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Are compression garments effective for the recovery of exercise-induced muscle damage? A systematic review with meta-analysis

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ABSTRACT

Purpose
The aim was to identify benefits of compression garments used for recovery of exercised-induced muscle damage.
Methods
Computer-based literature research was performed in September 2015 using four online databases: Medline (PubMed), Cochrane, WOS (Web Of Science) and Scopus. The analysis of risk of bias was completed in accordance with the Cochrane Collaboration Guidelines. Mean differences and 95% confidence intervals were calculated with Hedges' g for continuous outcomes. A random effect meta-analysis model was used. Systematic differences (heterogeneity) were assessed with I^2 statistic.
Results
Most results obtained had high heterogeneity, thus their interpretation should be careful. Our findings showed that creatine kinase (standard mean difference = -0.02, 9 studies) was unaffected when using compression garments for recovery purposes. In contrast, blood lactate concentration was increased (standard mean difference = 0.98, 5 studies). Applying compression reduced lactate dehydrogenase (standard mean difference = -0.52, 2 studies), muscle swelling (standard mean difference = -0.73, 5 studies) and perceptual measurements (standard mean difference = -0.43, 15 studies). Analyses of power (standard mean difference = 1.63, 5 studies) and strength (standard mean difference = 1.18, 8 studies) indicate faster recovery of muscle function after exercise.
Conclusions
These results suggest that the application of compression clothing may aid the recovery of exercise induced muscle damage, although the findings need corroboration.

KEYWORDS
Exercise, metabolism, venous hemodynamic, metabolites, muscle function.

1. INTRODUCTION

Amongst recovery interventions to help improve performance, the use of compression garments (CG) is currently widely used by athletes. These were first used in the medical industry for vascular patients, but their use has become more and more popular in athletes (Duffield & Portus, 2007). However, there are still contrasting results in the literature about the potential benefits of CG on the recovery of physiological parameters and subsequent performance.

Elastic CG externally compress the body through the pressure applied to the skin and musculature, which depends on the mechanical properties of the garment defined by the manufacturer (MacRae et al., 2011). Nevertheless, effective pressure gradients for compression clothes do not seem to have been studied systematically, which is not surprising given the modest effects of CG during or following exercise (MacRae et al., 2011). Furthermore, attention towards understanding the mechanical and physical properties of compression clothes in the published literature is rare (Troynikov et al., 2010), although pressure measurement has become more common in studies on CG in sports (Ali et al., 2010; Trenell et al., 2006).

The increasing popularity of compression clothing in different sports is likely due to their success in enhancing performance (Bringard et al., 2006; Doan et al., 2003) and recovery (Gill et al., 2006; Kraemer et al., 2010). As a result of different findings, manufacturers of these garments have reported that CG improve recovery, increase power and enhance athletic performance (Wallace et al., 2006). But the effects of wearing CG on physiological parameters, sports performance and recovery show equivocal findings (de Glanville & Hamlin, 2012). Graduated CG have been reported to reduce muscle oscillation (Doan et al., 2003), to increase blood flow and blood flow velocity, to improve peripheral circulation and venous return (Agu et al., 2004; Davies et al., 2009; Lawrence & Kakkar, 1980; O´Donnell et al., 1979; Ramelet, 2002; Sigel et al., 1975; Starkey, 2013), to increase arterial perfusion (Bochmann, et al., 2005), and to reduce the space available for swelling (Davies et al., 2009). CG can also enhance recovery by acting on markers of exercise-induced muscle damage (EIMD) such as preventing the temporary reduction in muscle strength, decreased rate of force development, or reduced range of motion (ROM) (Byrne et al., 2004; Cleak & Eston, 1992; Tee et al., 2007). Besides, they can decrease muscle soreness (MS) (Ali et al., 2007; Jakeman et al., 2010a; Kraemer et al, 2001a, 2001b; Kraemer et al., 2010) and enhance the clearance of blood lactate ($[La–]_p$) (Chatard et al., 2004) and creatine kinase (CK-3) (Duffield & Portus, 2007; Gill et al., 2006; Kraemer et al, 2001a; 2001b) following exercise. Nevertheless, others studies found no beneficial effect of CG on speed and explosive performance during recovery (Carling et al., 1995; French et al., 2008; Kraemer et al., 2010), ROM (French et al., 2008; Kraemer et al, 2001a; 2001b), MS (Carling et al., 1995; Davies et al., 2009; French et al., 2008; Trenell et al., 2006), or clearance of $[La–]_p$ (Duffield & Portus, 2007) and CK-3(Davies et al., 2009; French et al., 2008; Jakeman et al., 2010a).

As described above, the benefits of compression clothing on indicators of recovery of EIMD seem to have been demonstrated separately in several studies. Although several meta-analysis have been published to assess the effect of the application of compression clothing on recovery enhancement, they did not take into account the variability of results on muscle damage markers due to time-course (Born et al., 2013) or different muscle damage markers measured in previous researches (Hill et al., 2013). Therefore, the aims for this systematic review with meta-analysis were to review the current literature about the benefits of CG for recovery, identify potential explanatory mechanisms for these results and provide practical recommendations.

2. METHODS

2.1. Data sources

This research was completed in accordance with the recommendations of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement (Moher et al., 2010). A computerized literature search was performed using four online databases: Medline (PubMed), Cochrane, WOS (Web Of Science) and Scopus (ended in September 2015). The following key words used to find relevant papers were: "*clothes*", "*compression*", "*compressive*", "*delayed onset muscle soreness*", "*exercise*", "*exercise induced muscle damage*", "*fatigue*", "*garments*", "*muscle*", "*muscle damage*", "*muscle* *soreness", "post-exercise", "post-game", "recovery", "recovery strategy", "recovery modality", "sports", "stockings"*. The reference sections of all identified articles were also examined.

2.2. Inclusion and exclusion criteria

Studies were included if: 1) participants were randomized into a CG or control group (studies were also included if the same participant had one limb without CG -control group- and the other with CG -CG group-); 2) authors measured at least one variable at baseline and again at least 10 minutes after the exercise bout; 3) CG were worn before and/or during and/or following exercise; 4) participants of the study did not have any cardiovascular, metabolic, or musculoskeletal disorders. Studies were excluded if the experimental group received multiple treatments or the control group undertook any practice that could be perceived to improve recovery, like wearing garments without pressure.

2.3. Study selection

One author selected papers for inclusion (DM). Titles and abstracts of publications obtained by the search strategy were screened. All trials classified as relevant were retrieved and full text was peer-reviewed. Based on the information within the full reports, we used the inclusion and exclusion criteria to select the trials eligible for inclusion in the meta-analysis. Doubts at this stage were resolved by consensus (DM, JC). 48931 records were identified through database searches and 14 studies through reference list searches. 48886 studies were excluded by screening the abstract for inclusion criteria. As a result, 59 studies were assessed for eligibility. Of these studies, 39 were excluded because they were not in accordance with the inclusion criteria. Consequently, 20 studies met the inclusion criteria and were selected for the meta-analysis (Figure 1).

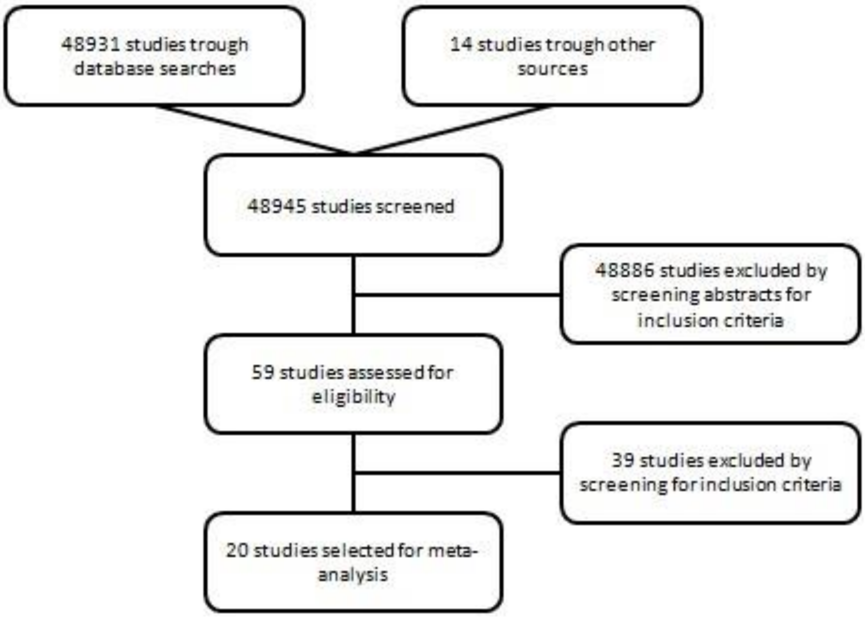


Fig. 1 Summary of search strategy and selection process based on included and excluded studies
1,5 column

2.4. Outcome variables

The literature was examined for the effects of CG on recovery using several outcome variables (reported in Table 1 as recovery indicators). The heterogeneity of the results can be influenced by type, familiarity, intensity and duration of the preceding exercise, duration of compression treatment, pressure applied (mainly reported without being measured by researchers as stated by Hill et al. (2014)), and type of CG. Subjects' characteristics, such as age, gender, body shape and composition, exercise familiarity, differences in training or nutrition status, and ethnicity may also influence the heterogeneity of the results.

2.5. Detail of Comparisons

The characteristics of the participants and the CG, measured variables, and the protocols used in the different studies are in Table 1 (Ali et al., 2007; Berry & McMurray, 1987; Boucourt et al., 2014; Bovenschen et al., 2013; Carling et al., 1995; Davies et al., 2009; Duffield et al., 2008; Duffield et al., 2010; Duffield & Portus, 2007; French et al., 2008; Goto & Morishima, 2014; Jakeman et al., 2010a, 2010b; Kraemer et al, 2001a, 2001b; Ménétrier et al., 2001; Perrey et al., 2008; Rimaud et al., 2010; Sperlich et al, 2013; Trenell et al., 2006). There was a total of 279 participants (n=169 men, n=99 women, and 11 not reported) with a mean and SD age of 23.6±2.99 years. There were important differences in sample size, age, gender and training status of the participants, design of studies, types of CG, time of treatment, and pressures applied.

