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SYSTEMATIC REVIEW

Compression Garments and Recovery from Exercise: A Meta-Analysis

Freddy Brown[1] · Conor Gissane[1] · Glyn Howatson[2,4] · Ken van Someren[3] · Charles Pedlar[1] · Jessica Hill[1]

Abstract

Background Adequate recovery from exercise is essential to maintain performance throughout training and competition. While compression garments (CG) have been demonstrated to accelerate recovery, the literature is clouded by conflicting results and uncertainty over the optimal conditions of use.

Objectives A meta-analysis was conducted to assess the effects of CG on the recovery of strength, power and endurance performance following an initial bout of resistance, running, or non-load-bearing endurance (metabolic) exercise.

Methods Change-score data were extracted from 23 peer-reviewed studies on healthy participants. Recovery was quantified by converting into standardized mean effect sizes (ES) [±95% confidence interval (CI)]. The effects of time (0–2, 2–8, 24, >24 h), pressure (<15 vs. ≥15 mmHg) and training status (trained vs. untrained) were also assessed.

Results CG demonstrated small, very likely benefits [$p < 0.001$, ES = 0.38 (95% CI 0.25, 0.51)], which were not influenced by pressure ($p = 0.06$) or training status ($p = 0.64$). Strength recovery was subject to greater benefits than other outcomes [$p < 0.001$, ES = 0.62 (95% CI 0.39, 0.84)], displaying large, very likely benefits at 2–8 h [$p < 0.001$, ES = 1.14 (95% CI 0.72, 1.56)] and >24 h [$p < 0.001$, ES = 1.03 (95% CI 0.48, 1.57)]. Recovery from using CG was greatest following resistance exercise [$p < 0.001$, ES = 0.49 (95% CI 0.37, 0.61)], demonstrating the largest, very likely benefits at >24 h [$p < 0.001$, ES = 1.33 (95% CI 0.80, 1.85)]. Recovery from metabolic exercise ($p = 0.01$) was significant, although large, very likely benefits emerged only for cycling performance at 24 h post-exercise [$p = 0.01$, ES = 1.05 (95% CI 0.25, 1.85)].

Conclusion The largest benefits resulting from CG were for strength recovery from 2 to 8 h and >24 h. Considering exercise modality, compression most effectively enhanced recovery from resistance exercise, particularly at time points >24 h. The use of CG would also be recommended to enhance next-day cycling performance. The benefits of CG in relation to applied pressures and participant training status are unclear and limited by the paucity of reported data.

Key Points

Small, significant and very likely benefits on exercise recovery can be achieved through use of compression garments (CG).

The greatest benefits from CG are evident in recovery of strength performance and from resistance exercise, which may imply that CG ameliorate muscle damage.

Next day cycling performance was also subject to large, very likely benefits following the use of CG.

✉ Freddy Brown
Freddy.Brown@stmarys.ac.uk

1 School of Sport, Health and Applied Science, St Mary's University College, Twickenham, UK

2 Faculty of Health and Life of Sciences, Northumbria University, Newcastle upon Tyne, UK

3 GSK Human Performance Lab, GlaxoSmithKline Consumer Healthcare, London, UK

4 Water Research Group, Northwest University, Potchefstroom, South Africa

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1 Introduction

1.1 Background

Establishing effective recovery methods for elite athletes is essential in order to increase the likelihood of victory, and to maintain training intensity in the face of ever improving performances and increasing training loads [1, 2]. While maintaining a high volume and intensity of training is necessary for optimizing training adaptation [3], athletes must also aim to preserve competitive performance throughout multiple weekly [4] or even daily contests [5]. In short, athletes who recover faster are likely to perform better and train harder [6].

Recent years have seen the emergence of a number of interventions aimed at accelerating recovery, including cold water immersion [7], contrast bathing [8], and compression garments (CG) [9]. However, recovery demands following training are highly specific to the intensity, duration and modality of exercise [10]. For example, while cycling performance is limited by metabolite accumulation and substrate depletion [11], it is also subject to relatively low levels of muscle damage in comparison to load-bearing exercise [12]. Such specificity may in part explain the conflicting evidence surrounding many emerging recovery interventions, as the damage incurred by different activities will require distinct physiological processes for regeneration [13]. Proper consideration of both exercise modality and subsequent performance outcome is therefore integral to the efficacy of any recovery strategy [10, 13].

In particular, the use of CG for recovery has been the subject of much speculation over the physiological mechanisms responsible [9, 14]. Compression has been proposed to prevent performance deterioration and improve recovery by accelerating nutrient delivery [15, 16] and metabolite removal [17, 18], as well as by ameliorating post-exercise oedema, delayed onset muscle soreness (DOMS), and muscle damage [19]. More importantly, such physiological benefits to recovery are frequently observed alongside accelerated recovery of muscular power [20], strength [21, 22] and endurance. As athletic performance is a composite of many physiological and psychological factors, it is possible that CG aid recovery on a number of levels. One of the most thoroughly investigated mechanisms for the benefits of CG [16, 19, 21] is the potential of such garments to minimize the symptoms of the exercise-induced muscle damage (EIMD) that typically occurs as a result of unaccustomed or eccentric exercise [23]. Whilst eccentric exercise is beneficial for training power [24, 25], strength and hypertrophy [26], such exercise is extremely damaging. Strength production may be impaired for up to 10 days [27, 28], while EIMD is also associated with both swelling and DOMS, which typically peak between 36 and 48 h [19]. Furthermore, as any load-bearing exercise will induce EIMD because of the inherent eccentric nature of running [12], muscle damage is an inescapable part of training for the majority of athletes.

Whilst the mechanisms behind the recovery benefits of CG are still unclear, the application of external compression is known to influence several areas of haemodynamic and cellular function [29]. In a clinical setting, CG have been shown to compress dilated veins and reduce venous reflux to enhance venous return and reduce oedema [30]. This also increases "muscle pump" to accelerate blood flow [31]. A similar mechanism may underlie the benefits of CG in an exercise setting. For example, enhanced recovery of strength and power performance is frequently reported alongside reduced levels of oedema [19]. While the successful management of oedema helps to reduce DOMS and increase mobility [16], this effect may also attenuate the progression of muscle damage. Fluid accumulation in muscle tissue increases osmotic pressure and subsequent cell lysis [32], while CG have been shown to reduce cellular trauma alongside swelling [30, 32]. Reductions in circulating levels of the intramuscular protein creatine kinase (CK) are frequently reported when CG are worn following exercise [19, 20, 33]. Haemodynamic effects of CG have also been postulated to aid recovery by enhancing levels of nutrient delivery [15, 16] and metabolite removal [34, 35]. Accordingly, observations of reduced muscle damage following post-exercise compression have been suggested to reflect enhanced cellular regeneration and protein synthesis [16] made possible by enhanced circulation [17].

Despite the prevailing consensus shifting in favour of CG as a recovery aid [9, 22, 36], recent reviews highlight inconsistent and variable results [9, 14, 34, 37]. For example, the recovery of strength has been frequently improved by CG at time points over 24 h, with reported benefits over controls consistently ranging from between 5 and 10% [9, 19, 21, 34, 38]. Conversely, CG were associated with impaired recovery of acceleration (2.5%) compared with controls following a 3-day basketball tournament [6], while recent reviews suggest compression confers only trivial effects on recovery from running [37, 39]. These discrepancies are likely due to the specific nature of post-exercise recovery demands arising from distinct exercise challenges and subsequent performance measures [12]. Variation in the populations studied may also influence the efficacy of CG [14, 40]. EIMD is known to elicit protective neurophysiological adaptations that reduce the damage arising from subsequent bouts [41]. This phenomenon has been termed the repeated bout effect and has been seen to last at least 6 months in untrained participants [40], becoming less pronounced as tolerance to

EIMD improves in line with training status [41]. Training history may therefore influence the efficacy of CG. In addition, variation in the duration of CG application, whether CG are worn during and after, or after exercise only, as well as the assessment of recovery at different time points, all continue to obstruct researchers' ability to draw definitive conclusions [14, 34, 39].

As CG are defined by the capacity to provide external pressure to the body surface [14], it could be argued that controlling for exerted pressure is the foremost priority for making any firm conclusions on efficacy. Many clinical benefits of CG appear to be proportional to the pressure they exert, from reducing swelling [29, 42] to augmenting blood flow [43]. However, many studies have neglected to report the pressures applied by CG [22], have calculated pressures by indirect modelling techniques [19], have estimated pressures from manufacturer recommendations [33] or have cited pressures measured in prior trials [44]. These inconsistencies have prevented definitive conclusions being made on the effects of CG pressure on recovery [34, 39], as indirect measures would likely be inaccurate given the wide variation arising from anthropometric differences [45]. As a result, off-the-shelf garments fitted according to the height and mass of an individual are unlikely to fit correctly. The relationship between the pressures exerted by CG and the ensuing recovery benefits has yet to be elucidated.

