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Literature review

Evidence of the physiotherapeutic interventions used currently after exercise-induced muscle damage: Systematic review and meta-analysis

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ABSTRACT

Introduction: Exhaustive and/or unaccustomed exercise, mainly involving eccentric muscle actions, induces temporary muscle damage, evidenced by delayed onset muscle soreness (DOMS) and decreased muscle function. Different strategies to recover from its signs and symptoms have been studied and, as a result, a significant number of articles on this issue have been published.
Objective: To assess whether some modalities currently used in physiotherapy such as massage, cryotherapy, stretching and low-intensity exercise are effective for treating the signs and symptoms of exercise-induced muscle damage.
Methods: Randomized controlled trials (RCTs), written in English or Portuguese, that included physiotherapeutic interventions [i.e., massage, cryotherapy, stretching and low-intensity exercise, on adult human subjects (18–60 years old) of both gender] were searched on electronic databases including MEDLINE, CINHAL, EMBASE, PEDro and SPORTDiscus.
Main outcome measures: "Muscle soreness" and "muscle strength" were the outcome measures included in the meta-analysis.
Results: Thirty-five studies were included; nine analysed the effects of massage, 10 examined the effects of cryotherapy, nine investigated the effects of stretching and seven focused on low-intensity exercise intervention.
Massage was the only intervention with positive effects, reducing soreness at 24 h, on average, 0.33 on 10 cm visual analog scale (95 percent CI: −0.59, −0.07) and increasing muscle recovery by 1.87 percent (95 percent CI: 0.30, 3.44). Additionally, there is inconclusive evidence to support the use of cryotherapy, while there is little evidence to prove the efficacy of stretching and low-intensity exercise.
Conclusion: Massage proved slightly effective in the relief of symptoms and signs of exercise-induced muscle damage. Therefore, its mean effect was too small to be of clinical relevance. There is a lack of evidence to support the use of cryotherapy, stretching and low-intensity exercise.

1. Introduction

Exhaustive and/or unaccustomed exercises (particularly those involving high intensity muscle contractions) are known to induce temporary muscle damage (Deschenes, Bush, McCoy, Volek, & Kraemer, 2000; Gleeson, Blannin, Walsh, Field, & Pritchard, 1998), evidenced by muscle soreness, reduction in muscle strength, muscle swelling and a reduced range of motion of the joints involved (Cheung, Hume, & Maxwell, 2003; Jamurtas et al., 2005; Lavender & Nosaka, 2006). The explanation for exercise-induced muscle damage remains unclear. However, the most accepted theory involves high mechanical tension exerted on the myofibril during eccentric muscle contraction and metabolic changes imposed by the exercise that leads to a loss of cellular homeostasis, particularly due to a high intracellular calcium concentration (Armstrong, 1984; Clarkson & Sayers, 1999). It is suggested that the initial stage of abnormal functioning of the myofibril and the structural changes of the cytoskeleton are caused by an increase of intracellular calcium concentration.

Although the first publication about exercise-induced muscle damage was in 1902 by Hough, this issue remains current, particularly with regard to research into the prevention and treatment of

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this clinical condition. As a result, several studies evaluated the effects of conventional physiotherapeutic interventions and found the negative effects of intensive exercise. O'Connor and Hurley (2003) conducted the first systematic literature review on the subject of effectiveness of physiotherapeutic interventions in the management of delayed onset muscle soreness (DOMS). Since then, a considerable amount of studies have been published, creating the need for a summary of recent research to identify valid and applicable evidence. The result is 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 injury often includes therapeutic massage, cryotherapy, stretching and active exercise. However, the efficacy of these interventions in preventing or changing the course of exercise-induced muscle damage is unclear (Cheung et al., 2003; Ernst, 1998; O'Connor & Hurley, 2003).

In this sense, the aim of this systematic review and meta-analysis was to examine whether some modalities currently used in physiotherapy such as massage, cryotherapy, stretching and low-intensity exercise are effective for relieving the signs and symptoms of exercise-induced muscle damage.

2. Materials and methods

2.1. Selection criteria for studies

Only RCTs including adult human subjects, written in English or Portuguese, were included in the study. Titles, abstracts and keywords identified from the results of the search were screened by two researchers and used as criteria for inclusion or exclusion (Fig. 1). When both reviewers did not reach an agreement, the full text of the respective study was obtained and analysed to establish suitability.

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

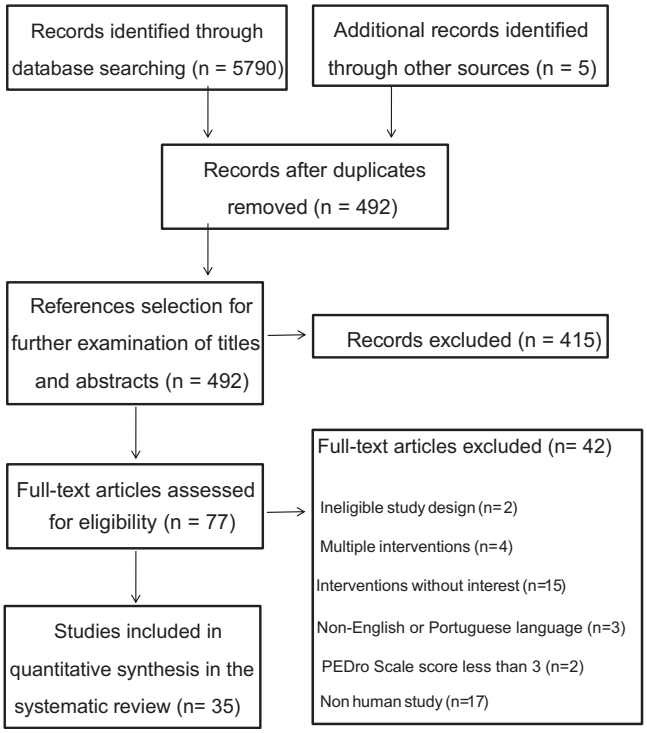

Fig. 1. Flow chart of inclusion process of articles used in the systematic review.