Table 1. Studies investigating the effect of compression garments on recovery enhancement

	Characteristics of Participants		*Characteristics of Compression Clothing*				
Study	*Sample size, gender, age (y)*	*Athletic category*	*Type*	*Applied pressure (mmHg)*	*Exercise protocol (timing and duration of application)*	*Recovery indicator (time following exercise)*	*Effects of CG*
Ali et al. (2007)	14, M, 22 ± 1	Recreational runners	Knee length stockings (GC)	18-22	2 x20 m. shuttle-runs separated by 1 h. (DE)	MS (1, 24 h.)	↔
						HR (1 h.)	↑
Berry & McMurray (1987)	6, M, 21.9 ± 4.85	Healthy college students	Stockings (GC)	8-18	Study 2: 3-min cycling at 110% VO_2; 30-min. recovery supine (DE, FE for 30 min.; or DE only)	Plasma volume (5, 15, 30 min.)	↔
						[La–]p GCS wore DE, FE (time NR)	↓
						[La–]p GCS wore DE only (time NR)	↔
Boucourt et al. (2014)	11, NR, 29.6 ± 2.8	Athletes	Sleeves	14-28	15 min. incremental cycling exercise: 3 min. at each intensity - 40, 80, 120, 160 and 200 W, preceded and followed by 10 min. in seated position (DE, FE for 10 min.)	stO2 (1 to 10 min.)	↑
Bovenschen et al. (2013)	6, M, 7, F, 40.5 ± 15.8	Recreational runners	Stockings one leg (GC)	25-35	Study 1: 10-km Running Track at comfortable running speed (DE)	MS study 1 and 2 (0, 30 min.; 48 h.)	↔
						Lower leg volume study 1 and 2 (0 min.)	↓
					Study 2: Stepwise, speed incremented (0.5 km/h every 3 min.) maximum treadmill (0%) test (DE)	Lower leg volume study 1 and 2 (5, 30 min.)	↔
Carling et al. (1995)	7, M, 16, F, 26 ± 4	Healthy college students	Sleeves	~ 17	70 maximal eccentric contractions of non-dominant elbow flexors (72 h. FE)	MS (10 min.; 24, 48, 72 h.)	↔
						Arm middle girth (10 min.; 24, 48, 72 h.)	↔
						Arm volume (10 min; 24, 48, 72 h.)	↔
						Maximal concentric elbow flexor force (10 min.; 24, 48, 72 h.)	↔
						Elbow extensor ROM (10 min.; 24, 48, 72 h.)	↔
Davies et al. (2009)	7, F, 19.7 ± 0.5 4, M, 26.3 ± 5.1	University netball and basketball players	Tights (GC)	15	5x20 plyometric drop jumps with 2-min. rest between sets (48 h. FE)	MS (24, 48 h.)	↔
						[CK-3] (24, 48 h.)	↔
						[LDH-5] (24, 48 h.)	↔
						Mid-thigh girth (24, 48 h.)	↔
						CMJ height (48 h.)	↔
						5-, 10-, 20-m sprint (48 h.)	↔
						5–0–5 agility (48 h.)	↔
Duffield et al. (2010)	11, M, 20.9 ± 2.7	Regional rugby players	Tights	NR	Intermittent sprinting - 10 min: 1x20-m sprint and 10 SJs/min. (DE, 24 h. FE)	MS (2 h.)	↔
						MS (24 h.)	↓
						RPE (0 h.)	↔
						pH (0, 2 h.)	↔
						[La–]p (0, 2 h.)	↔
						[CK-3] (2, 24 h.)	↔
						[C-RP]p (2, 24 h.)	↔
						[AST]p (2 h.)	↔
						[AST]p (24 h.)	↓
						Peak quadriceps extension force (0, 2, 24 h.)	↔
						Peak flexion of hamstrings (0, 2, 24 h.)	↔
						Knee extensor peak twitch force (0, 2, 24 h.)	↔

Duffield et al. (2008)	14, M, 19 ± 1	Club-standard rugby players U-21 of regional category.	Tights	NR	Simulated team game: 10-20 m. sprints in a simulated rugby game (4x15 min.) (DE, and 15 h. FE)	MS (pre, post day 1, 24 h. post day 1, post day 2, 48-h post-day 2.)	↓
						HR (pre-exercise and every 10 min. throughout the exercise protocol)	↔
						ST (BE, every 10 min. DE and FE)	↑
						TT (BE, every 10 min. DE and FE)	↔
						[La–]p (BE, DE and 10, 15 min. FE both days)	↔
						[CK-3] (BE , post day 1, 24 h. post day 1, 48-h. post-day 2)	↔
						Peak power (BE and after 2nd and 4th quarters of STG at day 1 and day 2)	↔
						20 m sprint (BE and after 2nd and 4th quarters of STG at day 1 and day 2)	↔
Duffield & Portus (2007)	10, M, 22.1 ± 1.1	Regional cricket players	WBC	NR	Maximal-distance throwing; throwing accuracy; intermittent sprinting: 20-m sprints/min. for 30 min. (DE, and 24 h. FE)	MS, arms (24 h.)	↓
						MS, legs (24 h.)	↓
						RPE (0 h.)	↔
						HR (0 h.)	↔
						Body mass (0 h.)	↔
						ST (0 h.)	↑
						pH (0 h.)	↔
						[La–]p (0 h.)	↔
						[CK-3] (24 h.)	↓
						SaO2 (0 h.)	↔
						pO2 (0 h.)	↔
French et al. (2008)	26, M, 24.12 ± 3.2	Active	Tights (GC)	12-20	6x10 parallel squats at 100% BW + 11th repetition at 1-RM (12 h. FE)	MS (0, 1, 24, 48 h.)	↔
						[CK-3] (1, 24, 48 h.)	↔
						[Mb]p (1, 24, 48 h.)	↔
						Mid-thigh girth (48 h.)	↔
						Mid-calf girth (48 h.)	↔
						CMJ height (48 h.)	↔
						5RM back squat (48 h.)	↔
						10 m sprint (48 h.)	↔
						30 m sprint (48 h.)	↓
						Multiplanar speed (48 h.)	↔
						Ankle dorsiflexion (0 h.)	↔
						Knee extension (0 h.)	↔
						Knee flexion (0 h.)	↔
						Hip extension (0 h.)	↔
						Hip flexion (0 h.)	↔
						Hip abduction (0 h.)	↔
Goto & Morishima (2014)	9, M, 21± 0.4	Trained in endurance	WBC	NR	6 exercises set for upper body muscles and 3 exercises set for lower body muscles with 10 repetitions at 70%RM with 90 s between sets and exercises.	MS (24 h.)	↓
						[Mb]p (1, 3, 5, 8, 24 h.)	↔
						[T]p (1, 3, 5, 8, 24 h.)	↔
						[IGF-1]p (1, 3, 5, 8, 24 h.)	↔
						[IL-6]p (1, 3, 5, 8, 24 h.)	↔
						[IL-1ra]p (1, 3, 5, 8, 24 h.)	↔

						Upper arm girth (24 h.)	↓
						Tigh girth (24 h.)	↓
						Knee extensor isokinetic muscle strength (1, 3, 5, 8, h.)	↔
						Knee extensor isokinetic muscle strength (24 h.)	↑
						RM chest press (1, 24 h.)	↔
						RM chest press (3, 5, 8 h.)	↑
Jakeman et al. (2010a)	17, F, 21.4 ± 1.7	Physically active	Tights (GC)	15-17	10x10 repetitions of plyometric drop jumps from a 0.6 m. box. 10 s. between jumps, 1 min. between sets (12 h. FE)	MS (1, 24, 48, 72 h.)	↓
						MS (96 h.)	↔
						[CK-3] (1, 24, 48, 72, 96 h.)	↔
						CMJ height (1, 24, 72, 96 h.)	↔
						CMJ height (48 h.)	↑
						SJ height (1 h.)	↔
						SJ height (24, 48, 72, 96 h.)	↑
						Knee extensor isokinetic muscle strength (1 h.)	↔
						Knee extensor isokinetic muscle strength (24, 48, 72, 96 h.)	↑
Jakeman et al. (2010b)	32, F, 21.4 ± 1.7	Physically active	Tights (GC)	15-17	10x10 repetitions of plyometric drop jumps from a 0.6 m. box. 10 s. between jumps, 1 min. between sets (12h FE)	MS (1, 24, 48, 72 h.)	↓
						MS (96 h.)	↔
						[CK-3] (1, 24, 48, 72, 96 h.)	↔
						CMJ height (1, 24, 48, 96 h.)	↔
						CMJ height (72h.)	↑
						SJ height (1, 24, 48, 72, 96 h.)	↑
						Knee extensor isokinetic muscle strength (1 h.)	↔
						Knee extensor isokinetic muscle strength (24, 48, 72, 96 h.)	↑
Kraemer et al. (2001a)	20, F, 21.2 ± 3.1	Non-strength-trained women without any resistance training	Sleeves (GC)	10	2x50 arm curls repetitions, with maximal a eccentric contraction every fourth passive repetition, with 3 min. rest between set (120 h. FE)	Global MS (24, 48, 72 h.)	↔
						Global MS (96, 120 h.)	↓
						[CK-3] (24, 48 h.)	↓
						[CK-3] (72, 96, 120 h.)	↔
						[Cortisol]p (24, 48, 72, 96, 120 h).	↔
						[LDH-5] (24, 48, 72, 96, 120 h.)	↔
						Arm girth (24, 48, 72, 96, 120 h.)	↓
						Elbow flexor peak torque (24, 48 h.)	↔
						Elbow flexor peak torque (72, 96, 120 h.)	↑
						Elbow flexor peak power (24, 48 h.)	↔
						Elbow flexor peak power (72, 96, 120 h.)	↑
						ROM resting elbow angle (24, 48, 72, 96, 120 h.)	↓
Kraemer et al. (2001b)	15, M, 21.2 ± 3.1	Non-strength-trained men	Sleeves (GC)	10	2x50 arm curls repetitions, with maximal a eccentric contraction every fourth passive repetition, with 3 min. rest between set (72 h. FE)	Global MS (24, 48 h.)	↑
						Global MS (72 h.)	↓
						[CK-3] (24, 48 h.)	↔
						[CK-3] (72 h.)	↓
						Arm girth (24, 48 h.)	↓
						Arm girth (72 h.)	↔

						Elbow flexor peak torque (24, 48 h.) Elbow flexor peak torque (72 h.) Elbow flexor peak power (24, 48, 72 h.) ROM resting elbow angle (24 h.) ROM resting elbow angle (48, 72 h.)	↑ ↔ ↑ ↔ ↑
Ménétrier et al. (2011)	14, M, 21.9 ± 0.7	Moderately trained in endurance	Stockings (GC)	15-27	15 min at rest, 30 min at 60% MAV on a 12% treadmill slope, 15 min. of recovery, a running time to exhaustion at 100% MAV on a 12% treadmill slope, and a last 30 min. recovery period (DE, and 30 min. FE)	StO2 (5, 10 min. following 1st trial; 5 min. following 2nd trial) StO2 (BE, 10, 20, 30 min. following 2nd trial)	↔ ↑
Perrey et al. (2008)	8, M, 26 ± 4	Healthy and physically active	Stockings one leg	NR	Backwards-downhill walking for 30 min. (5 h. per day at 2, 24, 48 and 72 h. FE)	MS (0, 2, 24, 48, h.) MS (72 h.) Peak torque twitch of plantar flexors (2, 48, 72 h.) Peak torque twitch of plantar flexors (24 h.) Peak voluntary torque of plantar flexors (2, 24, 48, 72 h.)	↔ ↓ ↔ ↑ ↔
Rimaud et al. (2010)	8, M, 27.1 ± 0.9	Regularly trained in endurance	Stockings (GC)	12-22	Incremental cycling test. Work rate was increased every 2 min. by 30 W until exhaustion, followed by 60 min. of passive recovery seated on a chair (DE, and 60 min. FE)	RPE (0 h.) HR (0 and during 15 min of recovery) SBP (0, 3, 5, 10, 15, 30, 60 min.) DBP (0, (3, 5, 10, 15, 30, 60 min.) [La–]p (0 h.) [La–]p (3, 5, 10, 15, 30, 60 min.) VO2max (0 h.)	↔ ↔ ↔ ↔ ↑ ↔ ↔
Sperlich et al. (2013)	6, M, 22 ± 2	Healthy men.	Shorts (GC) one leg	35	10-min. warm-up at 100W, high intensity cycling to exhaustion (+25 W/min), 1 min. of recovery followed by cycling at 75% of VO2max (20 min. BE and 40 min. FE)	MBF (30 min.) MGU (30 min.)	↓ ↔
Trenell et al. (2006)	11, M, 21.2 ± 3.1	Recreational athletes	Tights (GC) one leg	NR	Downhill walking protocol for 30 min. on a treadmill: 6 km·h-1, 25% grade (48 h. FE)	MS (1, 48 h.) pH (1, 48 h.) PCr/Pi (1, 48 h.) [Mg2+] (1, 48 h.) [PDE] (1h.) [PDE] (48 h.) [PME] (1, 48 h.)	↔ ↔ ↔ ↔ ↑ ↔ ↔