1.2 Objectives

The aim of this analysis was to systematically review the effects of CG for exercise recovery, in relation to exercise modality, subsequent performance outcomes, the duration and timing of CG application, participant training status and applied pressure.

2 Methods

2.1 Literature Search

Randomized controlled trials on the use of CG for performance recovery in healthy humans were identified following a search of academic databases using the following terms: [(compression garment OR compression tights OR compression stockings OR tights OR stockings OR garments) AND recovery AND (exercise OR EIMD OR performance OR recovery OR sport OR athlete)]. The databases SPORTDiscus, Web of Science and PubMed were used to identify academic papers (written in English), from the start of records until May 2016. Relevant papers were used for reference and citation searching. Only articles from peer-reviewed academic journals were included. Results were also screened with use of the Web of Science filters for "categories" [biochemical research methods OR biochemistry OR molecular biology OR biology OR physiology OR applied chemistry OR materials science OR biomaterials OR sport sciences OR engineering (biomedical)] AND "research areas" (sport sciences OR life sciences OR biomedicine OR biochemistry OR molecular biology).

2.2 Outcome Variables

Changes from baseline scores were extracted from studies that assessed the effects of CG (all types) compared to a control condition on the recovery of maximal physical performance following exercise. Standardized mean effect sizes (ES) were calculated from the differences in pre–post change scores between CG and control groups, using the standard deviation of these changes (SD_{change}). Accepted performance outcomes included the following: strength, power and endurance. Power outcomes had to measure the rate at which force was applied, and therefore included jump height, sprint speed/time, and wattage from force dynamometry protocols. Endurance performance, however, was defined as any continuous measured outcome that surpassed 1 min in duration and would be limited by aerobic capacity (below which outcomes were classified as power). Strength measures must have reported performance in units of mass, weight or force, and included force dynamometry, as well as total and maximum loads lifted in resistance protocols. To differentiate between trials assessing recovery and performance, only studies that featured a temporal separation between an initial damaging intervention and subsequent performance tests were included. For example, bouts of repeated sprinting or resistance exercise that featured rests between sets met our criteria if CG were worn throughout recovery periods.

2.3 Inclusion and Exclusion Criteria

Studies that did not yield change-score data were excluded from the analysis. Trials were excluded if CG were used in combination with an additional treatment (e.g. nutritional supplements) and if CG were not worn during or immediately after exercise (within 2 h). Studies were therefore excluded if CG were worn only throughout exercise and subsequently removed before the recovery period. Studies of clinical populations were excluded, as were studies that failed to provide sufficient data for the analysis of ES.

2.4 Data Collection and Risk of Bias Assessment

Change scores were extracted or calculated from selected studies. Where insufficient raw data were reported, these

Table 1 Details of studies included in the meta-analysis

Study	Subjects[a,b]	Design	Protocol	Exercise modality	Minimum pressure (mmHg)[c]	Garments	Performance test[d]	Performance outcome	Time points
Ali et al. [53]	14 Recreational male runners (22 ± 1 years)	Crossover RCT	MSFT	Running	18[e,f]	GT	MSFT	Endurance	1 h
Armstrong et al. [54]	33 Recreational marathon runners (23 males, 10 females, 39 ± 7 years)	Parallel RCT	Marathon	Running	30[f,g]	KS	↑ Incremental treadmill TTE	Endurance	14 day
Bieuzen et al. [47]	11 Highly trained male runners (35 ± 10 years)	Crossover RCT	Simulated trail races (15.6 km with 6.6 km hills)	Running	25[f,g]	KS	MVC_{knee}; CMJ	Strength, power	1, 24, 48 h
Born et al. [55]	12 Competitive female athletes (25 ± 3 years)	Crossover RCT	30 × 30-m sprints ($1 \cdot min^{-1}$)	Running	18.3[e,f]	GT	↓ Sprint time: $30 \times 30\ m^{30\ min}$ ($1 \cdot min^{-1}$)	Power	10, 20, 30 min
Duffield and Portus [56]	10 Physically fit, male, club-level cricket players (22 ± 1 years)	Crossover RCT	Sprints (30 × 20 m, with 1 min jogging)	Running	Not stated[f]	WB	Sprint time: 10 m; throwing distance	Power	0, 10, 20 min, 24 h
Duffield et al. [57]	14 Male rugby players (19 ± 1 years)	Crossover RCT	2× consecutive days of simulated games (80-min sprint and agility circuit)	Running	Not stated[h]	GT	Sprint time: 5 × 20 m (25-m recovery jog); PP_{scrum}	Power	24 h
Duffield et al. [58]	11 Male rugby players (21 ± 3 years)	Crossover RCT	10 × 20-m sprints and 100× DL bounds	Running	10[f,g]	GT	Sprint time: 10 × 20 m; 100 × DL bounds; MVC_{knee}	Strength, power	0, 2, 24 h
Hill et al. [21]	24 Recreational marathon runners (17 males, 7 females, 44 ± 11 years)	Parallel RCT	Marathon	Running	9.9[e,f]	GT	MVC_{knee}	Strength	0, 24, 48, 72 h
Montgomery et al. [6]	29 Male basketball players (19 ± 2 years)	Parallel RCT	3-day basketball tournament	Running	18[f,g]	GS	Sprint time: 20 m, ↓ $25\ m^{72\ h}$; CMJ	Power	24, 48, 72 h
Pruscino et al. [59]	8 Highly trained male field-hockey players (22 ± 2 years)	Crossover RCT	75-min match simulation exercise protocol (LIST)	Running	4.8[e,f]	GT	↑ MP CMJ × 5^{48h}; squat jump	Strength, power	1, 24, 48 h
Rugg and Sternlicht [60]	14 Competitive runners (8 males, 6 females, 28 ± 14 years)	Crossover RCT	15-min run (incremental: 50, 70, 85% HRR)	Running	Not stated[h]	GT	↑ CMJ	Power	15 min
Carling et al. [50]	23 Healthy, untrained college students (7 males, 16 females, 26 ± 4 years)	Parallel RCT	70× $MVCECC_{elbow}$	Resistance	17[f,g]	AS	MVC_{elbow}	Strength	10 min, 24, 48, 72 h
Cerquiera et al. [51]	13 Untrained young males (21 ± 1 years)	Parallel RCT	30× $MVCECC_{elbow}$	Resistance	Not stated[h]	AS	MVC_{elbow}	Strength	24, 48, 72, 96 h

Table 1 continued

Study	Subjects[a,b]	Design	Protocol	Exercise modality	Minimum pressure (mmHg)[c]	Garments	Performance test[d]	Performance outcome	Time points
Davies et al. [33]	11 Basketball and netball players (4 males, 7 females, 22 ± 3 years)	Crossover RCT	5 × 20 drop-jumps	Resistance	15[f,g]	GT	Sprint time: 5, 10, 20 m; CMJ	Power	48 h
Goto and Morishima [22]	9 Strength trained male recreational athletes (21 ± 1 years)	Crossover RCT	3–5 × 10 @ 70% 1 RM for 9 (whole body) exercises	Resistance	Not stated[h]	WB	↑ Bench press 1 RM$^{3, 5, 8 h}$; ↑ $MVC_{knee}^{24 h}$	Strength	1, 3, 5, 8, 24 h
Jakeman et al. [38]	17 Physically active females (21 ± 2 years)	Parallel RCT	10 × 10 drop-jumps	Resistance	14.9[f,g]	GT	↑ Squat jump$^{24, 48, 72, 96 h}$; ↑ CMJ$^{48 h}$; ↑ $MCV_{knee}^{24, 48, 72, 96 h}$	Strength, power	1, 24, 48, 72, 96 h
Kraemer et al. [19]	15 Healthy, untrained males (22 ± 3 years)	Paired parallel RCT	2 × 50 bicep curls ($MVCECC_{elbow}$ every 4th; 3-min rest)	Resistance	10[f,g]	AS	↑ $MVC_{elbow}^{48, 72 h}$; ↑ P_{pk} $MVC_{elbow}^{24, 48, 72 h}$	Strength, power	24, 48, 72 h
Kraemer et al. [49]	20 Untrained females (21 ± 3 years)	Parallel RCT	2 × 50 bicep curls ($MVCECC_{elbow}$ every 4th; 3-min rest), isometric hold	Resistance	10[f,g]	WB	↑ $MVC_{elbow}^{48, 72, 96 h}$; ↑ $P_{pk}MVC_{elbow}^{48, 72, 96 h}$	Strength, power	24, 48, 72, 96 h
Martorelli et al. [61]	15 Resistance trained men (23 ± 4 years)	Crossover RCT	6 × 6 bench press @ 50% 1 RM, 1-min rest	Resistance	Not stated[h]	AS	MP_{bench} (6 × 6 @ 50% 1 RM); MVC_{bench}	Strength, power	2 min 30 s, 5 min, 7 min 30 s, 10 min, 12 min 30 s, 30 min
Argus et al. [62]	11 Highly trained male cyclists (31 ± 6 years)	Crossover RCT	3 × 30-s sprints (20-min rest)	Metabolic	18[e,f]	GS	Sprint power: 3 × 30 s (30-min rest)	Power	30 min
de Glanville and Hamlin [35]	14 Trained multisport male athletes (34 ± 7 years)	Crossover RCT	40-km TT	Metabolic	6[e,f]	GT	↓ 40-km TT	Endurance	24 h
Driller and Halson [44]	10 Highly trained male cyclists (31 ± 6 years)	Crossover RCT	30-min cycling (15 min @ 70% PPO, 15-min TT)	Metabolic	11.8[e,f]	GT	↑ MP 15-min TT	Endurance	1 h