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

2.2. 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," "physical therapy," "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 paper identified to ensure that appropriate articles were obtained.

2.3. 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. (1998); it is a valid and reliable measure of the methodological quality of clinical trials (Maher, Sherrington, Herbert, Moseley, & Elkins, 2003; Morton, 2009).

Two authors familiar 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 disagreement 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. However, all studies receiving a score of at least three in the initial analysis were included. The descriptive data of participants, exercise protocol, interventions, outcomes, results and conclusions were extracted by one author in a standardized predefined way, and were then summarized by tabulation (Tables 2–5).

2.4. Quantitative data analysis

The mean change in "muscle soreness," measured on a 10-cm. Visual Analogue Scale (VAS), and percentage of change of muscle strength relative to baseline were defined as outcomes and used to assess the difference between the treatment and control group. Means and 95 percent confidence intervals (Cls) were calculated using standard meta-analysis software (RevMan 5.0. Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2008). Meta-analyses 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 that plotted effect estimates of the common outcome measure against sample size.

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[a]
	Ascensão et al. (2011)	1	1	0	1	0	0	0	1	1	1	1	6/10[a]
	Paddon-Jones and Quiley (1997)	1	1	0	1	0	0	0	1	1	1	1	6/10[a]
	Eston and 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 and 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	Abad et al. (2010)	1	1	0	1	0	0	1	1	0	1	1	6/10[a]
	Weber, Servedio, and Woodall (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
	Gulick et al. (1996)	0	1	0	0	0	0	0	1	0	1	0	3/10
	High et al, (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	Dannecker et al. (2002)	1	1	0	1	0	0	0	1	1	1	1	6/10[a]
	Chen, Nosaka, and Wu (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

[a] High methodological quality study.

3. Results

3.1. Studies included

In total, 35 studies were included in the systematic review; 10 analysed the effects of cryotherapy, nine for the effect of massage, nine for the effect of stretching and seven for the effects of low-intensity exercise (Table 1). Except for two studies that were published in Portuguese (Abad, Ito, Barroso, Ugrinowitsch, & Tricoli, 2010; Torres, Carvalho, & Duarte, 2005), all others were written in English.

The PEDro score for each study is detailed in Table 1. Only those carried out by Sellwood, Brukner, Williams, Nicol, and Hinman (2007), Ascensão, Leite, Rebelo, Magalhães, and Magalhães (2011), Paddon-Jones and Quiley (1997), Abad et al. (2010) and Dannecker, Koltyn, Riley, and Robinson, (2002) had high methodological quality; a lack of blinding is the most evident methodological flaw in the studies. Failure to conceal allocation was another general methodological limitation of the studies.

The meta-analysis was only performed on "muscle soreness" and "muscle strength" because they were the only variables with enough detailed data. Moreover, it was not possible to make the meta-analysis of the effect of stretching at 1 h, due to a lack of and/or insufficient data.

From the nine RCTs (Table 2) for assessing the effectiveness of massage after exercise-induced muscle damage, six found positive effects on "muscle soreness" (Farr, Nottle, Nosaka, & Sacco, 2002; Hilbert, Sforzo, & Swensen, 2003; Mancinelli, Davis, Aboulhosn, Eisenhofer, & Foutty, 2006; Smith et al., 1994; Willems, Hale, & Wilkinson, 2009; Zainuddin, Newton, Sacco, & Nosaka, 2005). In the variable "muscle function," only three studies demonstrated a positive effect. Farr et al. (2002) found positive effects in "muscle strength" and vertical jump, while Mancinelli et al. (2006) and Willems et al. (2009) found this only in the vertical jump.

Ten RCTs (Ascensão et al., 2011; Bailey et al., 2007; Eston & Peters, 1999; Goodall & Howatson, 2008; Howatson, Gaze, & Van-Someren, 2005; Howatson, Goodall, & Someren, 2009; Jakeman, Macrae, & Eston, 2009; Paddon-Jones & Quiley, 1997; Sellwood et al., 2007; Skurvydas et al., 2006) evaluating the effectiveness of cryotherapy were found (Table 3). Only one study examined the effect of ice massage (Howatson et al., 2005) while the others studied the effect of cold-water immersion. No study was found to analyse the effect of spray or ice packs on "muscle soreness."

Nine RCTs (Buroker & Schwane, 1989; Gulick, Kimura, Sitler, Paolone, & Kelly, 1996; High, Howley, & Franks, 1989; Johansson, Lindstrom, Sundelin, & Lindstrom, 1999; Lund, Vestergaard-Poulsen, Kanstrup, & Sejrsen, 1998; McGlynn, Laughlin, & Rowe, 1979; Torres et al., 2005; Torres, Appell, & Duarte, 2007; Wessel & Wan, 1994) were found (Table 4) that evaluated the effects of muscle stretching after exercise-induced muscle damage.

3.2. Effect of massage

The meta-analysis showed that massage applied after exercise is effective on "muscle soreness" only after 24 h. In fact, four RCTs (Abad et al., 2010; Farr et al., 2002; Hilbert et al., 2003; Willems

Table 2
Massage in the management of delayed onset muscle soreness.