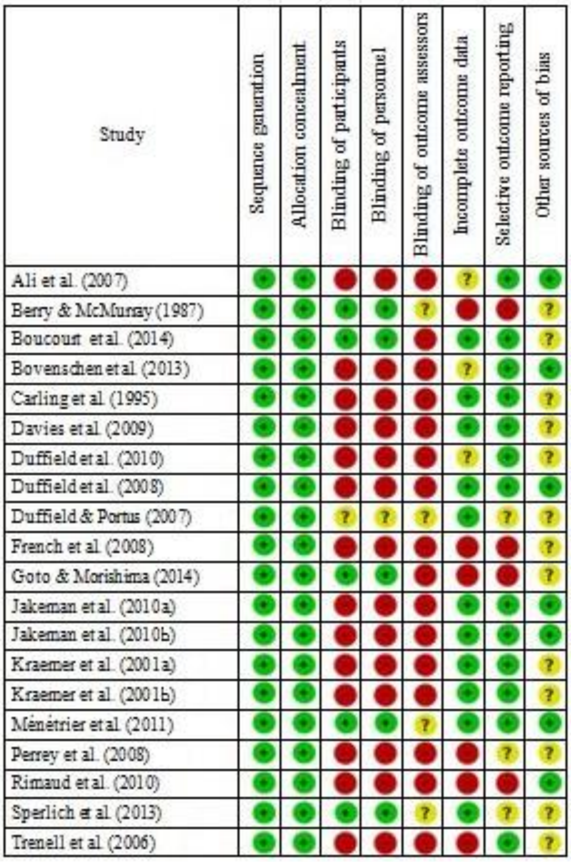
AST = aspartate transaminase; *BE* = before exercise ; *BW* = body weigh; *CK* = creatine kinase; *CMJ* = countermovement jump; *C-RP* = c-reactive protein; *DE* = during main exercise protocol; *DBP* = diastolic blood pressure; *F* = female; *FE* = following exercise; *GC* = graduated compression; *HR* = heart rate; *IGF-1* = insulin-like growth factor-1; *IL-1ra* = plasma interleukin-1 receptor antagonist; *IL-6* = plasma interleukin-6; *La–* = lactate; *LDH* = lactate dehydrogenase; *M* = male; *MAV* = maximal aerobic velocity; *Mb* = myoglobin; *MBF* = muscle blood flow; *MGU* = muscle glucose uptake; Mg^{2+} = magnesium; *NR* = not reported; $_P$ = plasma; *PCr* = phosphocreatine; *PDE* = phosphodiester; *pH*; *Pi* = inorganic phosphate; *PME* = phosphomonoester; pO_2 = oxygen partial pressure; *ROM* = range of motion; *RPE* = rating of perceived exertion; *RM* = repetition maximum; *SBP* = systolic blood pressure; *SJ* = squat jump; SaO_2 = oxygen saturation of haemoglobin; StO_2 = tissue oxygen saturation; *ST* = skin temperature; *T* = testosterone; *TT* = tympanic temperature; VO_2 = oxygen uptake; VO_2max = maximal VO_2; *WBC* = whole-body compression; ↑ indicates significantly higher than the no CG (control) condition; ↓ indicates significantly lower than the no CG (control) condition; ↔ indicates not significantly different from the no CG (control) condition; % indicates percentage; ~ indicates approximately; *[]* indicates concentration.

2.6.Extraction of data

Mean, standard deviation (SD) and sample size (SS) data were extracted by one author from tables of all included papers. Whenever necessary we made contact with the authors to get the data. When it was impossible, mean and SD were extrapolated from the figures. Some studies mentioned analysis of various outcomes without reporting them in graphs, or sending them to us on request. In these cases data were excluded from the analysis. Any disagreement was resolved by consensus (DM, JC), or third-party adjudication (NT).

2.7.Risk of bias

Methodological quality and risk of bias were assessed by two authors independently (DM, JC), and disagreements were resolved by third part evaluation (NT), in accordance with the Cochrane Collaboration Guidelines (Higgins & Green, 2008). The items on the list were divided into six domains: selection bias (random sequence generation, allocation concealment); performance bias (blinding of participants and researchers); detection bias (blinding of outcome assessment); attrition bias (incomplete outcome data); reporting bias (selective reporting); and other bias. For each research, domains were judged by consensus (DM, JC), or third-party adjudication (NT). They were characterized as ‘low’ if criteria for a low risk of bias were met (plausible bias unlikely to seriously alter the results) or ‘high’ if criteria for a high risk of bias were met (plausible bias that seriously weakens confidence in the results). If the risk of bias was unknown, it was considered ‘unclear’ (plausible bias that raises some doubt about the results). Full details are given in Figure 2 and Figure 3.



Study	Sequence generation	Allocation concealment	Blinding of participants	Blinding of personnel	Blinding of outcome assessors	Incomplete outcome data	Selective outcome reporting	Other sources of bias
Ali et al. (2007)	+	+	−	−	−	?	+	+
Berry & McMurray (1987)	+	+	+	+	?	−	−	?
Boucourt et al. (2014)	+	+	+	+	−	+	+	?
Bovenschen et al. (2013)	+	+	−	−	−	?	+	+
Carling et al. (1995)	+	+	−	−	−	+	+	?
Davies et al. (2009)	+	+	−	−	−	+	+	?
Duffield et al. (2010)	+	+	−	−	−	?	+	?
Duffield et al. (2008)	+	+	−	−	−	+	+	+
Duffield & Portus (2007)	+	+	?	?	?	+	?	?
French et al. (2008)	+	+	−	−	−	−	−	?
Goto & Morishima (2014)	+	+	+	+	−	−	−	?
Jakeman et al. (2010a)	+	+	−	−	−	+	+	+
Jakeman et al. (2010b)	+	+	−	−	−	+	+	+
Kraemer et al. (2001a)	+	+	−	−	−	+	+	?
Kraemer et al. (2001b)	+	+	−	−	−	+	+	?
Ménétrier et al. (2011)	+	+	+	+	?	+	+	+
Perrey et al. (2008)	+	+	−	−	−	−	?	?
Rimaud et al. (2010)	+	+	−	−	−	−	−	+
Sperlich et al. (2013)	+	+	+	+	?	+	?	?
Trenell et al. (2006)	+	+	−	−	−	−	+	?

Fig. 2 Risk of bias graph: review authors’ judgements about each risk of bias item presented as percentages across all included studies. (green) indicate low risk of bias; (?) indicate unknown risk of bias; (red) indicate high risk of bias

1 column

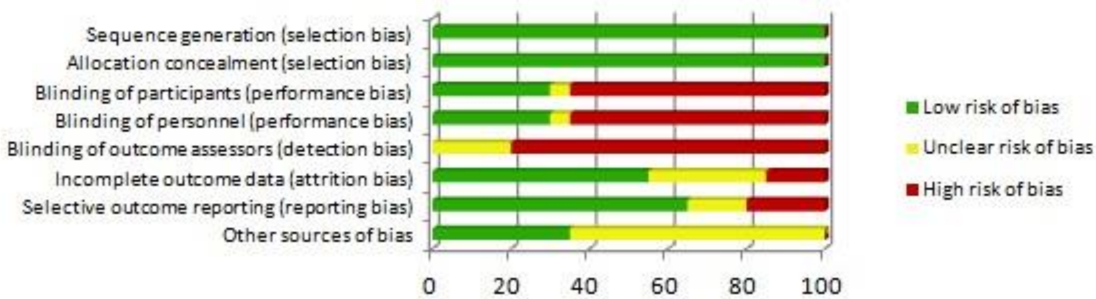


Fig. 3 Risk of bias summary: review authors' judgements about each risk of bias item for each included study
2 column

2.8.Statistical analysis

SS and data variance can influence the discussion of the practical applications of statistical significance when comparing the data of control and experimental groups. Effect size (ES) quantifies the size of the difference between two groups, and may be a true measure of the significance of the difference (Coe, 2002). For each study, mean differences and 95% confidence intervals (CI) were calculated with Hedges' g (Hedges & Olkin, 1985) for continuous outcomes. For continuous outcomes pooled on different scales, data were modified to fit the same scale. Hedges' g was computed using the difference between means of an experimental (compression) and control (non compression) group divided by the average population SD (Higgins & Green, 2008). Hedges' g can be small (<0.40), moderate (0.40–0.70) or large (>0.70) (Hedges & Olkin, 1985). To avoid problems using Q statistic to assess systematic differences (heterogeneity), we calculated an I^2 statistic, which indicates the percentage of observed total variation across studies that is due to real heterogeneity rather than chance (Higgins & Green, 2008). I^2 interpretation is intuitive and lies between 0% and 100%, 0% indicating no observed heterogeneity, and larger values showing increasing heterogeneity (Higgins et al., 2003). A restrictive categorization of values for I^2 would not be appropriate for all circumstances, although we would tentatively accept adjectives of low, moderate, and high to I^2 values of 25%, 50%, and 75% (Borenstein et al., 2009; Higgins & Thompson, 2002; Higgins et al., 2003). Because several studies did not use a control group, but instead a control (no treatment) vs. experimental condition comparison within the same subjects, we used a random effect meta-analysis model. The random effect model will tend to give a more conservative estimate (i.e. with wider confidence intervals), but the results from the two models usually agree when there is no heterogeneity. Under the random effect model the true effects in the studies are assumed to vary between studies and the summary effect is the weighted average of the effects reported in the different studies (Borenstein et al., 2009). In addition, weighting of the studies was applied according to the magnitude of the respective standard error. A significance level of $p \leq 0.05$ was applied. Statistical analysis and figures were carried out by Review Manager version 5.3.5 (The Nordic Cochrane Centre, The Cochrane Collaboration, Copenhagen, Denmark) and statistical analyses and figures of risk of bias were carried out by Microsoft Office Excel 2010.

3. RESULTS

3.1.Physiological and Physical Effects

We identified five studies that determined the effect of CG (stockings, tights and WBC) on $[La–]_p$ removal following exercise (Berry & McMurray, 1987; Duffield et al., 2008, 2010; Duffield & Portus, 2007; Rimaud et al., 2010) at an average pressure of 10-20 mmHg (range 8-18 – 12-22). These studies included 52 male (22.04 ± 2.11 years) recreational runners, regularly trained in endurance, regional rugby and cricket players and healthy college students. The analysis showed large negative effects on $[La–]_p$ removal following exercise (Figure 4) with a weighted small standard mean difference of 0.98 at all follow-up times, smaller than results reported at 0 hour (1.07).