Table 1 continued

Study	Subjects[a,b]	Design	Protocol	Exercise modality	Minimum pressure (mmHg)[c]	Garments	Performance test[d]	Performance outcome	Time points
Sperlich et al. [63]	10 Well-trained male athletes (25 ± 4 years)	Crossover RCT	$Sprint_{ski}$ (3 × 3 min), 3-min rest (MP)	Metabolic	9[e,h]	ST	$Sprint_{ski}$ (3 × 3 min, 3-min rest)	Endurance	6, 12 min

AS arm sleeves, *CMJ* countermovement jump, *DL* double leg, *GS* graduated stockings, *GT* graduated tights, *HRR* heart rate reserve, *KS* knee socks/calf sleeves, *LIST* Loughborough Intermittent Shuttle Test, *Metabolic* cardiovascular exercise with minimal eccentric component, *MP* mean power, MP_{bench} mean power bench press, *MSFT* multi-stage fitness test, MVC_{bench} maximal voluntary contraction bench press, $MVCECC_{elbow}$ maximal eccentric voluntary contraction elbow flexion, MVC_{elbow} maximal voluntary contraction elbow flexion, MVC_{knee} maximal voluntary contraction knee flexion, P_{pk} peak power, *PPO* peak power output, PP_{scrum} peak scrum power, *RCT* randomized controlled trial, *Resistance* resistance exercise with eccentric component, *RM* repetition maximum, $sprint_{ski}$ skiing ergometer sprint, *ST* sleeved top, *TT* time trial, *TTE* graduated time to exhaustion test (treadmill), *WB* whole body garments, *y* years ↑ significant increase from compression ($p < 0.05$), ↓ significant decrease from compression ($p < 0.05$)

[a] All participants categorized as ‘untrained’ in subsequent analyses labelled as such; all other participants, including ‘physically active’ and ‘athletes’, etc., categorized as ‘trained’

[b] Age data are mean ± standard deviation

[c] Minimum pressure applied by garments (or pressure given at the thigh if minimum pressure not recorded)

[d] Increases or decreases are related to units of measurement, with an increase in time to exhaustion, power, strength or jump height indicating improved performance. Decreases in sprint times or time trial times indicate improved performance

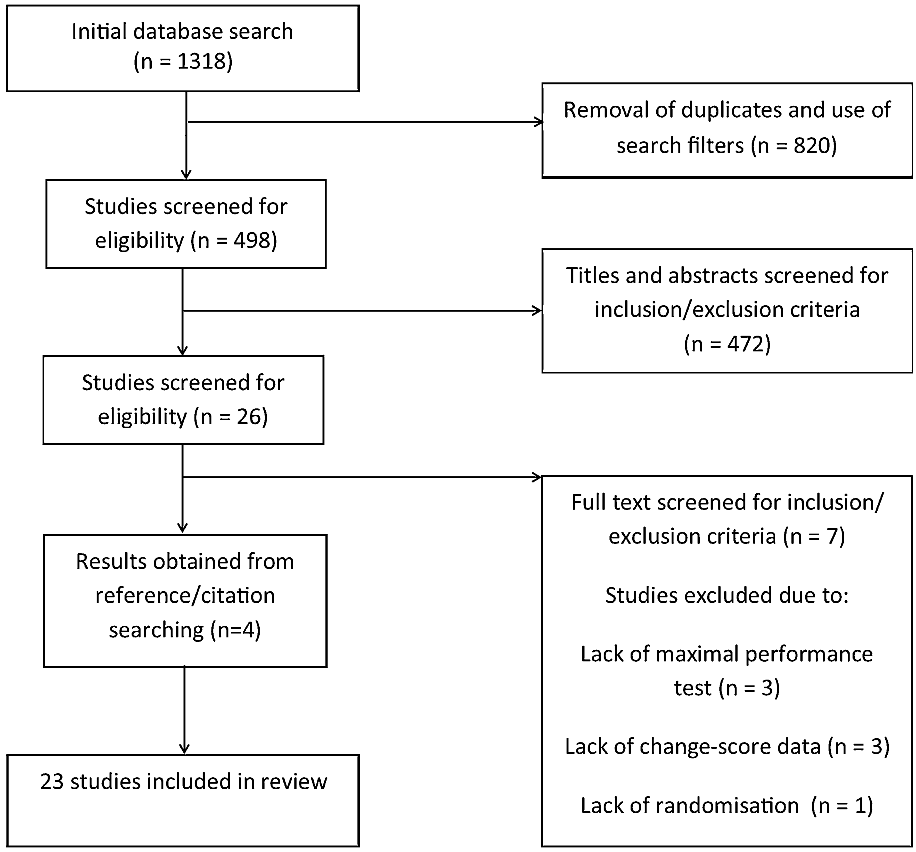
[e] Pressure measured directly

[f] Pressure applied after exercise

[g] Target/modelled pressure

[h] Pressure applied during and after exercise

Fig. 1 Schematic of study selection, from initial search to included studies



were requested from corresponding authors or extrapolated from figures after digital magnification. In accordance with current guidelines for conducting meta-analyses [46], where SD_{change} was not available, values were calculated using a correlation coefficient derived from studies that provided sufficient data [33, 44, 47]. Results were assessed with the I^2 statistic, quantifying the percentage of variability in ES from heterogeneity, rather than chance [48]. This was used to guide subsequent subgroup analysis. Risk of bias was reported in accordance with current consensus [46].

2.5 Stratification of Studies

Studies were categorized into three groups, according to the characteristics of the exercise used prior to the CG recovery intervention. The stratification was guided by the results of previous research, noting differences in recovery demands between high-intensity sports and lab-based eccentric damage protocols [7]. Accordingly, papers were grouped into studies on resistance exercise (defined as those that specifically targeted muscle damage with resistance training, force dynamometry or drop-jumps), running, and metabolic exercise protocols (defined as non-load-bearing endurance exercise, which included cycling or skiing ergometry). Subsequently, results were also analysed according to performance measures, being divided into strength, power and endurance outcomes. Furthermore, the relative benefits of CG were assessed in relation to the time point of subsequent testing, results being grouped into those taken at 0–2, 2–8, 24 and >24 h. Additionally, the influence of pressure on recovery was assessed by grouping studies into those that applied a (directly measured) minimum of $\geq$15 mmHg at the thigh and those that utilized looser fitting garments. This level of compression pressure is required for enhanced venous return [43]. Finally, studies were also grouped according to participant training status, trained individuals being defined as those regularly competing in a given sport, belonging to a sports club, or those regularly exercising three or more times per week. Participants were classified as untrained if described as such by the authors [19, 49] or they were inexperienced in the exercise modality that was studied [50, 51].

2.6 Statistical Analysis

Data were analysed using the RevMan statistical software package (version 5.0; The Nordic Cochrane Centre, The Cochrane Collaboration, Copenhagen, 2011) [46]. Standardized mean ES and 95% confidence intervals (CIs) were reported as (ES [LCL, UCL]), where LCL and UCL