Reference *(PEDro Score)*	Subjects	Exercise protocol	Intervention	Control	Criterion measures	Results	Conclusions
Abad et al., 2010 (6/10)	18 males [18–30 years]	Maximal eccentric extensors muscles contractions of the elbow [6 × 5 repetitions at 110% 1RM]	6-min of massage (0.5-min effleurage, 3.5-min petrissage, 1.5-min tappotement, 0.5-min effleurage) [immediately post-exercise]	1. Control group without treatment ($n = 6$) 2. Massage group ($n = 6$)	1. Limb girth 2. Muscle soreness 3.Muscle strength 4. Range of motion [before, at 0, 24, 48, 72,& 96h]	No significant differences between groups for all assessed measures	Massage was not effective to minimize DOMS
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 2 h 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 & 120 h]	Positive for muscle soreness and tenderness. Still positive for isokinetic strength and vertical jump at 1 and 24 h 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) C	Maximal eccentric knee flexors contractions [6 × 10 repetitions + 5]	20-min of massage (5-min effleurage, 1-min percussion, 12-min petrissage, 2-min effleurage) [at 2 h post-exercise]	1. Control group without treatment ($n = 9$)	1. Muscle soreness 3. Muscle strength [at 2, 6, 24 & 48 h] 4. Neutrophils count [at 6 & 24 h] 5. Range of motion [at 6, 24 & 48h]	Positive for muscle soreness at 48 h 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 × 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 contractions of the elbow [5 × 35 repetitions]	30-min of athletic massage (effleurage, shaking, petrissage, wringing and cross-fibre massage) [at 2 h 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 h 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 & 24 h 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

Willems 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 × 6 repetitions]	10-min of massage (2.5-min effleurage, 1-min petrissage, 2-min friction, 2-min petrissage & 2.5-min effleurage) [at 3 h 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.

et al., 2009) studying the effect of massage (total sample size 30) had sufficient data to make the meta-analysis possible at 24 h (Fig. 2A). The overall effects suggest a significant positive effect ($p = 0.01$) with a mean difference of 0.33 cm (95 percent CI: 0.59, 0.07) on a 10-cm VAS. The result of heterogeneity indicated that the differences observed between trials were unlikely to be caused by chance ($Chi^2 = 0.40$; $I^2 = 0$ percent).

The overall effect was not statistically significant in any one of the other moments ($p = 0.46$, $p = 0.07$ and $p = 0.32$ to 1, 48 and 72 h, respectively). The heterogeneity between the studies at 48 h ($I^2 = 46$ percent) made it difficult to clarify the true effect of massage after exercise-induced muscle damage at 48 h; i.e., whether massage effectively attenuates soreness, while at 1 and 72 h the consistency between studies ($I^2 = 0$) gives more guarantee about the failure of this intervention at these periods.

Relative to the effect of post-exercise massage on "muscle strength" (Fig. 2B), the meta-analysis demonstrated an overall effect only at 1 h and not at 24, 48 or 72 h with mean differences of 1.87 (95 percent CI: 0.30, 3.44), 3.41 (95 percent CI: −0.36, 7.18), 0.17 (95 percent CI: −4.69, 5.02) and 2.29 (95 percent CI: −0.15, 4.72) percent, respectively. Indeed, the assessment made at 1 h had a significant overall effect ($p = 0.02$) and all the included studies found similar results ($I^2 = 0$ percent), indicating little variability between studies that cannot be explained by chance (Higgins, Thompson, Deeks, & Altman, 2003).

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

3.3. Effect of cryotherapy

The evidence presented in this review does not support the use of cryotherapy on the variables assessed. Indeed, only four RCTs found positive effects for cryotherapy (Ascensão et al., 2011; Bailey et al., 2007; Eston & Peters, 1999; Skurvydas et al., 2006), contrasted against six other studies demonstrating no effect on all variables assessed (Goodall & Howatson, 2008; Howatson et al., 2005; Howatson et al., 2009; Jakeman et al., 2009; Paddon-Jones & Quiley, 1997; Sellwood et al., 2007). The analysis of trials that assessed "muscle soreness" using the VAS (Fig. 3A) showed no statistically significant overall effect at 1 and 24 h, with a mean difference of −0.43 cm (95 percent CI: −1.95, 1.10), −1.22 cm (95 percent CI: −3.31, 0.88). Although the overall effect of cryotherapy after 48 and 72 h was statistically significant (mean difference −1.22 cm (95 percent CI: −1.60, −0.84) and −2.11 cm (95 percent CI: −3.77, −0.45), respectively), these results should not be considered reliable because a significant statistical heterogeneity among the trials in each of the assessed moments was found ($I^2 = 39$ percent and 88 percent to 48 and 72 h, respectively).

With respect to "muscle strength," the effect of cryotherapy post-exercise was statistically significant ($p < 0.01$) at 24 h. However, this result could not be pooled due to the methodological heterogeneity studies ($I^2 = 65$ percent), i.e., 65 percent of the variation in the data can be attributed to heterogeneity (Fig. 3B).

At 1 h, no effect ($p = 0.29$) was found and the low heterogeneity observed between studies indicated that the mean difference of −2.56 percent (95 percent CI: −7.32, 2.19) between trials was unlikely to have been by chance ($Chi^2 = 0.27$; $I^2 = 0$ percent). Also at 48 and 72 h, no significant effects were observed ($p = 0.16$ and $p = 0.39$, respectively). However, the high heterogeneity verified ($I^2 = 65$ percent and $I^2 = 69$ percent, respectively) does not provide the same certainty in its ineffectiveness, i.e., in this case there is a possibility that these results were due to chance.

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. Creactive protein 2. Creatine kinase 3. Muscle strength 4. Muscle soreness 5. Myoglobin 6. Performance tests [before, at 30-min, 24 & 48 h]	Positive for muscle soreness, creatina kinase, mioglobin, Creactive 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 & 168 h]	Positive for muscle soreness (at 1,24 & 48 h), muscle strength of the knee flexors (at 24 & 48 h) and myoglobin (at 1 h 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 × 5 repetitions]	7 × 15-min cold-water immersion at 15(1)°C [immediately & 12, 24, 36, 48, 60, 72 h 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 & 72 h]	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 × 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 × 10 repetitions at 30°/s performed in the dynamometer]	15-min of ice massage directly on the skin [immediately & 24, 48 h 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 × 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 × 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 & Quiley, 1997 (6/10)	8 trained males [23.0(2.5) years]	Eccentric elbow flexor contractions of both arms [8 × 8 repetitions with 110% of the 1-RM]	5 × 20-min (60-min rest period) cold-water immersion at 5(1)°C [post-exercise]	1.Contralateral 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 × 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 × 10 repetitions with 120% of the 1-RM]	3 × 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 & 72 h]	No significant differences between groups for all assessed measures	Cold-water immersion 3 × 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 × 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