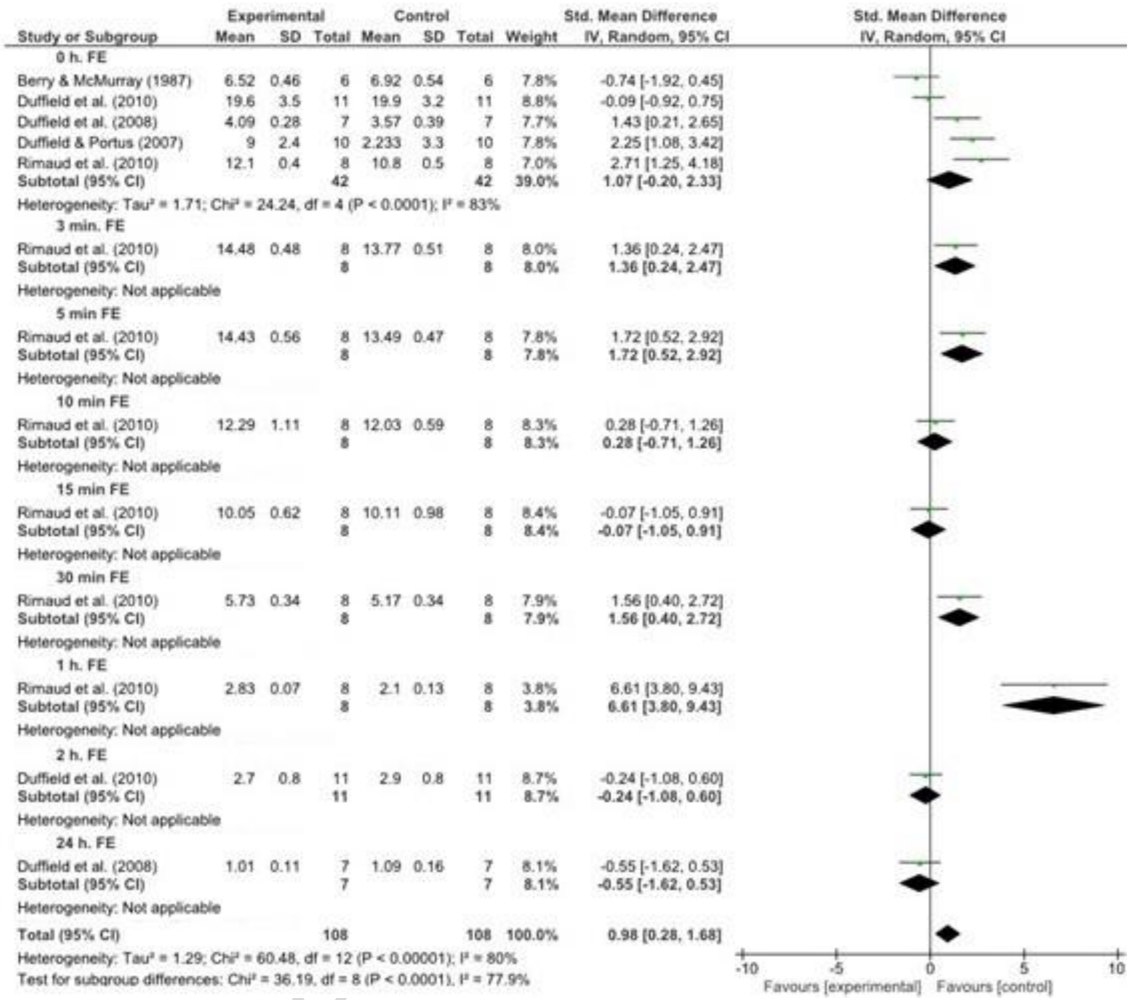
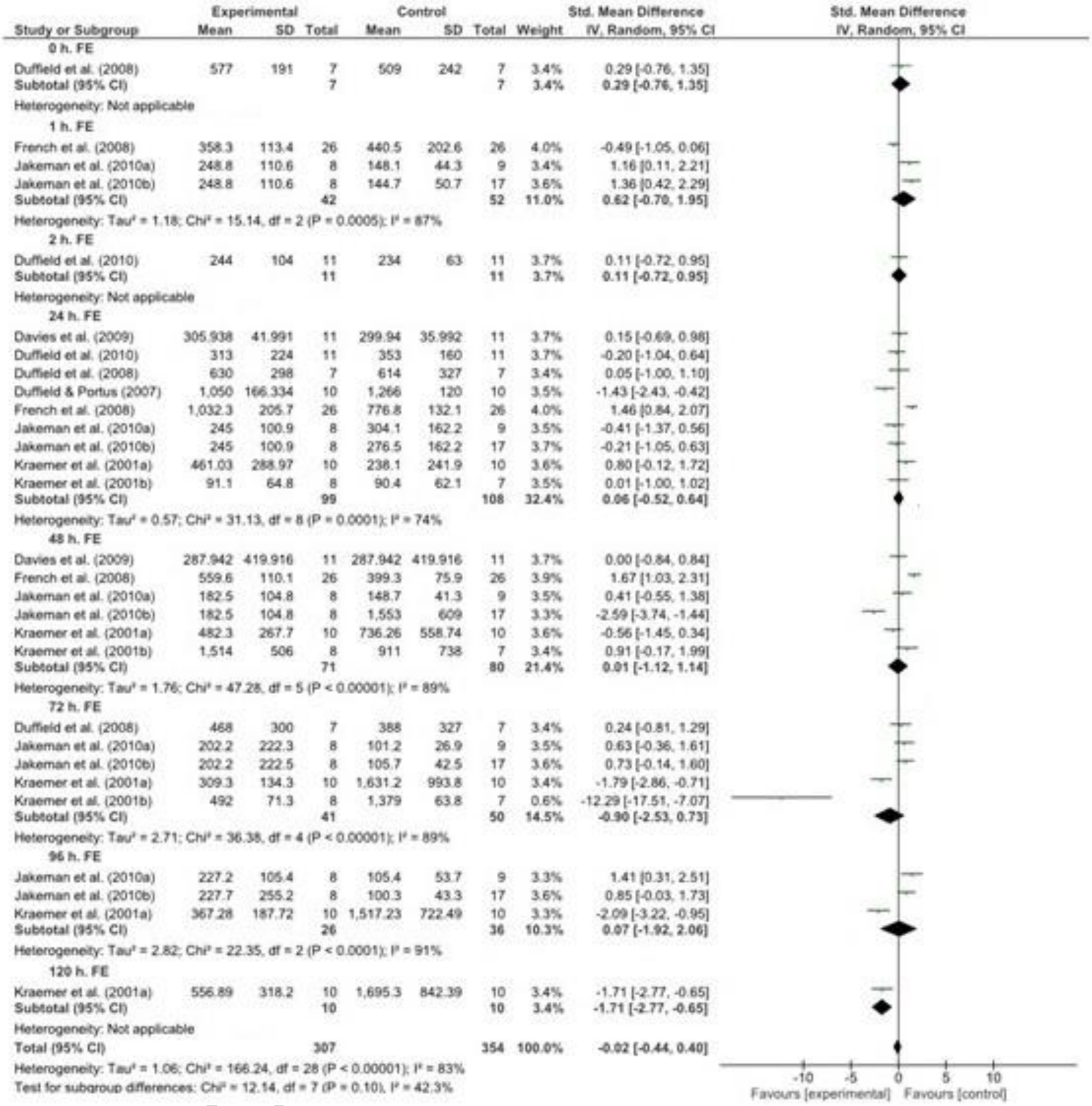


Fig. 4 Forest plot representing a comparison between the use of a CG and a control for measures of $[La^{-}]_p$

2 column

The search identified nine studies that examined the potential benefits of compression (stockings, tights, sleeves and WBC) on CK-3 removal (Davies et al., 2009; Duffield et al., 2008, 2010; Duffield & Portus, 2007; French et al., 2008; Jakeman et al., 2010a, 2010b; Kraemer et al., 2001a, 2001b) at an average pressure of 12.4-14.4 mmHg (range 10-10 – 12-20) in 80 male and 76 female (N = 156). These studies included participants ranging in experience from university and regional levels to non-strength-trained men and women or active people (21.65 ± 2.32 years), representing a variety of disciplines (rugby, cricket, netball and basketball). The use of CG had a small reduction on CK-3 concentrations following exercise (Figure 5). The analysis showed a weighted small standard mean difference of -0.02 at all follow-up times. At 1, 24, 48 and 96 hours following exercise, results shows a moderate increase (0.62 at 1 hour; 0.06 at 24 hours; 0.01 at 48 hours; 0.07 at 96 hours), although at 72 hours following exercise results are favorable to treatment (-0.90)



Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
0 h. FE								
Duffield et al. (2008)	577	191	7	509	242	7	3.4%	0.29 [-0.76, 1.35]
Subtotal (95% CI)			7			7	3.4%	0.29 [-0.76, 1.35]
Heterogeneity: Not applicable								
1 h. FE								
French et al. (2008)	358.3	113.4	26	440.5	202.6	26	4.0%	-0.49 [-1.05, 0.06]
Jakeman et al. (2010a)	248.8	110.6	8	148.1	44.3	9	3.4%	1.16 [0.11, 2.21]
Jakeman et al. (2010b)	248.8	110.6	8	144.7	50.7	17	3.6%	1.36 [0.42, 2.29]
Subtotal (95% CI)			42			52	11.0%	0.62 [-0.70, 1.95]
Heterogeneity: Tau² = 1.18; Chi² = 15.14, df = 2 (P = 0.0005); I² = 87%								
2 h. FE								
Duffield et al. (2010)	244	104	11	234	63	11	3.7%	0.11 [-0.72, 0.95]
Subtotal (95% CI)			11			11	3.7%	0.11 [-0.72, 0.95]
Heterogeneity: Not applicable								
24 h. FE								
Davies et al. (2009)	305.938	41.991	11	299.94	35.992	11	3.7%	0.15 [-0.69, 0.98]
Duffield et al. (2010)	313	224	11	353	160	11	3.7%	-0.20 [-1.04, 0.64]
Duffield et al. (2008)	630	298	7	614	327	7	3.4%	0.05 [-1.00, 1.10]
Duffield & Portus (2007)	1,050	166.334	10	1,266	120	10	3.5%	-1.43 [-2.43, -0.42]
French et al. (2008)	1,032.3	205.7	26	776.8	132.1	26	4.0%	1.46 [0.84, 2.07]
Jakeman et al. (2010a)	245	100.9	8	304.1	162.2	9	3.5%	-0.41 [-1.37, 0.56]
Jakeman et al. (2010b)	245	100.9	8	276.5	162.2	17	3.7%	-0.21 [-1.05, 0.63]
Kraemer et al. (2001a)	461.03	288.97	10	238.1	241.9	10	3.6%	0.80 [-0.12, 1.72]
Kraemer et al. (2001b)	91.1	64.8	8	90.4	62.1	7	3.5%	0.01 [-1.00, 1.02]
Subtotal (95% CI)			99			108	32.4%	0.06 [-0.52, 0.64]
Heterogeneity: Tau² = 0.57; Chi² = 31.13, df = 8 (P = 0.0001); I² = 74%								
48 h. FE								
Davies et al. (2009)	287.942	419.916	11	287.942	419.916	11	3.7%	0.00 [-0.84, 0.84]
French et al. (2008)	559.6	110.1	26	399.3	75.9	26	3.9%	1.67 [1.03, 2.31]
Jakeman et al. (2010a)	182.5	104.8	8	148.7	41.3	9	3.5%	0.41 [-0.55, 1.38]
Jakeman et al. (2010b)	182.5	104.8	8	1,553	609	17	3.3%	-2.59 [-3.74, -1.44]
Kraemer et al. (2001a)	482.3	267.7	10	736.26	558.74	10	3.6%	-0.56 [-1.45, 0.34]
Kraemer et al. (2001b)	1,514	506	8	911	738	7	3.4%	0.91 [-0.17, 1.99]
Subtotal (95% CI)			71			80	21.4%	0.01 [-1.12, 1.14]
Heterogeneity: Tau² = 1.76; Chi² = 47.28, df = 5 (P < 0.00001); I² = 89%								
72 h. FE								
Duffield et al. (2008)	468	300	7	388	327	7	3.4%	0.24 [-0.81, 1.29]
Jakeman et al. (2010a)	202.2	222.3	8	101.2	26.9	9	3.5%	0.63 [-0.36, 1.61]
Jakeman et al. (2010b)	202.2	222.5	8	105.7	42.5	17	3.6%	0.73 [-0.14, 1.60]
Kraemer et al. (2001a)	309.3	134.3	10	1,631.2	993.8	10	3.4%	-1.79 [-2.86, -0.71]
Kraemer et al. (2001b)	492	71.3	8	1,379	63.8	7	0.6%	-12.29 [-17.51, -7.07]
Subtotal (95% CI)			41			50	14.5%	-0.90 [-2.53, 0.73]
Heterogeneity: Tau² = 2.71; Chi² = 36.38, df = 4 (P < 0.00001); I² = 89%								
96 h. FE								
Jakeman et al. (2010a)	227.2	105.4	8	105.4	53.7	9	3.3%	1.41 [0.31, 2.51]
Jakeman et al. (2010b)	227.7	255.2	8	100.3	43.3	17	3.6%	0.85 [-0.03, 1.73]
Kraemer et al. (2001a)	367.28	187.72	10	1,517.23	722.49	10	3.3%	-2.09 [-3.22, -0.95]
Subtotal (95% CI)			26			36	10.3%	0.07 [-1.92, 2.06]
Heterogeneity: Tau² = 2.82; Chi² = 22.35, df = 2 (P < 0.0001); I² = 91%								
120 h. FE								
Kraemer et al. (2001a)	556.89	318.2	10	1,695.3	842.39	10	3.4%	-1.71 [-2.77, -0.65]
Subtotal (95% CI)			10			10	3.4%	-1.71 [-2.77, -0.65]
Heterogeneity: Not applicable								
Total (95% CI)			307			354	100.0%	-0.02 [-0.44, 0.40]
Heterogeneity: Tau² = 1.06; Chi² = 166.24, df = 28 (P < 0.00001); I² = 83%								
Test for subgroup differences: Chi² = 12.14, df = 7 (P = 0.10), I² = 42.3%								