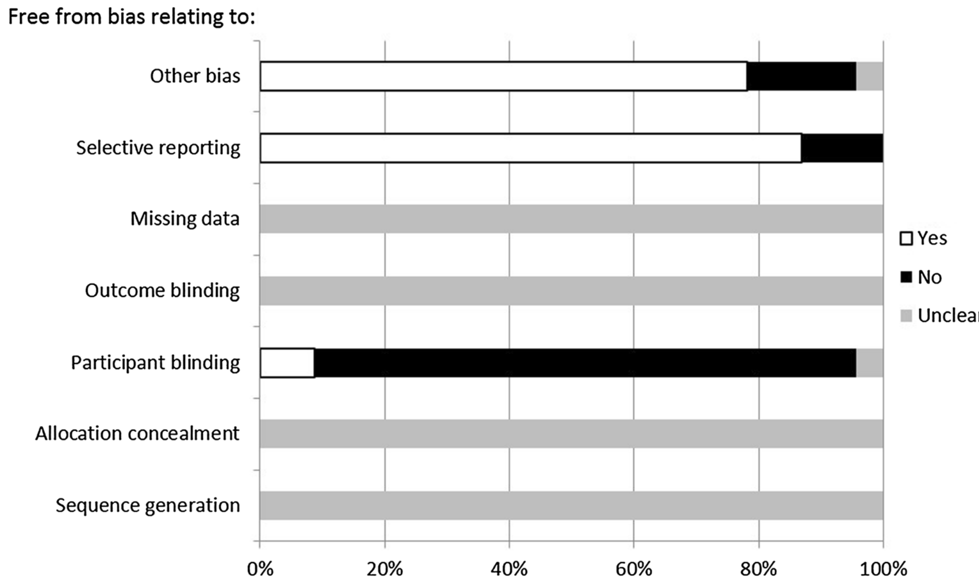


Fig. 2 Risk of bias analysis according to Cochrane Collaboration guidelines [46]

represent the lower and upper 95% confidence limits, respectively. Subgroup differences were presented as p values with χ^2 scores, while the likelihood of independent results was presented as p values alongside corresponding z scores. The threshold values for standardized changes were as follows: ≤0.2 (trivial), >0.2 (small), >0.5 (moderate) and >0.8 (large), where 0.2 was taken to represent the smallest worthwhile effect [52]. The threshold for statistical significance was set at $p = 0.05$, and changes were deemed very likely beneficial if the 95% CI cleared the threshold for the smallest worthwhile change [36, 52]. Effects were deemed unlikely beneficial if the 95% CI extended across the threshold for the smallest worthwhile change.

3 Results

3.1 Summary

In total, 136 data points from 23 studies were included in the analysis of the effect of CG over time (Table 1; Fig. 1). These spanned from 1995 to 2015, and included a total of 348 participants (256 males and 92 females). Trials featured the use of graduated tights (11 trials, 149 participants), stockings (two trials, 40 participants), knee socks/calf sleeves (two trials, 44 participants), arm sleeves (four trials, 71 participants), whole body garments (three trials, 34 participants), and a sleeved top (one trial, ten participants). After omitting anthropometric data from one study that reported insufficient results, the mean age and body mass of the participants were 25 ± 9 years and 74.9 ± 8.7 kg, respectively. These data were also used to compare and quantify the effects of CG for different

Fig. 3 Forest plot illustrating the effects of compression garments ▶ (CG) compared with control on all measures of recovery at 0–2 h. The results represent part of a comparison with 2–8, 24 and >24 h time points, and have been weighted accordingly. *Square boxes* represent the standardized mean effect for each study, with *lines* demonstrating 95% CIs. A *diamond* represents the overall standardized mean effect. *0* post-exercise, *bench* bench press, *bound* double leg bound, *CI* confidence interval, *CMJ* countermovement jump, *elbow* elbow flexion, *ham* hamstring flexion, *knee* knee extension, *metabolic* cardiovascular exercise with minimal eccentric component, *MSFT* multi-stage fitness test, *MVC* maximal voluntary contraction, *pk* peak, *resistance* resistance exercise with eccentric component, *scrum* peak scrum power, *ski* skiing ergometer, *TT* time trial

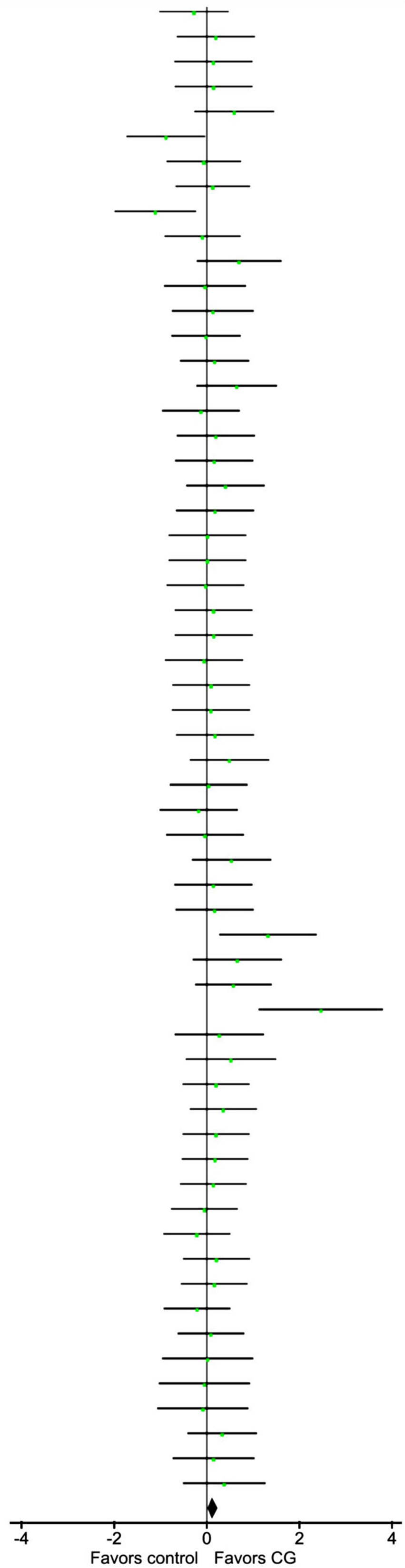
performance outcomes, exercise modalities, and participant training status. A significant ($p < 0.001$, $z = 5.53$), small and very likely beneficial effect of compression on recovery was observed when compared with a control group [ES = 0.38 (95% CI 0.25, 0.51)]. Risk of bias is indicated in Fig. 2.

3.2 Analysis of Pressure

Three studies were identified in the high-pressure group, applying pressures from 18 to 18.3 mmHg [53, 55, 62], while five studies [21, 35, 44, 59, 63] reported directly measuring pressures <15 mmHg (4.8–11.8 mmHg). No effect of compression pressure on the magnitude of recovery was apparent following extraction of 24 data points from the eight identified studies that took direct measurements at the garment–skin interface ($p = 0.06$, $\chi^2 = 3.46$). This trend towards improved recovery favoured the lower-pressure group [ES = 0.16 (95% CI −0.06, 0.38)] in comparison to trials applying greater pressures [ES = −0.28 (95% CI −0.70, 0.13)].