With the exception of the study conducted by Bailey et al. (2007), the application of a single session of cold-water immersion immediately after exercise had no effects on the different indirect markers of muscle damage. In fact, the studies carried out by Howatson et al. (2009) and Jakeman et al. (2009) found no difference between a single 12-min (at 15 °C) and 10-min (at 10 °C) cold-water immersion. Similar results were found by Sellwood et al. (2007); 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 that was immersed in tepid water at 24 °C. In contrast, Bailey et al. (2007) examined the effect of a 10-min cold-water immersion at 10 (±0.5)°C and found positive effects in "muscle soreness," "muscle strength" and myoglobin blood concentration after induced muscle damage with a 90-min intermittent shuttle run.

Four studies were found (Eston & Peters, 1999; Goodall & Howatson, 2008; Howatson et al., 2005; Skurvydas et al., 2006) that analysed the effect of repeated cryotherapy. Two studies suggested that cryotherapy applied repeatedly over time might contribute to muscle recovery, particularly in the reduction of muscle stiffness. Indeed, Eston and Peters (1999) immersed the upper limb 15-min immediately post-exercise and at 12, 24, 36, 48 and 72 h, while Skurvydas et al. (2006) performed two 15-min immersions immediately post-exercise at 4, 8 and 24 h. Both studies found positive effects. However, Goodall and Howatson (2008) and Howatson et al. (2005) do not corroborate these findings. Goodall and Howatson administered 12-min of cold-water immersion immediately post-exercise at 24, 48, and 72 h, and Howatson et al. applied 15-min of ice massage immediately post-exercise at 24 and 48 h, finding no difference in "muscle strength," soreness, limb girth, range of motion, plasmatic creatine kinase activity (CK) (Goodall & Howatson, 2008; Howatson et al., 2005) or myoglobin blood concentration (Howatson et al., 2005).

3.4. Effect of stretching

There are different protocols in the studies with respect to the timing of stretching relative to exercise: single stretching program before exercise (Johansson et al., 1999; Wessel & Wan, 1994); single stretching program after exercise (Gulick et al., 1996; High et al., 1989; Torres et al., 2007; Wessel & Wan, 1994); single stretching program before and repeated stretching program after exercise (High et al., 1989); and repeated stretching program after exercise (Buroker & Schwane, 1989; McGlynn et al., 1979). 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" (Fig. 4A and B) had no statistically significant overall effect at 24, 48 and 72 h ($p > 0.05$). The failure of this intervention becomes more apparent with the fact that there is a low ($I^2 = 0$ percent) heterogeneity between studies, except for "muscle soreness" at 24 h ($I^2 = 38$ percent).

3.5. Effect of low-intensity exercise

Finally, evaluating the effect of low-intensity exercise, only three of the seven studies (Table 5) carried out by Zainuddin, Sacco, Newton, and Nosaka (2006), Saxton and Donnelly (1995) and Hasson, Barnes, Hunter, and Williams (1989) detected temporary relief in muscle soreness. Regarding the positive effects on the other variables, the results demonstrated only a reduction in plasmatic CK activity in two studies (Donnelly, Clarkson, & Maughan, 1992; Saxton & Donnelly, 1995). The 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 h post-exercise. Moreover, the inconsistency of the

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 × 30 s static stretches [at 2h intervals for the first 24 h & 4 h 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
Gulick et al., 1996	34 males & 36 Females [21–40 years]	Eccentric forearm extensor contractions [15 × 15 repetitions]	10 min of static stretching [immediately post-exercise]	1. Control group ($n = 10$)	1. Limb girth 2. Muscle soreness 3. Muscle strength 4. Range of motion [before, at 0, 20 min, 24, 48 &72]	No significant differences between groups for all assessed measures	Static stretching is not effective for relieving DOMS
High et al, 1989 (3/10)	31 males & 31 females [19.5 years]	Step test [until exhaustion; 64 stepping cycles per minutes]	5 × 50 s 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 × 10 repetitions]	4 × 20 s 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 × 30 s 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 × 2-min static stretches [at 6, 25, 30, 49& 54 h 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 × 30 s 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 × 30 s 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 × 20 repetitions]	10 × 60 s 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, & 48 h] 3. Pressure pain threshold [at 0, & 48 h]	No significant differences between groups for all assessed measures	Static stretching has no effect on preventing or alleviating DOMS