Fig. 5 Forest plot representing a comparison between the use of a CG and a control for measures of CK-3
2 column

We identified two studies that examined the effect of compression (tights and sleeves) on lactate dehydrogenase (LDH-5) (Davies et al., 2009;Kraemer et al., 2001a) at an average pressure of 12.5 mmHg (range 10 – 15), in 4 male and 27 female (N = 31) university netball and basketball players and non-strength-trained women (22,4 ± 2.9 years). Figure 6 shows the meta-analysis of the effects of compression treatment, with a weighted mean small standard mean difference of -0.52 at all follow-up times. Although LDH-5 removal seems to be negative at 24 hours following exercise (0.65), results are in favor of compression at any time point after then.

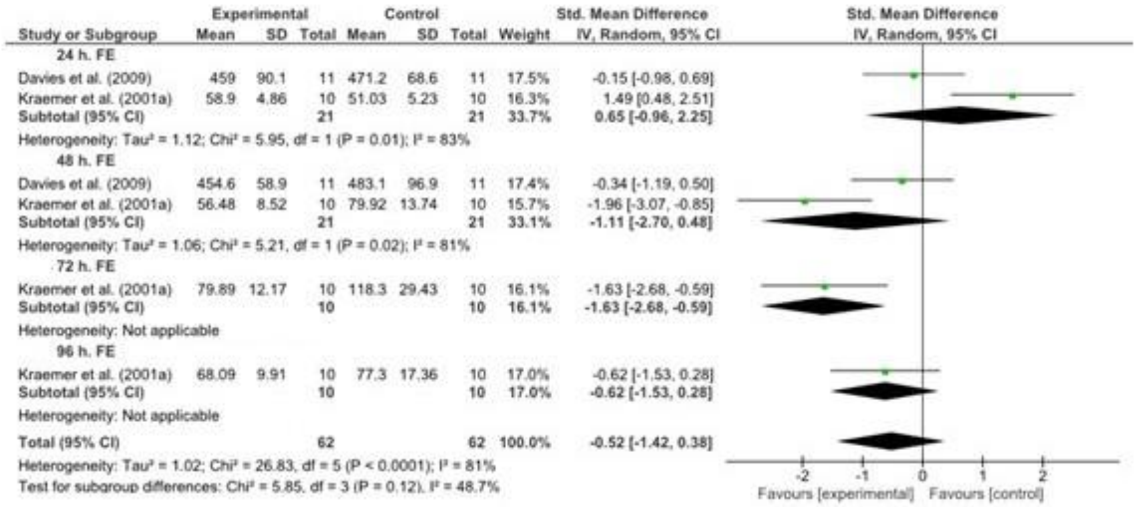


Fig. 6 Forest plot representing a comparison between the use of a CG and a control for measures of LDH-5
2 column

The search identified five studies that examined the use of compression (stockings, tights and sleeves) to reduce muscle swelling of the limbs (Bovenschen et al., 2013; Carling et al., 1995; Davies et al., 2009; Kraemer, et al., 2001a, 2001b) at an average pressure of 15.4-17.4 mmHg (range 10 – 25-35), in 32 male and 50 female (N = 82). These studies included participants ranging in experience from university level (basketball, netball) to non-strength-trained men and women or recreational runners (25.81 ± 5.26 years). Figure 7 shows the meta-analysis of the effects of the compression treatment, with a weighted mean small standard mean difference of -0.73 at all follow-up times. Results from these studies showed that swelling is reduced with the treatment at all time points (-0.12 at 0 hour; -0.08 at 5 minutes; -0.02 at 30 minutes; -0.56 at 24 hours; -1.01 at 48 hours; -1.22 at 72 hours following exercise)

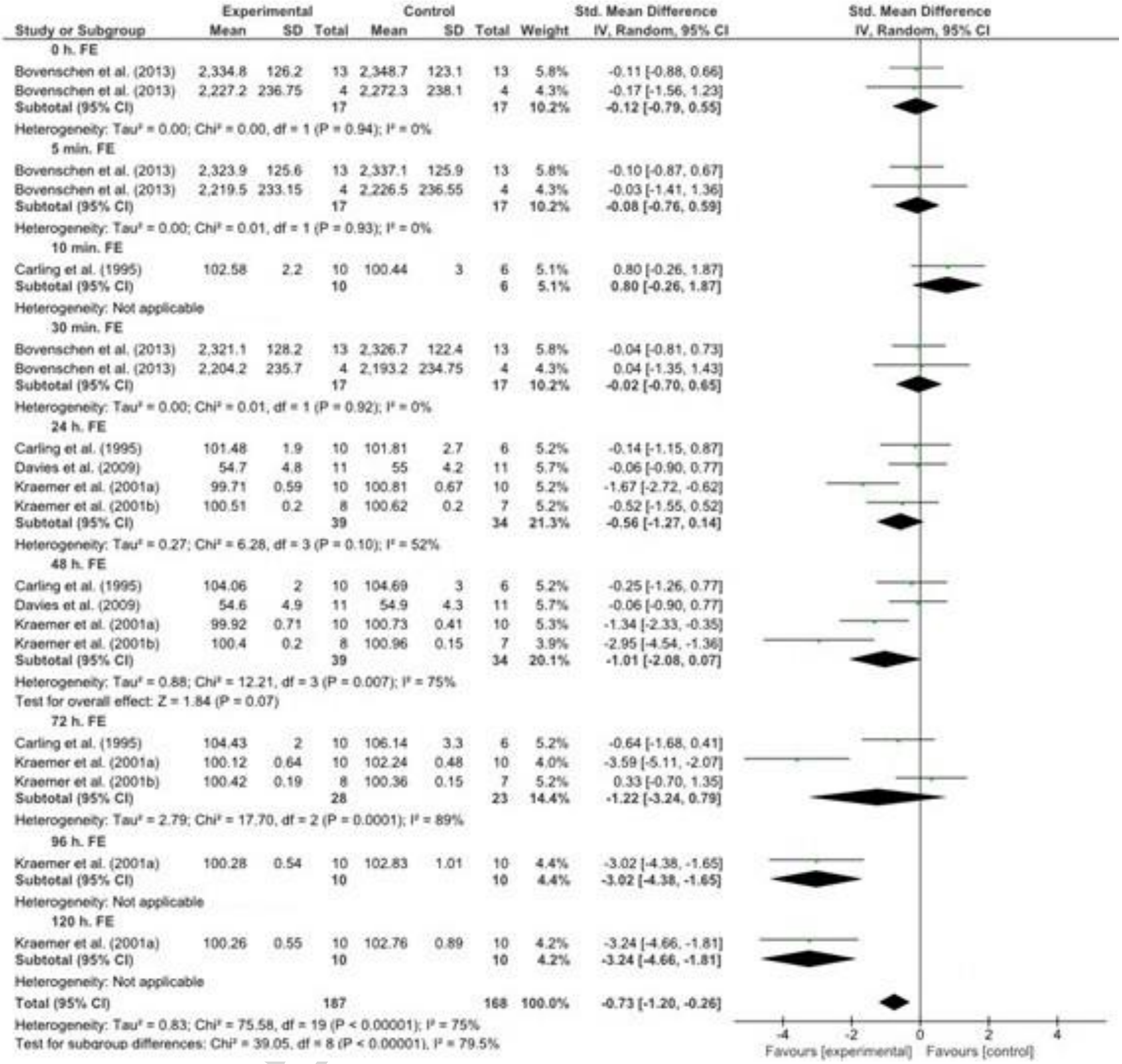


Fig. 7 Forest plot representing a comparison between the use of a CG and a control for measures of muscle swelling
2 column

3.2.Subsequent-Performance Measures.

We included five studies that determined the effect of CG (tights and sleeves) on the recovery of power measured by squat jump, countermovement jump and dynamometer cart peak power (Duffield et al., 2008; Jakeman et al., 2010a, 2010b; Kraemer et al., 2001a, 2001b) at an average pressure of 12.5-13.5 mmHg (range 10 – 15-17) in 29 male and 69 female (N = 98). Participants (20.84 ± 2.12 years) were non-strength-trained men and women, physically active and rugby players of regional category. The analysis showed large and positive effects on the recovery from power tasks (Figure 8) with a weighted mean small standard mean difference of 1.63 at all follow-up times. Results obtained at any time point following exercise were also favorable to the use of CG (0.86 at 1 hour; 1.82 at 24 hours; 2.12 at 48 hours; 2.23 at 72 hours; 1.19 at 96 hours following exercise)

