(4) years]	Eccentric knee extensor muscle contractions [5 x 10 repetitions with 120% of the 1-RM]	3 x 1-min cold-water immersion at 5 (±1) °C [immediately post-exercise]	1.Control group (4 males & 16 females)	1. Creatine kinase 2. Limb girth 3. Muscle soreness 4. One-legged hop-for-distance 5. Pressure pain threshold [at 0, 24, 48 & 72h]	No significant differences between groups for all assessed measures	Cold-water immersion 3 x 1-min at 5°C demonstrates no effect
Skurvydas et al., 2006 (4/10)	20 males [20.4(1.8) years]	Counter- movement jumps [100 repetitions]	2 x 15-min cold water immersion at 15(±1)°C [immediately & 4, 8, 24 h after exercise]	1.Cross-over design: treatment group and control group	1. Creatine kinase 2. Force evoked by electrostimulation 3. Muscle soreness 4. Muscle strength 5. Vertical jump [at 24, 48 & 72h]	Positive for creatine kinase, muscle soreness, muscle strength, vertical jump and force evoked by electrostimulation	Cold-water immersion accelerates the disappearance of the majority of indicators

Table 4: Stretching in the management of delayed-onset muscle soreness

Reference *(PEDro Score)*	Subjects	Exercise protocol	Intervention	Control	Criterion measures	Results	Conclusions
Buroker & Schwane, 1989 (5/10)	16 males & 7 females [18-33 years]	Step test [20-min; 15 stepping cycles per minutes]	10 x 30 s static stretches [at 2h intervals for the first 24h & 4h intervals for the following 48h]	1. Control group (n=8)	1. Creatine kinase 2. Limb girth 3. Muscle soreness 4. Muscles strength [before, at 24, 48 & 72h]	No significant differences between groups for all assessed measures	Static stretching is not effective for relieving DOMS
High & Howley, 1989 (3/10)	31 males & 31 females [19.5 years]	Step test [until exhaustion ; 64 stepping cycles per minutes]	5 x 50s static stretches [immediately post-exercise]	1. Stepping warm-up, no step test (n=16) 2. Warm-up and stretches (n=16) 3. Step test only (n=16)	1. Muscle soreness [at 24, 48, 72, 96 &120h]	No significant differences between groups for muscle soreness	Static stretching has no effect on preventing DOMS
Johansson et al., 1999 (4/10)	10 females [24 (3) years]	Maximal eccentric knee flexor contractions [10 x 10 repetitions]	4 x 20s static stretching [immediately post-exercise]	1. Contra-lateral leg	1. Muscle soreness 2. Muscle strength 3. Pressure pain threshold [before , at 24, 48 & 96h]	No significant differences between groups for all assessed measures	Pre-exercise static stretching has no preventive effect on DOMS
Lund et al., 1998 (4/10)	7 females [28-46 years]	Eccentric quadriceps muscle contractions [with 60% of maximum eccentric peak torque until exhaustion]	3 x 30s static stretches [before, immediately & for the next 7 days post-exercise.]	1. Cross-over design: treatment group and control group	1. Creatine kinase 2. Muscle soreness 3. Muscle strength 4. Ratio of phosphocreatine to inorganic phosphate [before, at 0, 24 48, 72, 96 120, 144, & 168h]	No significant differences between experiences for all assessed measures	Passive stretching after eccentric exercise cannot prevent DOMS
McGlynn et al., 1979 (3/10)	36 males [18-26 years]	Eccentric elbow flexor contraction [with 80% of the 1-RM until exhaustion; 30 concentric and 30 eccentric contractions/min]	4 x 2-min static stretches [at 6, 25, 30, 49& 54h post-exercise]	1. Control group (n=12)	1. Electromyography activity 2. Muscle soreness [before, at 0, 24, 48 & 72h]	Positive for EMG activity No significant differences for muscle soreness	Static stretching decreases EMG activity
Torres et al. 2005 (5/10)	17 males [18-32 years]	Maximal eccentric knee extensor contractions [2 sets until exhaustion]	10 x 30s static stretches [immediately post-exercise]	1. Stretching group (n=10) 2. Eccentric exercise group (n=8) 3. Stretching/eccentric group (n=9)	1. Creatine kinase 2. Oxaloacetic glutamic transaminase 3. Muscle soreness 4. Muscle strength 5. Limb girth	No significant differences between experiences for all assessed measures	Passive stretching after eccentric exercise cannot prevent DOMS
Torres et al., 2007 (5/10)	30 males [18-32 years]	Maximal eccentric knee extensor contractions [2 sets until exhaustion]	10 x 30s static stretches [immediately post-exercise]	1. Stretching group (n=10) 2. Eccentric exercise group (n=10) 3. Stretching/eccentric group (n=10)	1. Muscle stiffness [before, at 1, 24, 48, 72 & 96h]	Positive for different parameters during *Wartenberg Test*	Stretching program alleviates reduction in range of motion induced by exercise
Wessel & Wan, 1994 (4/10)	13 males; & 7 females [19-31 years]	Maximal concentric /eccentric knee flexor contractions [3 x 20 repetitions]	10 x 60s static stretches [group before exercise (n=10); group after exercise (n=10)]	1. Contra-lateral leg	1. Muscle soreness [at 12, 24, 48, 60 & 72h] 2. Range of motion [at 0, & 48h] 3. Pressure pain threshold [at 0, & 48h]	No significant differences between groups for all assessed measures	Static stretching has no effect on preventing or alleviating DOMS