Study	Challenge	Outcome	Time	Measure	Effect size (mean ± 95% CI)
Ali et al. [53]	Running	Endurance	1 h	MSFT	-0.28 [-1.02, 0.47]
Argus et al. [62]	Metabolic	Power	1 h	Bike 30 s sprint	0.19 [-0.64, 1.03]
Argus et al. [62]	Metabolic	Power	30 min	Bike 30 s sprint	0.14 [-0.69, 0.98]
Bieuzen et al. [47]	Running	Strength	1 h	MVC_{knee}	0.15 [-0.69, 0.98]
Bieuzen et al. [47]	Running	Power	1 h	CMJ	0.59 [-0.27, 1.45]
Born et al. [55]	Running	Power	20 min	30 m sprint	-0.88 [-1.73, -0.04]
Born et al. [55]	Running	Power	20 min	30 m sprint	-0.07 [-0.87, 0.73]
Born et al. [55]	Running	Power	30 min	30 m sprint	0.13 [-0.67, 0.93]
Born et al. [55]	Running	Power	30 min	30 m sprint	-1.11 [-1.98, -0.24]
Carling et al. [50]	Resistance	Strength	10 min	MVC_{elbow}	-0.09 [-0.91, 0.72]
Driller and Halson [44]	Metabolic	Endurance	1 h	15 min TT	0.69 [-0.22, 1.60]
Duffield and Portus [56]	Running	Power	10 min	20 m sprint	-0.04 [-0.91, 0.84]
Duffield and Portus [56]	Running	Power	10 min	10 m sprint	0.13 [-0.75, 1.01]
Duffield et al. [57]	Running	Power	0	20 m sprint	-0.02 [-0.76, 0.72]
Duffield et al. [57]	Running	Power	0	Scrum	0.17 [-0.57, 0.91]
Duffield et al. [58]	Running	Power	10 min	Bound 10	0.64 [-0.22, 1.50]
Duffield et al. [58]	Running	Power	7 min	20 m sprint 8	-0.12 [-0.96, 0.71]
Duffield et al. [58]	Running	Power	10 min	Bound 8	0.20 [-0.64, 1.03]
Duffield et al. [58]	Running	Power	10 min	Bound 9	0.16 [-0.68, 1.00]
Duffield et al. [58]	Running	Power	1 min	20 m sprint 2	0.40 [-0.45, 1.24]
Duffield et al. [58]	Running	Power	4 min	20 m sprint 5	0.18 [-0.66, 1.02]
Duffield et al. [58]	Running	Power	8 min	20 m sprint 9	0.01 [-0.82, 0.85]
Duffield et al. [58]	Running	Power	9 min	20 m sprint 10	0.01 [-0.82, 0.85]
Duffield et al. [58]	Running	Power	10 min	Bound 5	-0.03 [-0.86, 0.81]
Duffield et al. [58]	Running	Power	10 min	Bound 6	0.15 [-0.69, 0.98]
Duffield et al. [58]	Running	Power	3 min	20 m sprint 4	0.15 [-0.69, 0.99]
Duffield et al. [58]	Running	Power	10 min	Bound 2	-0.06 [-0.90, 0.77]
Duffield et al. [58]	Running	Power	10 min	Bound 7	0.09 [-0.74, 0.93]
Duffield et al. [58]	Running	Strength	2 h	MVC_{ham}	0.09 [-0.75, 0.93]
Duffield et al. [58]	Running	Strength	0	MVC_{knee}	0.18 [-0.66, 1.01]
Duffield et al. [58]	Running	Strength	2 h	MVC_{knee}	0.49 [-0.36, 1.34]
Duffield et al. [58]	Running	Power	10 min	Bound 3	0.04 [-0.79, 0.88]
Duffield et al. [58]	Running	Force	0	MVC_{ham}	-0.18 [-1.01, 0.66]
Duffield et al. [58]	Running	Power	6 min	20 m sprint 7	-0.04 [-0.88, 0.80]
Duffield et al. [58]	Running	Power	2 min	20 m sprint 3	0.53 [-0.32, 1.38]
Duffield et al. [58]	Running	Power	5 min	20 m sprint 6	0.14 [-0.70, 0.98]
Duffield et al. [58]	Running	Power	10 min	Bound 4	0.17 [-0.67, 1.00]
Goto and Morishima [22]	Resistance	Strength	1 h	Bench	1.31 [0.27, 2.36]
Goto and Morishima [22]	Resistance	Strength	1 h	MVC_{knee}	0.65 [-0.30, 1.61]
Hill et al. [21]	Running	Strength	0	MVC_{knee}	0.57 [-0.25, 1.39]
Jakeman et al. [38]	Resistance	Power	1 h	Squat jump	2.45 [1.11, 3.79]
Jakeman et al. [38]	Resistance	Power	1 h	CMJ	0.27 [-0.69, 1.23]
Jakeman et al. [38]	Resistance	Strength	1 h	MVC_{knee}	0.52 [-0.45, 1.49]
Martorelli et al. [61]	Resistance	Power	12 min 30 s	Bench set 6 pk	0.20 [-0.52, 0.92]
Martorelli et al. [61]	Resistance	Power	2 min 30 s	Bench set 2 pk	0.35 [-0.37, 1.08]
Martorelli et al. [61]	Resistance	Power	10 min	Bench set 5 pk	0.20 [-0.52, 0.92]
Martorelli et al. [61]	Resistance	Strength	30 min	MVC_{bench}	0.18 [-0.54, 0.89]
Martorelli et al. [61]	Resistance	Power	5 min	Bench set 3 mean	0.14 [-0.58, 0.86]
Martorelli et al. [61]	Resistance	Power	7 min 30 s	Bench set 4 pk	-0.05 [-0.77, 0.66]
Martorelli et al. [61]	Resistance	Power	5 min	Bench set 3 pk	-0.21 [-0.93, 0.50]
Martorelli et al. [61]	Resistance	Power	2 min 30 s	Bench set 2 mean	0.21 [-0.51, 0.92]
Martorelli et al. [61]	Resistance	Power	12 min 30 s	Bench set 6 mean	0.16 [-0.56, 0.88]
Martorelli et al. [61]	Resistance	Power	10 min	Bench set 5 mean	-0.21 [-0.93, 0.51]
Martorelli et al. [61]	Resistance	Power	7 min 30 s	Bench set 4 mean	0.09 [-0.63, 0.81]
Pruscino et al. [59]	Running	Strength	1 h	CMJ	0.02 [-0.96, 1.00]
Pruscino et al. [59]	Running	Power	1 h	CMJ	-0.05 [-1.03, 0.93]
Pruscino et al. [59]	Running	Strength	1 h	Squat jump	-0.08 [-1.06, 0.90]
Rugg et al. [60]	Running	Power	15 min	CMJ	0.33 [-0.42, 1.08]
Sperlich et al. [63]	Metabolic	Endurance	6 min	Ski 3 min sprint	0.15 [-0.73, 1.02]
Sperlich et al. [63]	Metabolic	Endurance	12 min	Ski 3 min sprint	0.37 [-0.51, 1.26]
Test for overall effect: $z = 2.52$ ($p = 0.01$)					**0.14 [0.03, 0.24]**

Heterogeneity: $\chi^2 = 45.6$, ($p = 0.90$); $I^2 = 0\%$



Study	Challenge	Outcome	Time	Measure	Effect size (mean ± 95% CI)
2-8 h					
Goto and Morishima [22]	Resistance	Strength	8 h	MVC_{knee}	1.05 [0.05, 2.05]
Goto and Morishima [22]	Resistance	Strength	5 h	Bench	1.69 [0.57, 2.81]
Goto and Morishima [22]	Resistance	Strength	8 h	Bench	1.38 [0.32, 2.43]
Goto and Morishima [22]	Resistance	Strength	3 h	Bench	1.69 [0.57, 2.81]
Goto and Morishima [22]	Resistance	Strength	5 h	MVC_{knee}	0.90 [-0.09, 1.88]
Goto and Morishima [22]	Resistance	Strength	3 h	MVC_{knee}	0.49 [-0.45, 1.43]
Test for overall effect: $z = 5.33$ ($p < 0.001$)					**1.14 [0.72, 0.56]**
Heterogeneity: $\chi^2 = 4.18$, ($p = 0.52$); $I^2 = 0\%$					
24 h					
Bieuzen et al. [47]	Running	Power	24 h	CMJ	0.48 [-0.37, 1.33]
Bieuzen et al. [47]	Running	Strength	24 h	MVC_{knee}	0.83 [-0.05, 1.70]
Carling et al. [50]	Resistance	Strength	24 h	MVC_{elbow}	0.33 [-0.50, 1.15]
Cerquiera et al. [51]	Resistance	Strength	24 h	MVC_{elbow}	0.62 [-0.35, 1.60]
de Glanville and Hamlin 2012 [35]	Metabolic	Endurance	24 h	40 km TT	1.05 [0.25, 1.85]
Duffield and Portus [56]	Running	Power	24 h	Throw	0.10 [-0.78, 0.98]
Duffield et al. [57]	Running	Power	24 h	20 m sprint	-0.15 [-0.89, 0.60]
Duffield et al. [57]	Running	Power	24 h	Scrum	0.41 [-0.34, 1.16]
Duffield et al. [58]	Running	Strength	24 h	MVC_{knee}	0.10 [-0.74, 0.93]
Duffield et al. [58]	Running	Strength	24 h	MVC_{ham}	0.24 [-0.60, 1.08]
Goto and Morishima [22]	Resistance	Strength	24 h	Bench	1.14 [0.12, 2.15]
Goto and Morishima [22]	Resistance	Strength	24 h	MVC_{knee}	0.71 [-0.25, 1.67]
Hill et al. [21]	Running	Strength	24 h	MVC_{knee}	0.35 [-0.46, 1.16]
Jakeman et al. [38]	Resistance	Power	24 h	CMJ	3.18 [1.63, 4.73]
Jakeman et al. [38]	Resistance	Power	24 h	CMJ	8.30 [4.98, 11.63]
Jakeman et al. [38]	Resistance	Strength	24 h	MVC_{knee}	3.15 [1.61, 4.69]
Kraemer et al. 2001 [49]	Resistance	Power	24 h	MVC_{elbow}	-0.13 [-1.01, 0.75]
Kraemer et al. 2001 [49]	Resistance	Strength	24 h	MVC_{elbow}	-0.16 [-1.04, 0.71]
Kraemer et al. 2001 [19]	Resistance	Strength	24 h	MVC_{elbow}	0.08 [-0.94, 1.09]
Kraemer et al. 2001 [19]	Resistance	Power	24 h	MVC_{elbow}	0.51 [-0.53, 1.55]
Montgomery et al. [6]	Running	Power	24 h	CMJ	0.08 [-0.79, 0.96]
Pruscino et al. [59]	Running	Strength	24 h	Squat jump	-0.29 [-1.27, 0.70]
Pruscino et al. [59]	Running	Strength	24 h	CMJ	-0.38 [-1.37, 0.61]
Pruscino et al. [59]	Running	Power	24 h	CMJ	-0.23 [-1.22, 0.75]
Test for overall effect: $z = 2.97$ ($p = 0.003$)					**0.49 [0.17, 0.82]**
Heterogeneity: $\chi^2 = 65.4$ ($p < 0.001$); $I^2 = 65\%$					