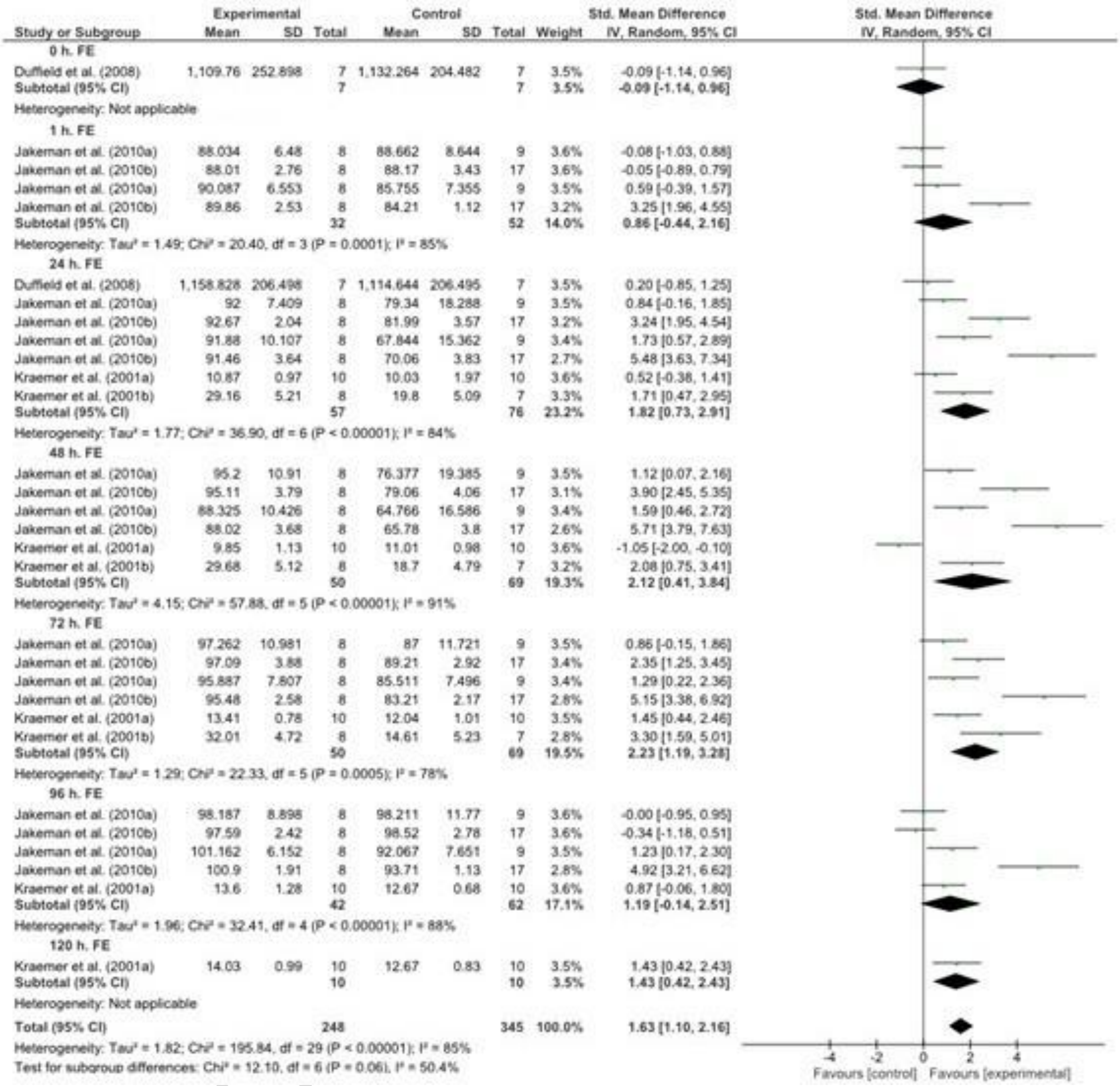


Fig. 8 Forest plot representing a comparison between the use of a CG and a control for measures of muscle power
2 column

We included eight studies that determined the effect of CG (tights and sleeves) on the recovery of muscle strength measured by maximal voluntary contraction, peak torque, isokinetic muscle strength and 1 repetition maximum (RM) (Carling et al., 1995; Duffield et al., 2010; Goto & Morishima, 2014; Jakeman et al., 2010a, 2010b; Kraemer et al., 2001a, 2001b; Perrey et al., 2008) at an average pressure of 13.4-13.8 mmHg (range 10 – 17) in 50 male and 85 female (N = 135). These studies included various participants with experience ranging from college and regional levels to non-strength-trained men and women, active people, or trained in endurance (22,29 ± 2.59 years). Figure 9 shows the meta-analysis of the effects of the compression treatment, with a weighted mean small standard mean difference of 1.18 at all follow-up times. Results obtained at 0 hour following exercise (0.18) and 2 hours following exercise (0.35) indicated small effect on recovery of muscle strength, whereas at 1 (0.92), 3 (2.36), 5 (2.98), 8 (2.88), 24 (1.01), 48 (1.47), 72 (1.57) and 96 hours following exercise (1.88) the effect of the treatment was large.

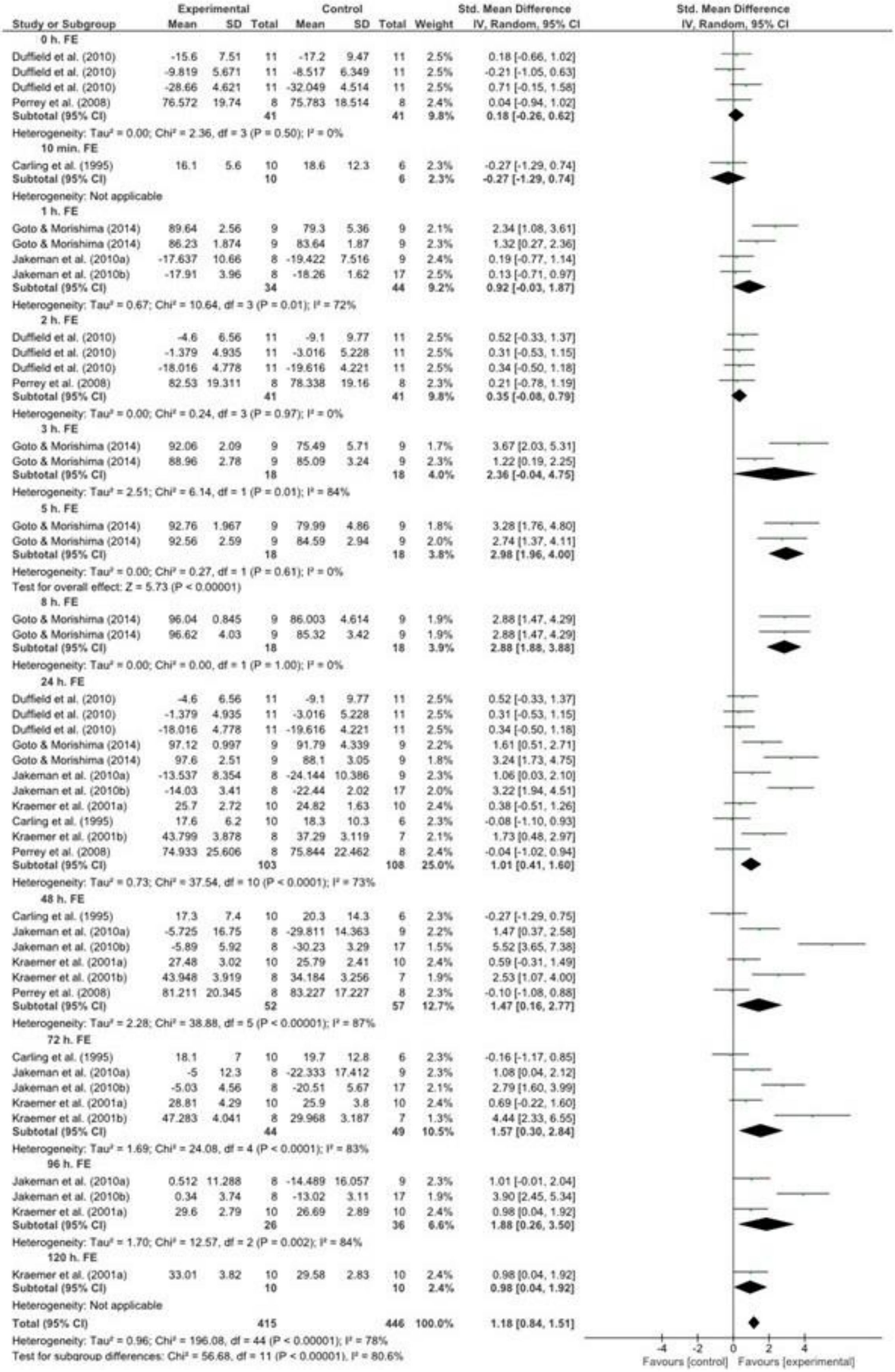


Fig. 9 Forest plot representing a comparison between the use of a CG and a control for measures of muscle strength

2 column

3.3.Perceptual Responses

The search identified fifteen studies that examined the effectiveness of CG (stockings, tights and sleeves) on perceived MS (Ali et al., 2007; Bovenschen et al., 2013; Carling et al., 1995; Davies et al., 2009; Duffield et al., 2008, 2010; Duffield & Portus, 2007; French et al., 2008; Goto & Morishima, 2014; Jakeman et al., 2010a, 2010b; Kraemer et al., 2001a, 2001b; Perrey et al., 2008; Trenell et al., 2006) at an average pressure of 15.3-18.1 mmHg (range 10 – 25-35), in 135 male and 99 female (N = 234). These studies included recreational runners and athletes, active participants, non-strength-trained men and women, healthy college students, university netball and basketball players, U-21 rugby players of regional category, regional cricket players, and people trained in endurance (23.32 ± 3.22 years). Figure 10 shows the meta-analysis of the effects of compression treatment, with a weighted mean small standard mean difference of -0.43 at all follow-up times. Although at 1 h. following exercise (0.15) MS seemed to be increased, results obtained showed that MS was reduced with the treatment (-0.19 at 0 hour; -0.41 at 2 hours; -0.49 at 24 hours; -0.51 at 48 hours; -0.82 at 72 hours; -0.90 at 96 hours following exercise)