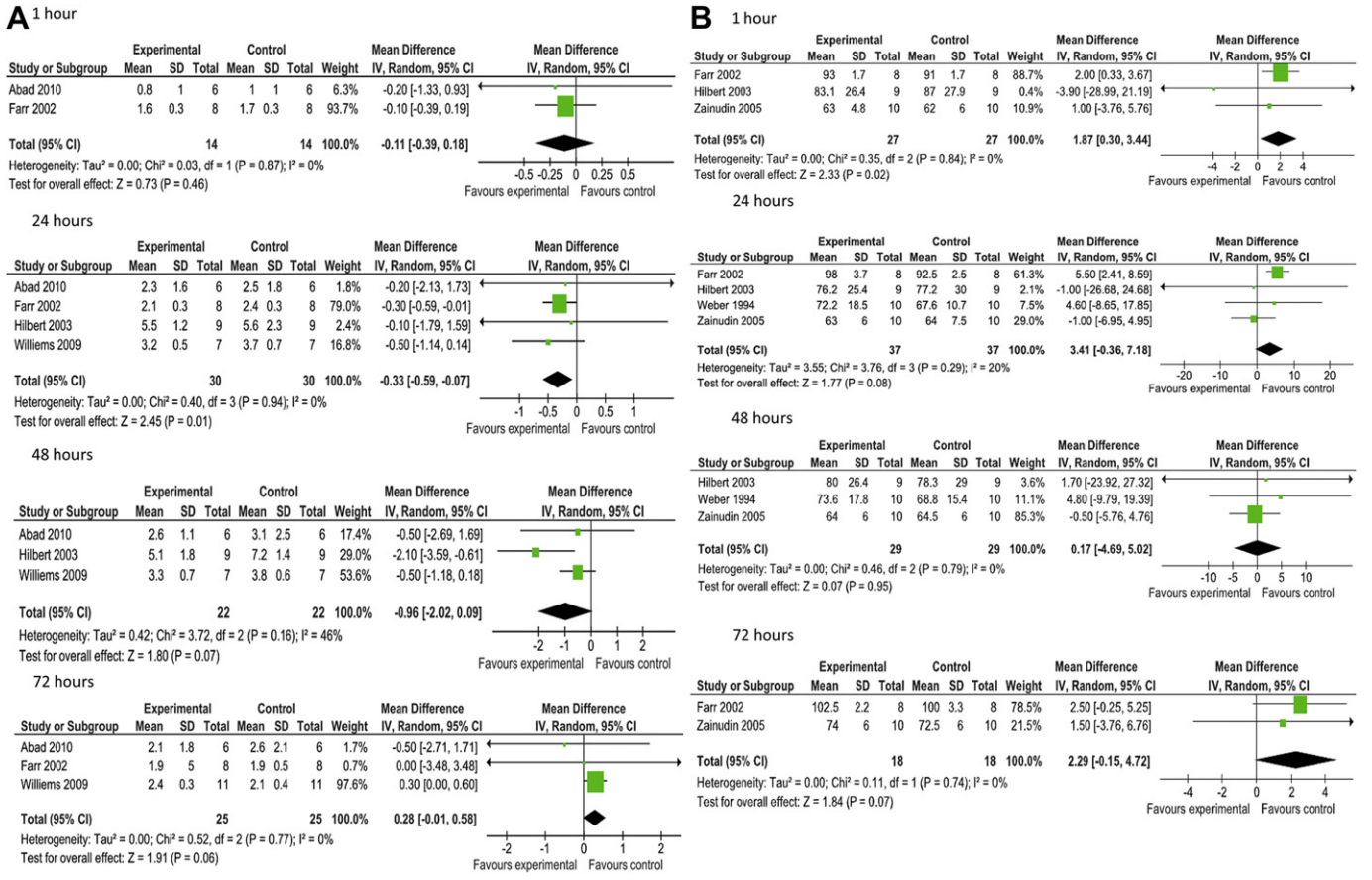

Fig. 2. A – Effects of massage on delayed onset muscle soreness at 1, 24, 48 and 72 hours (Visual Analogue Scale). B – Effects of massage on muscle strength at 1, 24, 48 and 72 hours (Percentage of change to baseline). Note: Effect in favour of the control group means less ability to produce muscle strength thus it should be viewed as a positive effect of massage in the experimental group.

results of the studies (moderate or high heterogeneity) does not form the grounds of any recommendations for low-intensity exercise intervention.

4. Discussion

The meta-analysis was performed only on "muscle soreness" and "muscle strength" because they are the only variables whose data are sufficiently detailed and their assessment is similar. In addition, "muscle soreness" and "muscle strength" are not only the most used outcomes but also the two best markers of muscle damage (Byrne, Twist, & Eston, 2004; Clarkson, Nosaka, & Braun, 1992); therefore, the effect of a physiotherapeutic intervention can be assessed by these two variables with some confidence.

In general, the results suggest that massage is the only effective intervention, while the cryotherapy intervention has little evidence supporting its use. Other 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 (Howatson & Someren, 2008). It has been established that massage might have a number of physiological and psychological effects, particularly by increasing blood circulation and lymphatic flow, decreasing oedema production and muscular tone, and hence contributing to the repair of damaged muscles 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 20–30 min administered immediately or up to 2 h post-exercise relieves "muscle soreness" at 24 h. However, the effect beyond this period is not shown. We hypothesize that massage may stimulate the afferent fibres of type Ia, Ib, and II, leading to a reduction in the pain sensation "transported" by type III and IV (Armstrong, 1984). In other words, pain stimulation is balanced against tactile stimulation and these two kinds of stimulus are capable of inhibiting each other. Therefore, excessive tactile stimulation as represented by massage may suppress pain transmission, but only temporarily.

Regarding the effect of its application on "muscle strength," massage only has a small positive effect on muscle recovery at 1 h. Although the effects of massage on pain and "muscle strength" are statistically significant, they are clinically small, being only 0.33 out of 10 points on VAS and approximately 2 percent of peak torque in the "muscle strength."

Regarding the other variables related to inflammatory response, which could be theoretically altered, such as the limb girth or neutrophil concentration, the results were contradictory. The study conducted by Lightfoot, Char, McDermott, and Goya (1997) that used different techniques of massage for a 10-min period had positive effects on limb girth. However, the study by Zainuddin et al. (2005), although using only "petrissage" and applying the same amount of time (10 min), found no changes. A similar analysis could be made for the neutrophils count, where two conflicting studies were found. Smith et al. (1994) applied a 30-min massage two hours after exercise and observed a decrease in the neutrophils, while the 20-min. massage performed in the study carried out by Hilbert et al. (2003) did not induce any changes.