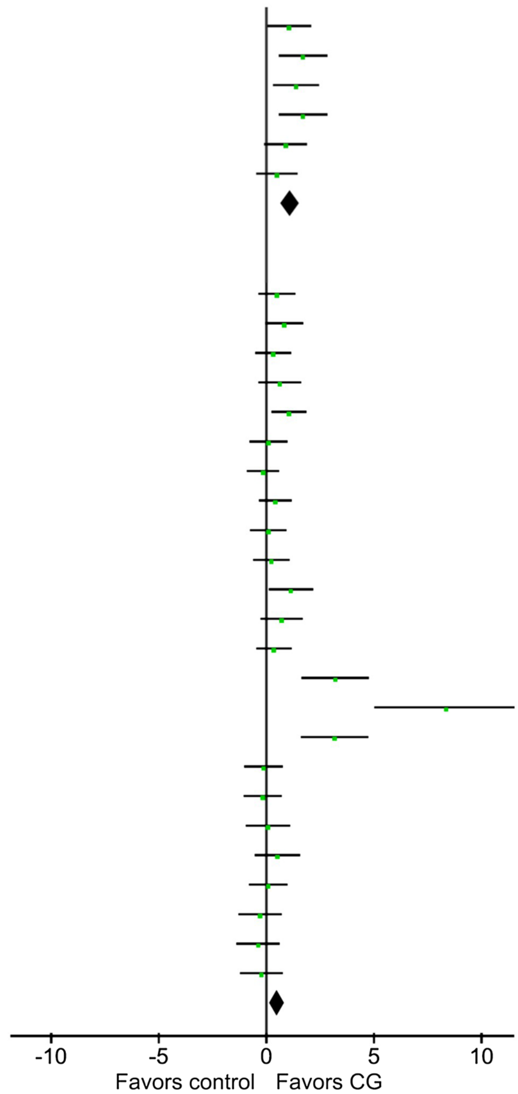


Fig. 4 Forest plot illustrating the effects of compression garments (CG) compared with control on all measures of recovery at 2–8 and 24 h. The results represent part of a comparison with 0–2 and >24 h time points, and have been weighted accordingly. *Square boxes* represent the standardized mean effect for each study, with *lines* demonstrating 95% CIs. A *diamond* represents the overall standardized mean effect. *Bench* bench press, *CI* confidence interval, *CMJ* countermovement jump, *elbow* elbow flexion, *ham* hamstring flexion, *knee* knee extension, *metabolic* cardiovascular exercise with minimal eccentric component, *MVC* maximal voluntary contraction, *resistance* resistance exercise with eccentric component, *scrum* peak scrum power, *throw* maximal throwing distance, *TT* time trial

3.3 Training Status

No significant difference was found between the effects of CG on the recovery of trained and untrained participants across all time points, considering all exercise modalities and performance outcomes ($p = 0.64$, $\chi^2 = 0.21$). Subgroup analysis resulted in no meaningful reduction of heterogeneity: I^2 values of 66 and 63% for trained and untrained participants, respectively, compared with 66% for the combined group. Both trained ($p < 0.001$, $z = 4.84$) and untrained populations ($p = 0.007$, $z = 2.70$) experienced significant benefits from CG on recovery. However, whilst the small benefits of CG were very likely beneficial for trained participants, as demonstrated by the 95% CI failing to transect the threshold for the smallest worthwhile effect [ES = 0.37 (95% CI 0.22, 0.51)], this was not the case for untrained participants [ES = 0.45 (95% CI 0.12, 0.78)].

Study	Challenge	Outcome	Time	Measure	Effect size (mean ± 95% CI)
Armstrong et al. [54]	Running	Endurance	14 d	TTE	0.45 [-0.25, 1.15]
Bieuzen et al. [47]	Running	Strength	48 h	MVC_{knee}	-0.21 [-1.05, 0.63]
Bieuzen et al. [47]	Running	Power	48 h	CMJ	0.79 [-0.09, 1.66]
Carling et al. [50]	Resistance	Strength	48 h	MVC_{elbow}	-0.17 [-0.99, 0.65]
Carling et al. [50]	Resistance	Strength	72 h	MVC_{elbow}	0.05 [-0.77, 0.87]
Cerquiera et al. [51]	Resistance	Strength	96 h	MVC_{elbow}	0.00 [-0.95, 0.95]
Cerquiera et al. [51]	Resistance	Strength	48 h	MVC_{elbow}	0.28 [-0.67, 1.24]
Cerquiera et al. [51]	Resistance	Strength	72 h	MVC_{elbow}	0.17 [-0.78, 1.12]
Davies et al. [33]	Resistance	Power	48 h	10 m sprint	-0.30 [-1.14, 0.54]
Davies et al. [33]	Resistance	Power	48 h	5 m sprint	-0.48 [-1.33, 0.37]
Davies et al. [33]	Resistance	Power	48 h	10 m sprint (505)	0.37 [-0.47, 1.22]
Davies et al. [33]	Resistance	Power	48 h	20 m sprint	-0.30 [-1.14, 0.54]
Davies et al. [33]	Resistance	Power	48 h	CMJ	0.07 [-0.77, 0.90]
Hill et al. [21]	Running	Strength	72 h	MVC_{knee}	0.22 [-0.58, 1.03]
Hill et al. [21]	Running	Strength	48 h	MVC_{knee}	0.35 [-0.46, 1.16]
Jakeman et al. [38]	Resistance	Strength	48 h	MVC_{knee}	7.11 [4.22, 10.00]
Jakeman et al. [38]	Resistance	Power	96 h	CMJ	0.00 [-0.95, 0.95]
Jakeman et al. [38]	Resistance	Strength	72 h	MVC_{knee}	5.82 [3.39, 8.25]
Jakeman et al. [38]	Resistance	Power	96 h	Squat jump	5.92 [3.46, 8.38]
Jakeman et al. [38]	Resistance	Power	48 h	Squat jump	6.35 [3.73, 8.96]
Jakeman et al. [38]	Resistance	Power	72 h	Squat jump	3.36 [1.76, 4.96]
Jakeman et al. [38]	Resistance	Power	72 h	CMJ	3.83 [2.08, 5.58]
Jakeman et al. [38]	Resistance	Strength	96 h	MVC_{knee}	5.33 [3.07, 7.58]
Jakeman et al. [38]	Resistance	Power	48 h	CMJ	4.68 [2.64, 6.71]
Kraemer et al. 2001 [49]	Resistance	Strength	120 h	MVC_{elbow}	1.60 [0.57, 2.64]
Kraemer et al. 2001 [49]	Resistance	Strength	72 h	MVC_{elbow}	1.18 [0.21, 2.14]
Kraemer et al. 2001 [49]	Resistance	Strength	48 h	MVC_{elbow}	0.76 [-0.16, 1.67]
Kraemer et al. 2001 [49]	Resistance	Power	48 h	MVC_{elbow}	-1.53 [-2.56, -0.51]
Kraemer et al. 2001 [49]	Resistance	Power	96 h	MVC_{elbow}	-0.16 [-1.04, 0.72]
Kraemer et al. 2001 [49]	Resistance	Power	120 h	MVC_{elbow}	0.11 [-0.77, 0.99]
Kraemer et al. 2001 [49]	Resistance	Power	72 h	MVC_{elbow}	-0.11 [-0.99, 0.77]
Kraemer et al. 2001 [49]	Resistance	Strength	96 h	MVC_{elbow}	1.18 [0.21, 2.14]
Kraemer et al. 2001 [19]	Resistance	Power	72 h	MVC_{elbow}	2.71 [1.19, 4.22]
Kraemer et al. 2001 [19]	Resistance	Strength	48 h	MVC_{elbow}	2.39 [0.97, 3.81]
Kraemer et al. 2001 [19]	Resistance	Power	48 h	MVC_{elbow}	1.16 [0.04, 2.29]
Kraemer et al. 2001 [19]	Resistance	Strength	72 h	MVC_{elbow}	2.56 [1.09, 4.03]
Montgomery et al. [6]	Running	Power	72 h	CCT	-1.12 [-2.08, -0.17]
Montgomery et al. [6]	Running	Power	48 h	CMJ (pre)	-0.34 [-1.22, 0.55]
Montgomery et al. [6]	Running	Power	72 h	CMJ (pre)	-0.19 [-1.07, 0.69]
Montgomery et al. [6]	Running	Power	72 h	25 m sprint	-0.33 [-1.21, 0.55]
Montgomery et al. [6]	Running	Power	72 h	20 m acc	-1.38 [-2.38, -0.38]
Montgomery et al. [6]	Running	Power	72 h	LD	1.70 [0.64, 2.75]
Montgomery et al. [6]	Running	Power	72 h	CMJ (post)	-0.26 [-1.14, 0.62]
Pruscino et al. [59]	Running	Power	48 h	CMJ	-0.40 [-1.39, 0.59]
Pruscino et al. [59]	Running	Strength	48 h	CMJ	-0.05 [-1.03, 0.93]
Pruscino et al. [59]	Running	Strength	48 h	Squat jump	-0.35 [-1.34, 0.64]
Test for overall effect: $z = 4.14$ ($p < 0.001$)					**0.76 [0.40, 1.12]**
Heterogeneity: $\chi^2 = 255$ ($p < 0.001$); $I^2 = 82\%$					