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
0 h. FE								
Duffield et al. (2008)	5.5	1.5	7	6.6	1.5	7	1.9%	-0.69 [-1.78, 0.40]
Duffield & Portus (2007)	3.533	1.266	10	4.4	0.9	10	2.1%	-0.76 [-1.67, 0.16]
Duffield & Portus (2007)	3.233	1.133	10	3.9	1.1	10	2.2%	-0.57 [-1.47, 0.33]
French et al. (2008)	7.486	0.719	26	6.824	1.033	26	2.7%	0.73 [0.17, 1.30]
Perrey et al. (2008)	1	0.9	8	1	0.8	8	2.0%	0.00 [-0.98, 0.98]
Subtotal (95% CI)			**61**			**61**	**10.9%**	**-0.19 [-0.87, 0.48]**
Heterogeneity: Tau^2 = 0.39; Chi^2 = 12.20, df = 4 (P = 0.02); I^2 = 67%								
10 min. FE								
Carling et al. (1995)	0.83	0.83	10	1	1	6	2.0%	-0.18 [-1.19, 0.83]
Subtotal (95% CI)			**10**			**6**	**2.0%**	**-0.18 [-1.19, 0.83]**
Heterogeneity: Not applicable								
1 h. FE								
Ali et al. (2007)	2.7	0.36	14	2.7	0.36	14	2.4%	0.00 [-0.74, 0.74]
Ali et al. (2007)	3.6	0.45	14	2.7	0.45	14	2.1%	1.94 [1.02, 2.86]
French et al. (2008)	5.997	1.079	26	5.641	1.173	26	2.7%	0.31 [-0.24, 0.86]
Jakeman et al. (2010a)	1.175	1.264	8	3.244	1.656	9	1.9%	-1.32 [-2.40, -0.24]
Jakeman et al. (2010b)	3.057	2.404	8	2.587	1.222	17	2.2%	0.27 [-0.57, 1.12]
Trenell et al. (2006)	2.3	2.2	11	3.3	2.1	11	2.2%	-0.45 [-1.30, 0.40]
Subtotal (95% CI)			**81**			**91**	**13.6%**	**0.15 [-0.57, 0.87]**
Heterogeneity: Tau^2 = 0.62; Chi^2 = 24.06, df = 5 (P = 0.0002); I^2 = 79%								
2 h. FE								
Duffield et al. (2010)	3.125	2	11	4.625	1.875	11	2.2%	-0.74 [-1.61, 0.13]
Perrey et al. (2008)	0.7	0.9	8	0.7	0.8	8	2.0%	0.00 [-0.98, 0.98]
Subtotal (95% CI)			**19**			**19**	**4.2%**	**-0.41 [-1.13, 0.32]**
Heterogeneity: Tau^2 = 0.05; Chi^2 = 1.24, df = 1 (P = 0.27); I^2 = 19%								
24 h. FE								
Ali et al. (2007)	2.7	0.45	14	2.7	0.63	14	2.4%	0.00 [-0.74, 0.74]
Carling et al. (1995)	2.34	1.17	10	2.5	1.17	6	2.0%	-0.13 [-1.14, 0.88]
Davies et al. (2009)	2.2	1	11	2	1.1	11	2.3%	0.18 [-0.65, 1.02]
Duffield et al. (2010)	3.5	1.625	11	6.125	1.75	11	2.1%	-1.50 [-2.46, -0.53]
Duffield et al. (2008)	6.9	1.6	7	8	1.7	7	1.9%	-0.62 [-1.71, 0.46]
Duffield & Portus (2007)	2.2	0.967	10	3.4	1.1	10	2.1%	-1.11 [-2.07, -0.15]
Duffield & Portus (2007)	1.667	1.2	10	3	1.2	10	2.1%	-1.06 [-2.01, -0.11]
French et al. (2008)	6.548	0.587	26	7.054	0.768	26	2.7%	-0.73 [-1.29, -0.17]
Goto & Morishima (2014)	4.9	6	9	7.3	5	9	2.1%	-0.41 [-1.35, 0.52]
Jakeman et al. (2010a)	4.112	2.25	8	7.04	0.596	9	1.8%	-1.74 [-2.90, -0.58]
Jakeman et al. (2010b)	3.57	1.43	8	5.137	1.56	17	2.2%	-1.00 [-1.89, -0.10]
Kraemer et al. (2001a)	2.05	0.53	10	2.18	0.62	10	2.2%	-0.22 [-1.10, 0.66]
Kraemer et al. (2001b)	3.1	0.55	8	2.2	0.35	7	1.6%	1.81 [0.54, 3.07]
Perrey et al. (2008)	4.5	1.6	8	4.7	1.6	8	2.0%	-0.12 [-1.10, 0.86]
Subtotal (95% CI)			**150**			**155**	**29.3%**	**-0.49 [-0.88, -0.11]**
Heterogeneity: Tau^2 = 0.31; Chi^2 = 31.86, df = 13 (P = 0.003); I^2 = 59%								
48 h. FE								
Carling et al. (1995)	3.83	1.34	10	4.17	1.84	6	2.0%	-0.21 [-1.22, 0.81]
Davies et al. (2009)	2.2	1.1	11	2.6	1.3	11	2.2%	-0.32 [-1.16, 0.52]
French et al. (2008)	6.397	0.58	26	7.167	1.167	26	2.7%	-0.82 [-1.39, -0.26]
Jakeman et al. (2010a)	5.5875	1.745	8	7.4	1.11	9	1.9%	-1.19 [-2.25, -0.14]
Jakeman et al. (2010b)	2.642	1.541	8	6.637	1.358	17	1.8%	-2.73 [-3.90, -1.55]
Kraemer et al. (2001a)	4.22	0.77	10	3.95	1.85	10	2.2%	0.18 [-0.70, 1.06]
Kraemer et al. (2001b)	3.75	0.56	8	3.3	0.5	7	1.9%	0.79 [-0.27, 1.86]
Perrey et al. (2008)	5.4	1.6	8	5.6	1.4	8	2.0%	-0.13 [-1.11, 0.86]
Trenell et al. (2006)	3.5	2.4	11	4.4	2.2	11	2.2%	-0.38 [-1.22, 0.47]
Subtotal (95% CI)			**100**			**105**	**19.0%**	**-0.51 [-1.05, 0.03]**
Heterogeneity: Tau^2 = 0.46; Chi^2 = 25.76, df = 8 (P = 0.001); I^2 = 69%								
72 h. FE								
Carling et al. (1995)	3.83	2.17	10	3.83	2.84	6	2.0%	0.00 [-1.01, 1.01]
Duffield et al. (2008)	2.5	1.7	7	3.5	2.1	7	1.9%	-0.49 [-1.56, 0.58]
Jakeman et al. (2010a)	2.762	1.196	8	4.6	1.434	9	1.9%	-1.31 [-2.39, -0.24]
Jakeman et al. (2010b)	1.971	1.06	8	3.187	1.03	17	2.1%	-1.13 [-2.04, -0.22]
Kraemer et al. (2001a)	3.61	1.01	10	3.18	1.03	10	2.2%	0.40 [-0.48, 1.29]
Kraemer et al. (2001b)	1.83	0.47	8	4	0.4	7	0.8%	-4.65 [-6.84, -2.46]
Perrey et al. (2008)	3.3	1.4	8	4.1	1.8	8	2.0%	-0.47 [-1.47, 0.53]
Subtotal (95% CI)			**59**			**64**	**13.0%**	**-0.82 [-1.61, -0.03]**
Heterogeneity: Tau^2 = 0.80; Chi^2 = 22.55, df = 6 (P = 0.0010); I^2 = 73%								
96 h. FE								
Jakeman et al. (2010a)	1.025	1.33	8	1.455	0.485	9	2.1%	-0.42 [-1.38, 0.55]
Jakeman et al. (2010b)	1	1.357	8	1.162	0.68	17	2.2%	-0.17 [-1.01, 0.68]
Kraemer et al. (2001a)	1.02	0.48	10	2.51	0.74	10	1.8%	-2.29 [-3.47, -1.11]
Subtotal (95% CI)			**26**			**36**	**6.1%**	**-0.90 [-2.10, 0.30]**
Heterogeneity: Tau^2 = 0.86; Chi^2 = 8.81, df = 2 (P = 0.01); I^2 = 77%								
120 h. FE								
Kraemer et al. (2001b)	0.24	0.27	8	0.54	0.47	7	1.9%	-0.75 [-1.81, 0.31]
Subtotal (95% CI)			**8**			**7**	**1.9%**	**-0.75 [-1.81, 0.31]**
Heterogeneity: Not applicable								
Total (95% CI)			**514**			**544**	**100.0%**	**-0.43 [-0.66, -0.19]**
Heterogeneity: Tau^2 = 0.45; Chi^2 = 148.60, df = 47 (P < 0.00001); I^2 = 68%								
Test for subgroup differences: Chi^2 = 5.27, df = 8 (P = 0.73), I^2 = 0%								

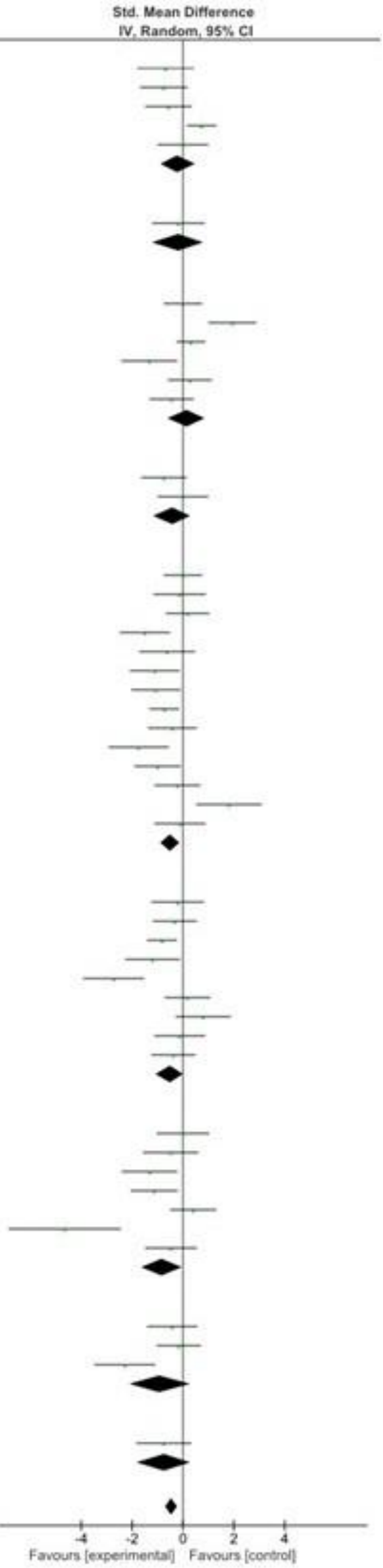


Fig. 10 Forest plot representing a comparison between the use of a CG and a control for measures of perceived MS
2 column

4. DISCUSSION

These results suggest that the application of compression clothing may aid the recovery of EIMD. However they must be interpreted with caution, because they also indicate very high heterogeneity. I^2 statistic focuses on the effect of any type of heterogeneity on the meta-analysis (Higgins et al., 2003), which includes additive components due to within-study variation (usually between-patient variation) and between-study variation (heterogeneity) (Higgins & Thompson, 2002). Each study was conducted with different methods and participants, thus it can be assumed that the high heterogeneity reported in most results of this meta-analysis is due to these aspects.

4.1.Physiological and Physical Effects

The literature suggests that compression-induced increase in venous blood flow could increase the clearance of metabolites and the supply of nutrients (Berry & McMurray, 1987; Chatard et al., 2004). However we have found negative effects of CG on $[La–]_p$ removal following exercise (Fig. 5). It is worth mentioning that $[La–]_p$ per se is not necessarily a valid indicator of recovery quality (Barnett, 2006). However, the fact that lactate is somewhat retained in the previously active muscle with compression stockings rather than being cleared more quickly without (Berry & McMurray, 1987; Rimaud et al., 2010) suggests that the efficacy of wearing compression stockings during passive recovery may be limited (Rimaud et al., 2010). It may instead favor muscle glyconeogenesis (Bangsbo et al., 1997), an important fate of lactate during recovery (Fournier et al., 2002; McDermott & Bonen, 1992). Furthermore, some studies reporting changes in $[La–]_p$ (Berry & McMurray, 1987; Chatard et al., 2004) have also reported small plasma volume shifts, which may account for the observed reductions in $[La–]_p$.

Strenuous exercise that damages skeletal muscle cell structure results in an increase in blood CK-3 Armstrong et al., 1991; Epstein, 1995; Mair et al., 1995). This response is a reflection of both diffusion and clearance from the circulatory system (Clarkson & Hubal, 2002). CK-3 travels from the damaged muscle tissue into the interstitial fluid prior to entering the circulation (Hortobagyi & Denahan, 1989), thus CK-3 does not appear in the blood until several hours after the injection (Volfinger et al., 1994). On the one hand, several studies reported that CK-3 concentrations in experimental groups were not as high as those found in control groups, but differences among groups started occurring 24 (Duffield & Portus, 2007), 48 (Kraemer et al., 2001a) or 72 hours following exercise (Kraemer et al., 2001b). On the other hand, several studies showed no difference between conditions, although CK-3 activity increased significantly after damaging exercise in both groups (Davies et al., 2009; Duffield et al., 2008, 2010; French et al., 2008; Jakeman et al., 2010a, 2010b). Previous findings (Born et al., 2013; Hill et al., 2013) have pointed out that the use of CG is able to reduce concentrations of CK-3, which may be attributed to an attenuation in the release of CK-3 into the bloodstream, the improved venous return and the enhanced clearance of metabolites (Ali et al., 2007; Kraemer et al., 2004). However our results (Fig 6.) indicate that this benefit is not clearly shown, and it remains unclear why. Nevertheless, LDH-5 (Fig. 7) seems to be reduced, especially 48 hours following exercise. The responses of CK-3 and LDH-5 might depend upon where the primary site of muscle damage occurred (Kraemer et al., 2001a), the training status of the participants (Maughan & Gleeson, 2010; Pyne, 1994), the type and familiarity with the exercise modality used, and therefore, the extent of myocellular release of specific proteins. The high inter- and intra-individual variability in CK-3 and LDH-5 response question its accuracy at gauging the magnitude of muscle damage because these parameters mostly serve as global markers for damage to contractile elements and as indicators of recovery, rather than providing evidence for its progress (Clarkson et al., 1986; Friden & Lieber, 2001).