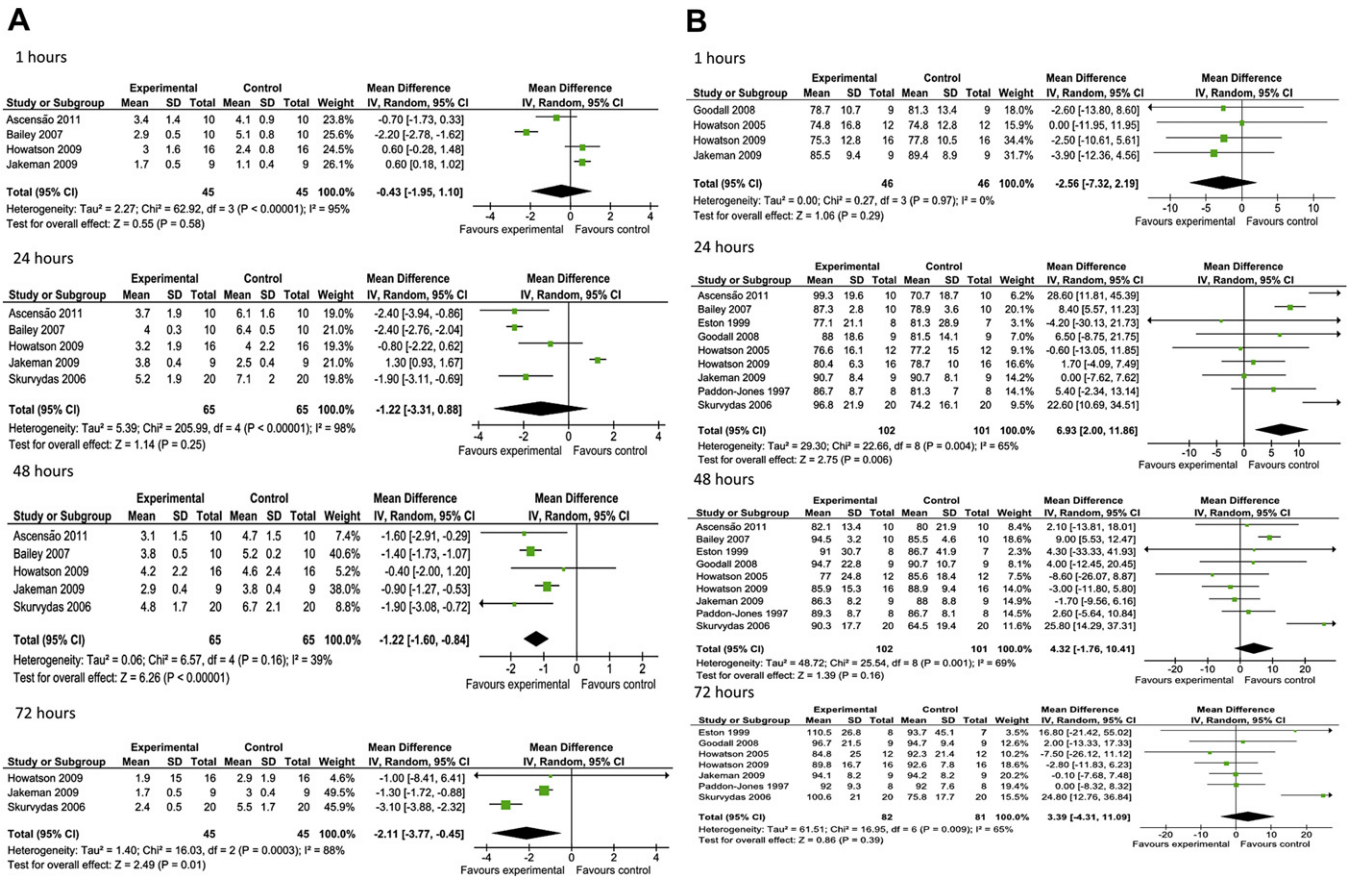

Fig. 3. A – Effects of cryotherapy on delayed onset muscle soreness at 1, 24, 48 and 72 hours (Visual Analogue Scale). B – Effects of cryotherapy on muscle strength at 1, 24, 48 and 72 hours (Percentage of change to baseline). Note: Effect in favour of the control group means less ability to produce muscle strength thus it should be viewed as a positive effect of cryotherapy in the experimental group.

Cryotherapy is known to be used in the initial treatment of traumatic soft tissue injuries (Cheung et al., 2003) and in the recovery from sport activities, particularly with the aim to minimize DOMS (Jakeman et al., 2009; Sellwood et al., 2007; Skurvydas et al., 2008; Wilcock, Cronin, & Hing, 2006). 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 (Armstrong, 1984; Cheung et al., 2003). The superficial application of cold results in changes in skin, subcutaneous, intramuscular and joint temperature. Consequently, this decrease in tissue temperature stimulates cutaneous receptors, leading to excitation of the sympathetic adrenergic fibres, causing the constriction of local arterioles and venules, and thus diminishing inflammatory processes (Cheung et al., 2003; Sellwood et al., 2007). In this sense, a reduction in perceived pain and/or in limb girth could be regarded as a result of the decrease in local inflammation. However, the goal to determine the effectiveness of cryotherapy becomes difficult due to the fact that the studies differ substantially in their interventions, particularly with respect to number of participants, timing and duration.

In fact, although the results have demonstrated significant positive overall effects at 48 and 72 h, the inconsistency of the results discourages its recommendation. The moderate to high I^2 values show that most of the variability across studies is due to heterogeneity rather than chance (Higgins et al., 2003). These findings suggest that there is little evidence in favour of cryotherapy, and therefore corroborates those obtained by Burguess and Lamber (2010). In fact, these authors carried out a systematic review of 13 articles of primary research, finding inconclusive evidence to support the use of cryotherapy modalities for recovery from exercise-induced muscle damage.

Regarding the application of stretching, its effects have been related to changes in both mechanical and neural factors, leading to the recovery of muscle function after exercise-induced muscle damage. Early in 1966, DeVries (1966) argued that muscle stretches might reduce muscle spasms after intense exercise, thus recommending its use. Subsequently, the results found by McGlynn et al. in 1979 also demonstrated a decrease in the electromyography activity after stretching the musculature involved in intensive exercise, thereby reducing muscle spasm. More recently, Torres et al. (2007), using a substantially different methodology, found a 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 studies using static stretching included in this systematic review demonstrated no differences in any of the variables collected (Buroker & Schwane, 1989; High et al., 1989; Johansson et al., 1999; Lund et al., 1998; Wessel & Wan, 1994).