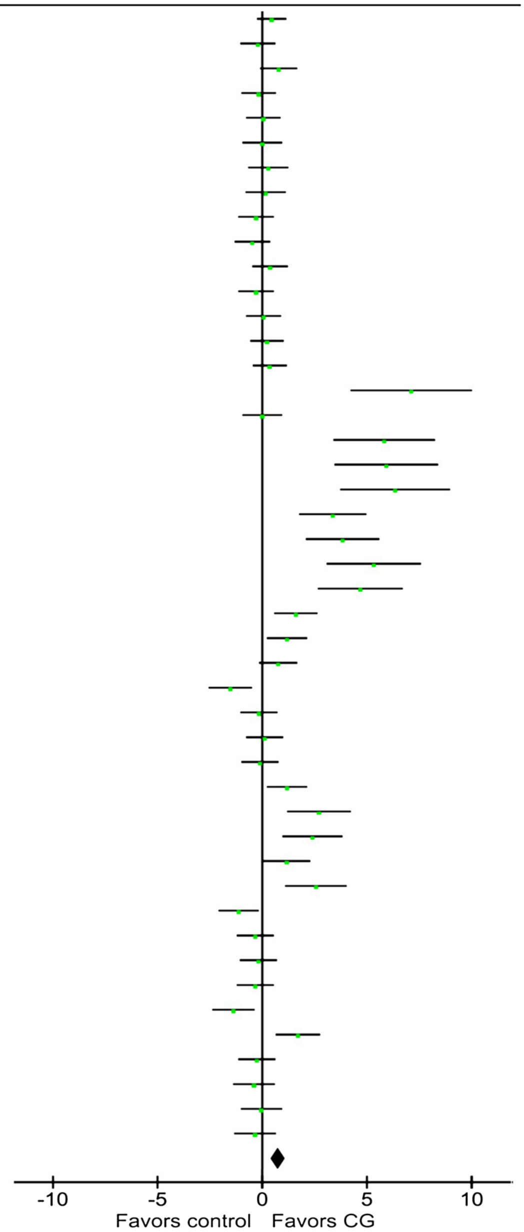


Fig. 5 Forest plot illustrating the effects of compression garments (CG) compared with control on all performance measures of recovery at >24 h. The results represent part of a comparison with 0–2, 2–8 and 24 h time points, and have been weighted accordingly. *Square boxes* represent the standardized mean effect for each study, with *lines* demonstrating 95% CIs. A *diamond* represents the overall standardized mean effect. *505* agility test, *acc* acceleration, *CCT* (basketball) court coverage time, *CI* confidence interval, *CMJ* countermovement jump, *elbow* elbow flexion, *LD* (basketball) line drill, *knee* knee extension, *MVC* maximal voluntary contraction, *post* post-match, *pre* pre-match, *resistance* resistance exercise with eccentric component, *TTE* graduated time to exhaustion test (treadmill)

3.4 Time-Point Analysis

When all performance measures were considered, CG-mediated recovery was significantly influenced by time point ($p < 0.001$, $\chi^2 = 31.6$). This was reflected in reduced heterogeneity in three of the four time periods analysed, with I^2 values of 0, 0, 65 and 82% being reported for the 0–2, 2–8, 24 and >24 h time points, respectively, compared with 66% for the combined group. Whilst recovery was significantly enhanced by CG at each time point (Figs. 3, 4, 5), effects were trivial and unlikely beneficial at 0–2 h [$p = 0.01$, $z = 2.52$; ES = 0.14 (95% CI 0.03, 0.24)]. However, later time points were subject to significant (moderate and large) effects, including 2–8 h

[$p < 0.001$, $z = 5.33$, ES = 1.14 (95% CI 0.72, 1.56)], 24 h [$p = 0.003$, $z = 2.97$, ES = 0.49 (95% CI 0.17, 0.82)] and >24 h [$p < 0.001$, $z = 4.14$, ES = 0.76 (95% CI 0.40, 1.12)].

3.5 The Effects of Compression Garments (CG) on Recovery Outcomes

The magnitude of CG-mediated recovery was significantly different ($p = 0.03$, $\chi^2 = 6.94$) between performance outcomes (strength, power and endurance; Figs. 6, 7, 8). Accordingly, I^2 values were smaller in two of three subgroups (strength = 64%, power = 66%, endurance = 22%) compared with the total group ($I^2 = 66\%$). Strength recovery was subject to the largest benefits from CG ($p < 0.001$, $z = 5.30$), which were moderate in magnitude and very likely beneficial [ES = 0.62 (95% CI 0.39, 0.84)]. The effects of CG on strength recovery were significantly greater than on power over all time points ($p = 0.008$, $\chi^2 = 6.93$). No other differences between outcomes were apparent. Analysis of strength recovery at different times revealed significant ($p < 0.001$, $z = 5.33$), large, very likely beneficial effects at 2–8 h [ES = 1.14 (95% CI 0.72, 1.56)] and >24 h [$p < 0.001$, $z = 3.70$, ES = 1.03 (95% CI 0.48, 1.57)].

The effects of CG on power recovery (Fig. 7) were significant across all time points ($p = 0.008$, $z = 2.64$), although the small effect was not very likely to represent a worthwhile benefit [ES = 0.23 (95% CI 0.06, 0.41)]. Significant but not very likely benefits from CG on the recovery of power were demonstrated only at >24 h [$p = 0.02$, $z = 2.31$, ES = 0.59 (95% CI 0.09, 1.10)].

The recovery of endurance performance over all time points, following all exercise challenges (including both running and metabolic exercise), was also significantly improved with the use of CG ($p = 0.04$, $z = 2.04$). Endurance recovery was subject to small but not very likely benefits from CG [ES = 0.39 (95% CI 0.02, 0.77), Fig. 8]. A significant ($p = 0.01$, $z = 2.58$), large and very likely beneficial effect was apparent at 24 h [ES = 1.05 (95% CI 0.25, 1.85)], with no effects at either 0–2 or >24 h.

3.6 The Benefits of CG for Different Types of Damaging Exercise

There was a significant effect of exercise modality on the effects of CG over all time points (Figs. 9, 10, 11) for all measures of recovery ($p < 0.001$, $\chi^2 = 28.6$). Heterogeneity, as shown by the I^2 statistic, was lower in two of the three subgroups (resistance = 79%, running = 0%, metabolic = 0%) compared with the combined data set ($I^2 = 66\%$). Recovery from resistance exercise (Fig. 9) was subject to the greatest effects [ES = 0.49 (95% CI 0.37, 0.61)], which, although small, were very likely beneficial and significant ($p < 0.001$, $z = 8.09$). Analysing the resistance exercise group separately revealed large, very likely [ES = 1.14 (95% CI 0.72, 1.56)] and significant ($p < 0.001$, $z = 5.33$) benefits at 2–8 h, as well as at 24 h [$p = 0.004$, $z = 2.92$, ES = 1.10 (95% CI 0.36, 1.83)] and >24 h [$p < 0.001$, $z = 4.97$, ES = 1.33 (95% CI 0.80, 1.85)]. In contrast, the impact of CG on recovery was insignificant ($p = 0.23$, $z = 1.20$), trivial and unlikely following running [ES = 0.06 (95% CI −0.04, 0.17)]. Accordingly, the effects on CG on recovery were significantly greater following resistance exercise compared with running ($p < 0.001$, $\chi^2 = 27.6$).

The recovery of endurance or power performance following metabolically challenging (non-load-bearing) exercise was subject to significant ($p = 0.01$, $z = 2.49$) benefits from CG. However, these moderate benefits were unlikely [ES = 0.44 (95% CI 0.09, 0.79)]. When analysed independently, the effects of CG on recovery from metabolic exercise were significant only at the 24 h time point ($p = 0.01$, $z = 2.58$). This effect was large and very likely beneficial [ES = 1.05 (95% CI 0.25, 1.85)].