The inflammatory response which follows tissue damage to the sarcolemma, leads to a disruption of calcium homeostasis, cell necrosis and infiltration of neutrophil cells (Armstrong, 1984; Friden et al., 1989). This release of the proteins from the damaged contractile elements into the interstitial fluid (Kraemer et al., 2001a) results in sensations of pain and soreness and creates an increase in tissue osmosis (Volfinger et al., 1994). Because of the osmotic gradient, fluid from the circulatory system is absorbed, which increases the interstitial fluid and intracompartmental pressure, resulting in an edema (Kraemer et al., 2001a). Applying compression can reduce exercise-induced edema by promoting lymphatic outflow and transporting the profuse fluid from the interstitium of the muscle back into the circulation (Burnand et al., 1980; Kraemer et al., 2001a). This is due to an external pressure gradient that attenuates changes in osmotic pressure and reduces the space available for swelling and haematoma to occur (Kraemer et al., 2004). Although several studies reported no significant difference between compression and control groups (Carling et al., 1995; Davies et al., 2009), others found differences after a running exercise (Bovenschen et al., 2013), at 24 hours (Goto & Morishima, 2014), 48 hours (Kraemer et al., 2001b) and the fifth day of recovery (Kraemer et al., 2001a). Based on our results (Fig. 8) the greater benefits of compression in reducing swelling occurred at 48 and 72 hours following exercise, when swelling appears intramuscularly and subcutaneously (Kraemer et al., 2004). A reduction in the edema could attenuate the inflammatory response that would promote further structural damage (Kraemer et al., 2001a), and hence potentially be the underlying cause of the decreased perception of soreness (Jakeman et al., 2010a), or the enhanced recovery of power and strength measurements when wearing CG.

4.2. Subsequent-Performance Measures.

The decreased force after fatiguing exercise protocols (Clarkson et al., 1992; Howell et al., 1993; Newham et al., 1983; Nottle & Nosaka, 2005) is due to pain and structural damage (Kraemer et al., 2001a, 2001b), local muscle trauma (Allen, 2001) and the possible reduction in contractile function due to the peripheral contractile interference (Duffield et al., 2010; Green, 1997) caused by the accumulation of metabolic intermediates (Green, 1997). This disruption of the neural function has also been associated with the inhibition of muscle function (Michaut et al., 2002; Perrey et al., 2008) suggesting the existence of a "central modulation", presented in the literature as a central protection of the muscle from further peripheral fatigue and damage (Gandevia, 2001). The muscle fiber alignment provided by CG (Kraemer et al., 2001b) may limit EIMD and stimulate a better recovery of membrane structures, which may speed-up the recovery of contractile components and excitation–contraction coupling processes, and may serve as an external mechanical support to the muscle. However these findings may also be explained by other physiological markers. This might be why power (Fig. 9) and strength (Fig. 10) results at all follow-up times revealed a great positive effect when applying compression compared with control groups, confirming the findings of earlier research (Born et al., 2013; Hill et al., 2013). Although benefits were reported immediately following exercise, power and strength values were higher when subjects were wearing CG, especially 24 hours following exercise. Several authors have indicated that the compression treatment seems to be particularly beneficial between 48 and 72 hours following exercise for peak torque and isokinetic muscle strength (Jakeman et al., 2010a, 2010b; Kraemer et al., 2001a, 2001b; Perrey et al., 2008) and at 24 hours following exercise for voluntary muscle activation (Perrey et al., 2008). These results suggest that despite the fact that contractile properties could recover relatively early, the recovery of the ability to generate force seems to be delayed. The individual stretch-shortening cycle (SSC) contribution to increased power output should also be considered (Miyaguchi & Demura, 2006). As it largely removes the contribution of the SSC to performance, the SJ along with knee extension may be considered as a better indicator of knee extensor performance than CMJ performance (Jakeman et al., 2010a). Other performance areas related to power but not analyzed here are sprint and agility performances. Sprint or repeated-sprint performance (5, 10, 20 and 30 m.) measured in several studies (Davies et al., 2009; Duffield et al., 2008; French et al., 2008), as well as the 5–0–5 agility test (Davies et al., 2009), or multiplanar speed (French et al., 2008) show equivocal findings because there was no significant difference between CG and a control group 24–48 hours after various types of exercise.

4.3. Perceptual Responses

Exercise-induced MS accompanies muscle damage, and ratings of perceived MS are widely used to evaluate CG effects during recovery (MacRae et al., 2011) because it provides further information regarding the state of the muscle environment, although it may not specifically reflect the magnitude of exercise-induced muscle damage (Nosaka et al., 2002). The underlying mechanisms behind the cause of delayed onset muscle soreness (DOMS) remain unclear (Cheung et al., 2003; MacIntyre et al., 1995), because active inflammatory cells are not always present with signs and symptoms of DOMS (Schwane et al., 1982). Therefore other factors are likely to contribute to the perception of soreness (Friden et al., 1986; Newham, 1988; Stauber et al., 1990). DOMS are related to mechanical forces in the contractile or elastic tissue, that result in the disruption of the muscle fiber and surrounding connective tissue (Armstrong, 1984; Stauber et al., 1990), the inflammatory response (Smith, 1991) or a combination of both (Clarkson & Hubal, 2002; Connolly et al., 2003). Moreover, the time course between damage and pain is controversial, as the inflammatory response starts as rapidly as a few hours after tissue injury, before muscles become painful (Armstrong et al., 1980). The positive effects of CG on these symptoms could cause reductions in perceived MS regardless of measurement time, but we must be cautious with this interpretation due to the subjectivity of these measurements (Brophy-Williams et al., 2014; Davies et al., 2009). MS Results obtained at different follow-up times indicated that CG alleviated the perception of DOMS. As such, the use of CG may be beneficial to promote psychological recovery from high-intensity exercise regardless of potential physiological changes.

5. LIMITATIONS, RECOMMENDATIONS.

Many factors can influence the inconclusive findings and the high heterogeneity stated. Although studies reported pressures ranging from 15 to 35 mmHg, which are within the range of values considered as beneficial, it is likely that participants may not have received adequate levels of pressure to induce measurable changes (Brophy-Williams et al., 2014; Hill et al., 2015). The variations in pressure classifications between countries (Bianchi & Todd, 2000; Clark & Krimmel, 2006; Linnitt & Davies, 2007), different manufacturers of CG (Jonker et al., 2001), type of CG (graduated compression or not), anatomical regions covered by the garment (Bottaro et al., 2011; Kraemer et al., 2001a), postures and foot positions (Wertheim et al., 1999) and gender (Tiidus & Enns, 2008; Volfinger et al., 1994) may also contribute to the inconsistencies between results. Moreover, some athletes may be more or less susceptible to alterations in myocyte membrane permeability, or have differing biomarker clearance rates due to individual responses to exercise and training status. Further research with different types of CG (whenever was possible with a placebo condition) is needed to identify the optimal pressure to induce the greatest increase in venous blood flow (Brophy-Williams et al., 2014; Driller & Halson, 2013). It is also necessary to know the optimal length of time that CG must be worn, the effect of compression clothes to tolerate greater training loads or maintain consistency between trials, over a number of days following exercise and how this treatment affects longer-term recovery, the influence of posture and his relation to the pressure exerted, and if wearing compression while participants sleeps affect MS perception.

Due to the variation in muscle damage characteristics from one individual to another (Warhol et al., 1985), the variability in responses to EIMD (Clarkson & Hubal, 2002), the complex nature of EIMD, and the inconsistent findings, limited practical recommendations can be reported. Athletes should benefit from these resources especially in sports where limited rest between competitions is available, when there is a significant increase in training intensity and volume, or during travel. To provide the ideal graduated compression, the CG need to be custom fit to the contours of an individuals´ limbs. Although therapeutic compression should be applied immediately after EIMD and for at least 72 hours following exercise (Kraemer et al., 2004), the benefits of CG seem to be most pronounced when they are applied for recovery purposes 12 to 48 hours following exercise (Born et al., 2013). To date, it can be assumed that the longer an athlete can wear compression for following exercise, the better (Vaile et al., 2010).

6. CONCLUSIONS.

Based on our results, CG may be able to assist athletic recovery following exercise, but the findings are often isolated (need corroboration) or inconclusive (mixed results across studies). Most results obtained have high heterogeneity, thus findings should be interpreted with caution, because sometimes true effects are assumed to vary between studies. In addition, similarly to other reviews, it is possible that certain studies appeared after the manuscript was completed. Therefore, although various unknown factors may affect our findings, CG seem to be beneficial for the recovery of several markers of EIMD in athletes.. Compression treatment does not attenuate the concentration of CK-3 following exercise, and there seems to be increases in $[La–]_p$ and reductions on LDH-5 concentration. Nevertheless, it accelerates the recovery of muscle function, mainly 24 hours following exercise. Power and strength results indicate the benefits of CG on other physiological variables, such as those related to muscle swelling. Finally, perceptual measurements tend to be better with compression, being most pronounced 72 hours following exercise. Thus, the present review found conclusive evidence that swelling, power, strength, and MS are improved during recovery with CG, HR seems to be unaffected, but there are little and inconsistent evidence of the benefit of CG in other markers of EIMD like $[La–]_p$, CK-3 or LDH-5.

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8. COMPLIANCE WITH ETHICAL STANDARDS

These authors have no support or funding to report, and declare they have no conflict of interest related to the content of this systematic review.

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LEGENDS OF FIGURES

Fig. 1 Summary of search strategy and selection process based on included and excluded studies

Fig. 2 Risk of bias graph: review authors' judgements about each risk of bias item presented as percentages across all included studies. indicate low risk of bias; indicate unknown risk of bias; indicate high risk of bias

Fig. 3 Risk of bias summary: review authors' judgements about each risk of bias item for each included study

Fig. 4 Forest plot representing a comparison between the use of a CG and a control for measures of [La–]$_p$

Fig. 5 Forest plot representing a comparison between the use of a CG and a control for measures of CK-3

Fig. 6 Forest plot representing a comparison between the use of a CG and a control for measures of LDH-5

Fig. 7 Forest plot representing a comparison between the use of a CG and a control for measures of muscle swelling

Fig. 8 Forest plot representing a comparison between the use of a CG and a control for measures of muscle power

Fig. 9 Forest plot representing a comparison between the use of a CG and a control for measures of muscle strength

Fig. 10 Forest plot representing a comparison between the use of a CG and a control for measures of perceived MS

CONTRIBUTORSHIP STATEMENT

Diego Marqués-Jiménez has made substantial contributions to conception and design, acquisition of data, analysis and interpretation of data and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Julio Calleja-González and Nicolás Terrados have made substantial contributions to conception and design, acquisition of data, analysis and interpretation of data, have been involved in drafting the manuscript or revising it critically for important intellectual content, have given final approval of the version to be published and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Iñaki Arratibel and Anne Delextrat have been involved in drafting the manuscript or revising it critically for important intellectual content, has given final approval of the version to be published and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Highlights

- Controversy in pressure, time of treatment and type of garment to maximize benefit.
- Conclusive evidence increasing power and strength.
- Conclusive evidence reducing perceived muscle soreness and swelling.
- No clear evidence of decreased lactate or creatine kinase.
- Little evidence of decreased lactate dehydrogenase.