Furthermore, our analysis on stretching observed low heterogeneity between studies ($I^2 = 0$ percent); the inconsistency between studies indicated that a lack of effect after exercise-induced muscle damage cannot be attributed to chance. Therefore, its recommendation to alleviate the signs and symptoms of exercise-induced muscle damage must be challenged. Although

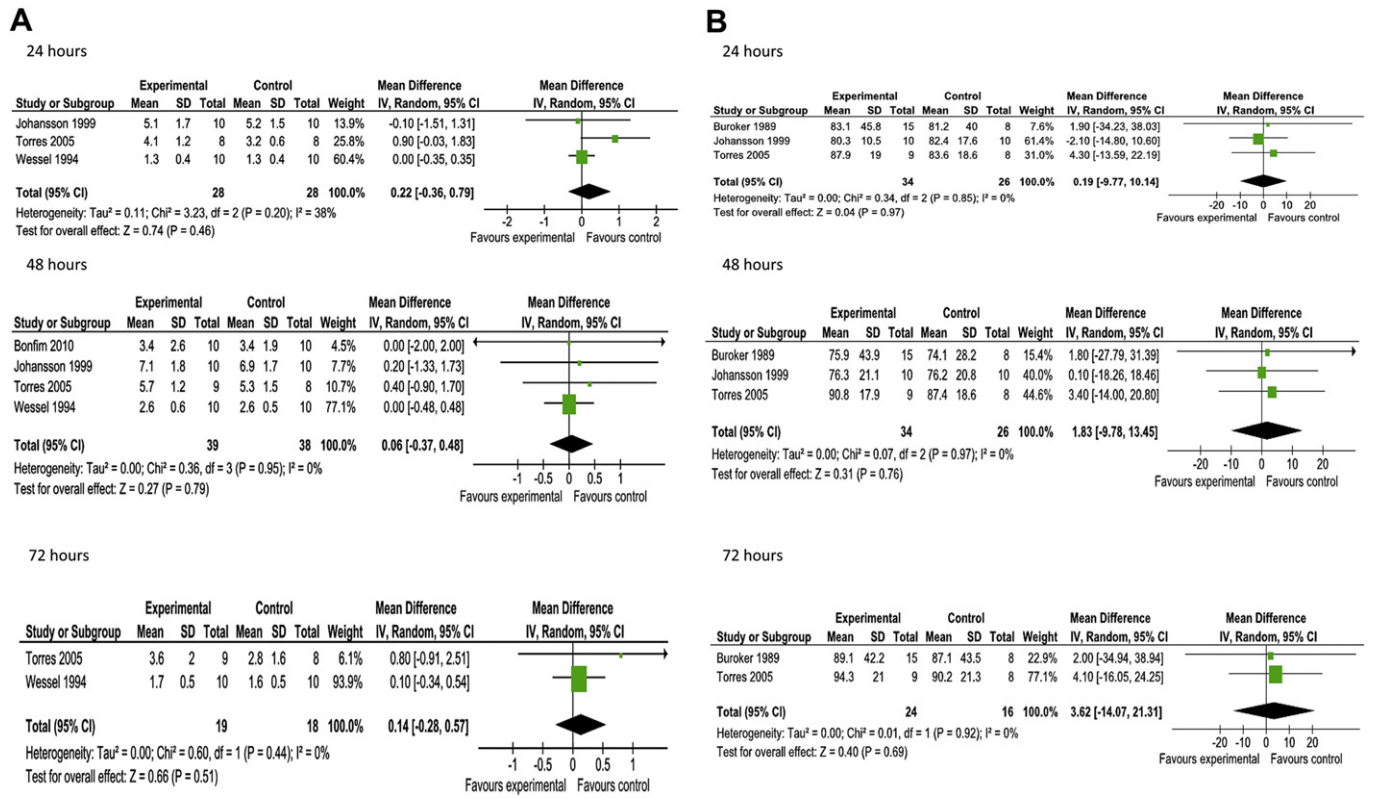

Fig. 4. A – Effects of stretching on delayed onset muscle soreness at 24, 48 and 72 hours (Visual Analogue Scale). B – Effects of stretching on muscle strength at 24, 48 and 72 hours (Percentage of change to baseline). Note: Effect in favour of the control group means less ability to produce muscle strength thus it should be viewed as a positive effect of stretching in the experimental group.

studying only "muscle soreness," Herbert and Gabriel (2002), in a systematic review of five studies, and Herbert and Noronha (2007) in a meta-analysis of ten studies, also found that stretching before and after exercise did not confer protection from "muscle soreness," which corroborates our present findings.

Low-intensity exercise is another conventional intervention that is thought to increase the rate of recovery of symptoms after exercise-induced muscle damage (Armstrong, 1984; Cheung et al., 2003). 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 as that given for the effect of massage. Both hypotheses suggest that there is a rise in the stimulation of sensitive fibres of type Ia, Ib, and II, which may lead to an interference in the pain sensation "transported" by type III and IV (Weerakkody, Whitehead, Canny, Gregory, & Proske, 2001). However, our meta-analysis demonstrated the lack of support for the idea that low-intensity exercise may be effective, particularly in "muscle soreness." Indeed, only three (Hasson et al., 1989; Saxton & Donnelly, 1995; Zainuddin et al., 2006) of the seven studies (Table 5) detected temporary relief in "muscle soreness." Overall, our study demonstrated no significant effects of low-intensity exercise on "muscle soreness" after exercise-induced muscle damage, particularly at 24, 48 and 72 h post-exercise. Therefore, low-intensity exercise is probably not effective in the recovery of the damaged muscle.

Concerning the positive effects on other variables such as plasmatic CK activity, only two studies found significant effects (Donnelly et al., 1992; Saxton & Donnelly, 1995). Therefore, it is unclear whether low-intensity exercise has a role in improving the functioning of the cell membrane.

Regarding the methodological quality of the RCTs, lack of blinding is the most evident methodological flaw in these studies. Blind subjects, physiotherapists who administered the intervention and the assessors who measured outcomes, were more often taken into account. Failure to conceal allocation was another general methodological limitation of the studies.