Table 5: Low-intensity exercise in the management of delayed-onset muscle soreness

Reference *(PEDro Score)*	Subjects	Exercise protocol	Intervention	Control	Criterion measures	Results	Conclusions
Chen et al., 2008 (5/10)	50 males [21.1(2.3) years]	Downhill running [30-min; at -15% (-8.5º)]	Four groups (n=10 per group) performed a 30-min level run on the treadmill in the intensity of 40, 50, 60 & 70% of $VO_{2max.}$ [at days 1-6]	1.Control group (n=10)	1. Creatine kinase 2. Lactate deshydrogenase 3. Muscle strength 4. Muscle soreness [before & days 1-7]	No significant differences between groups for all assessed measures	Daily running did not have beneficial or adverse effects on recovery of damage and running economy regardless of the intensity
Dannecker et al., 2002 (6/10)	24 males & 26 females [21(6.4) years]	Eccentric elbow flexor contractions [n x 10 repetitions; at 80% 1-RM]	20-min of cycle ergometer endurance exercise at 80% of estimated maximum cardiorespiratory endurance [48h post-exercise]	1.Control group (n=27), 20-min watching emotional neutral video	1. Anxiety 2. Muscle soreness 3. Pressure pain threshold [Before & at 48h before and after intervention]	No significant differences between groups for all assessed measures	Cycle ergometer exercise was not found to alter DOMS
Donnelly et al., 1992 (4/10)	4 males & 14 females [19(1) years]	Concentric/eccentric elbow flexors/extensors [70 maximal contractions]	25 submaximal concentric/eccentric elbow flexors and extensors contractions at 50% of the maximum torque [1 day post-exercise]	Control group (n=9)	1. Creatine kinase 2. Muscle strength 3. Muscle soreness 4. Range of motion [before & days 1-5]	Positive for creatine kinase activity after induced muscle damage	Light exercise had no apparent effect of muscle function recovery
Hasson et al., 1989 (5/10)	6 males & 4 females [20-36 years]	Bench-stepping [10-min; 15 cycles/min]	6 x 20 maximum contractions at ≈ 300º/s (n=5) [at 24h post-exercise]	1.Control group (n=5)	1. Muscle strength 2. Muscle soreness [at 24 & 48h]	Positive for muscle soreness and muscle strength at 48h post-exercise	High speed voluntary muscle contractions are effective in decreasing muscle soreness and facilitating return of normal muscular performance
Saxton & Donnelly, 1995 (5/10)	8 males [19-33 years]	Eccentric elbow flexor [70 maximal contractions]	5 x 10 submaximal concentric elbow flexor contractions at 50% of their maximal voluntary contraction [at days 1-4]	1.Contralateral arm	1. Creatine kinase 2. Muscle soreness 3. Muscle strength 4. Range of motion [at days 1-7 & 10]	Positive for muscle soreness at 48h & 96h for creatine kinase	Concentric exercise had limited effect in the alleviation of DOMS
Weber et al., 1994 (5/10)	40 females [18-35 years]	Eccentric elbow flexor contractions [maximal contractions until exhaustion]	8-min upper-body ergometry 60 rpm for a workload of 400kg/min (n=10) [at 0 & 24h]	1.Control group (n=10) 2.Group microcurrent electrical stimulation (n=10) 3.Massage group (n=10)	1. Muscle soreness 2. Muscle strength [before, at 24 & 48h]	No significant differences between groups for all assessed measures	Light to moderate concentric exercise is not effective in alleviating DOMS
Zainuddin et al., 2006 (3/10)	10 males & 4 females [24.4(2.4)years]	Eccentric elbow flexor [10 x 6 repetitions maximum contractions]	10 x 60 continuous elbow flexion (240º/s) and extension (210º/s) contractions [at days 1-4]	1.Contralateral arm	1. Creatine kinase 2. Limb girth 3. Muscle soreness 4. Muscle strength 5. Pressure pain threshold 6. Range of motion [before & at days 1-4]	Positive for muscle soreness and tenderness immediately after light concentric exercise.	Light concentric exercise has a temporary analgesic effect on DOMS, but no recovery from muscle damage

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