In general, the analyses of data from RCTs yield robust indications of the effects of the physiotherapeutic intervention in the outcomes; although some variability in the protocols used to induce muscle damage and different duration and frequency of the interventions were observed, the results give a clear indication of what should be used to improve recovery after intense exercise.

The participants evaluated represent a healthy young adult population (mean age of 23 years old) and consequently the applicability of findings for this population to children and to older adults is uncertain.

The PEDro score showed deficits in the methodological quality of some of the studies that should be taken into account in future studies, mainly with respect to the lack of blinding and small sample size. Therefore, further RCTs with higher quality are still required in order to clarify the long-term effects of physiotherapeutic interventions on recovery.

5. Conclusions

This systematic review and meta-analysis demonstrated that therapeutic massage is the only intervention that had a positive effect on the recovery of "muscle soreness" and function; however, its mean effect is too small to be considered clinically relevant. Moreover, there is inconclusive evidence to support the use of cryotherapy as well as stretching and low-intensity exercise.

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% (−8.5°)]	Four groups ($n = 10$ per group) performed a 30-min level run on the treadmill in the intensity of 40, 50, 60 & 70% of VO2max. [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 × 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 × 20 maximum contractions at ≈ 300°/s ($n = 5$) [at 24 h post-exercise]	1. Control group ($n = 5$)	1. Muscle strength 2. Muscle soreness [at 24 & 48 h]	Positive for muscle soreness and muscle strength at 48 h 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 × 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 48 h & 96 h 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 400 kg/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 × 6 repetitions maximum contractions]	10 × 60 continuous elbow flexion (240°/s) and extension (210°/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

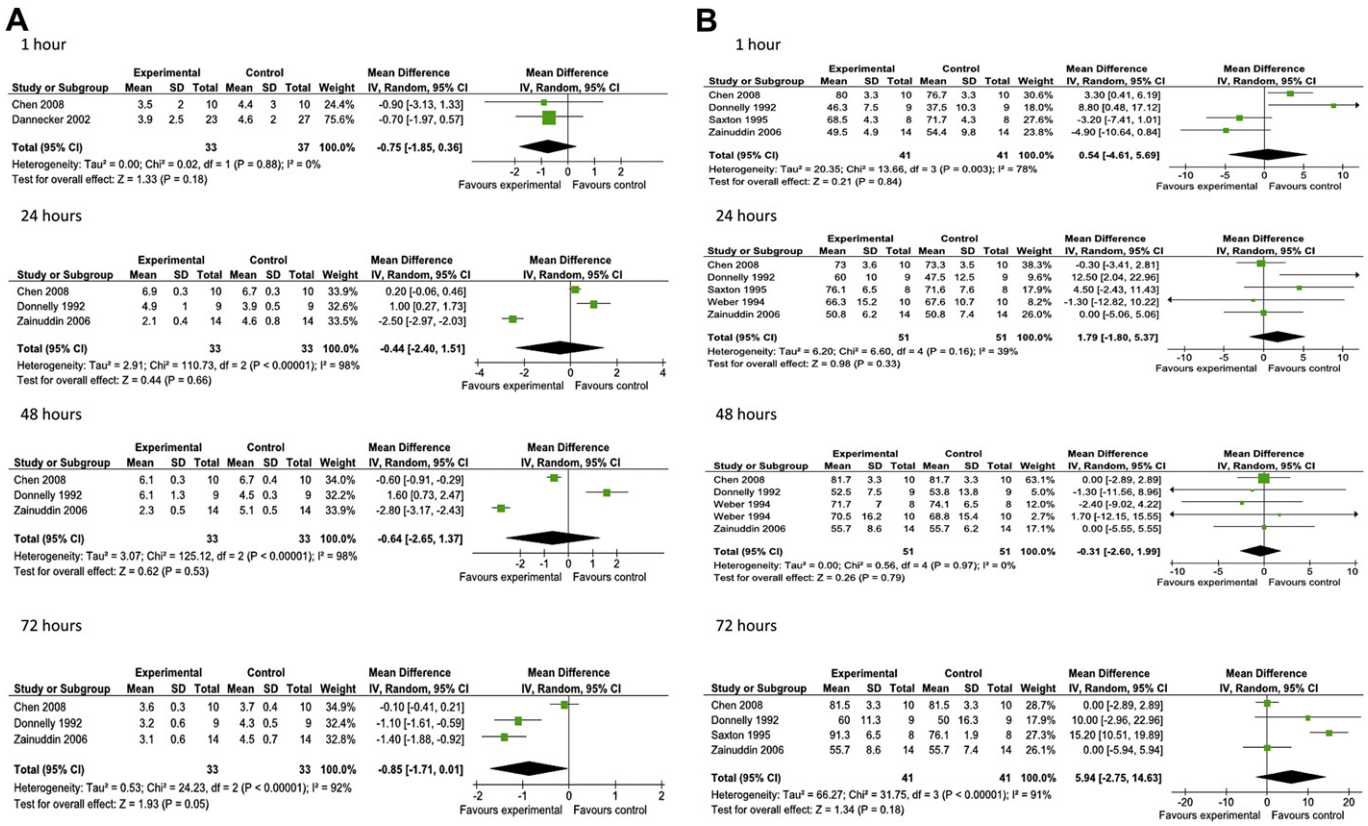

Fig. 5. A – Effects of low-intensity exercise on delayed onset muscle soreness at 1, 24, 48 and 72 hours (Visual Analogue Scale). B – Effects of low-intensity exercise on muscle strength at 1, 24, 48 and 72 hours (Percentage of change to baseline). Note: Effect in favour of the control group means less ability to produce muscle strength thus it should be viewed as a positive effect of low-intensity exercise in the experimental group.

Therefore, all of the modalities may be challenged as contributors in the recovery from muscle damage.

Conflict of interest

None declared.

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