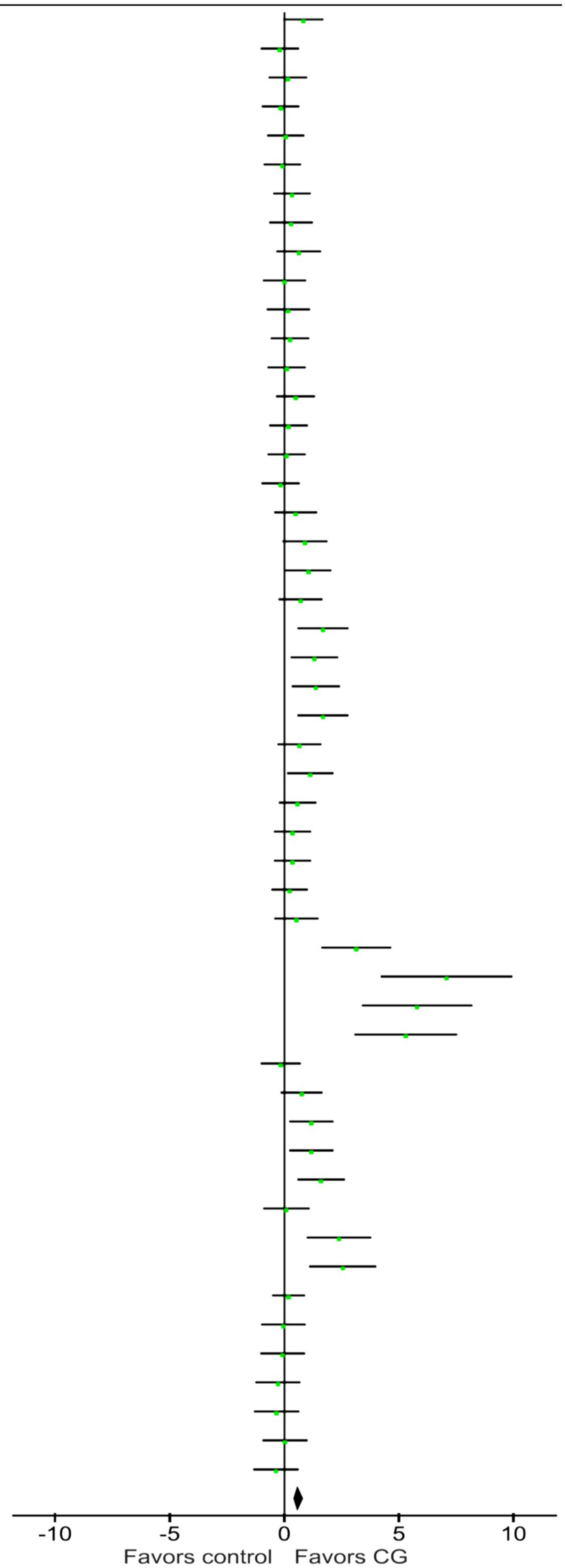
Fig. 6 Forest plot illustrating the effects of compression garments (CG) compared with control on strength recovery at all time points. The results represent part of a comparison with power and endurance performance, and have been weighted accordingly. *Square boxes* represent the standardized mean effect for each study, with *lines* demonstrating 95% CIs. A *diamond* represents the overall standardized mean effect. *0* post-exercise, *bench* bench press, *CI* confidence interval, *CMJ* countermovement jump, *elbow* elbow flexion, *ham* hamstring flexion, *knee* knee extension, *MVC* maximal voluntary contraction, *resistance* resistance exercise with eccentric component ▶

4 Discussion

This meta-analysis, which included 136 data points from 23 studies, is the first to evaluate the effects of CG in relation to performance outcomes, exercise challenges, training status and recovery time points. Its findings may help inform practice by identifying the optimal conditions under which CG may aid recovery. In summary, CG would seem to be most effective for recovery from resistance exercise and prior to strength performance. Large, very likely benefits were demonstrated in these conditions, as well as for next-day cycling performance. The benefits of CG in relation to applied pressures and participant training status are unclear and limited by the paucity of reported data.

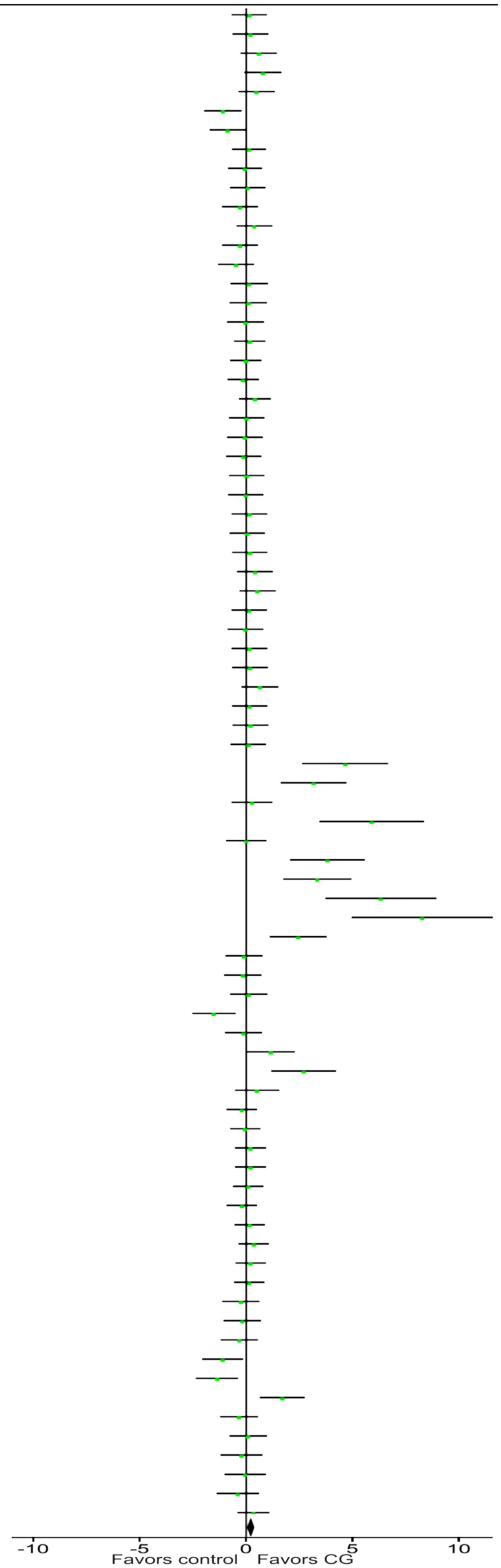
Study	Challenge	Time	Measure	Effect size (mean ± 95% CI)
Bieuzen et al. [47]	Running	24 h	MVC_{knee}	0.83 [-0.05, 1.70]
Bieuzen et al. [47]	Running	48 h	MVC_{knee}	-0.21 [-1.05, 0.63]
Bieuzen et al. [47]	Running	1 h	MVC_{knee}	0.15 [-0.69, 0.98]
Carling et al. [50]	Resistance	48 h	MVC_{elbow}	-0.17 [-0.99, 0.65]
Carling et al. [50]	Resistance	72 h	MVC_{elbow}	0.05 [-0.77, 0.87]
Carling et al. [50]	Resistance	10 min	MVC_{elbow}	-0.09 [-0.91, 0.72]
Carling et al. [50]	Resistance	24 h	MVC_{elbow}	0.33 [-0.50, 1.15]
Cerquiera et al. [51]	Resistance	48 h	MVC_{elbow}	0.28 [-0.67, 1.24]
Cerquiera et al. [51]	Resistance	24 h	MVC_{elbow}	0.62 [-0.35, 1.60]
Cerquiera et al. [51]	Resistance	96 h	MVC_{elbow}	0.00 [-0.95, 0.95]
Cerquiera et al. [51]	Resistance	72 h	MVC_{elbow}	0.17 [-0.78, 1.12]
Duffield et al. [58]	Running	24 h	MVC_{ham}	0.24 [-0.60, 1.08]
Duffield et al. [58]	Running	24 h	MVC_{knee}	0.10 [-0.74, 0.93]
Duffield et al. [58]	Running	2 h	MVC_{knee}	0.49 [-0.36, 1.34]
Duffield et al. [58]	Running	0	MVC_{knee}	0.18 [-0.66, 1.02]
Duffield et al. [58]	Running	2 h	MVC_{ham}	0.09 [-0.75, 0.93]
Duffield et al. [58]	Running	0	MVC_{ham}	-0.18 [-1.01, 0.66]
Goto and Morishima [22]	Resistance	3 h	MVC_{knee}	0.49 [-0.45, 1.43]
Goto and Morishima [22]	Resistance	5 h	MVC_{knee}	0.90 [-0.09, 1.88]
Goto and Morishima [22]	Resistance	8 h	MVC_{knee}	1.05 [0.05, 2.05]
Goto and Morishima [22]	Resistance	24 h	MVC_{knee}	0.71 [-0.25, 1.67]
Goto and Morishima [22]	Resistance	5 h	Bench	1.69 [0.57, 2.81]
Goto and Morishima [22]	Resistance	1 h	Bench	1.31 [0.27, 2.36]
Goto and Morishima [22]	Resistance	8 h	Bench	1.38 [0.32, 2.43]
Goto and Morishima [22]	Resistance	3 h	Bench	1.69 [0.57, 2.81]
Goto and Morishima [22]	Resistance	1 h	MVC_{knee}	0.65 [-0.30, 1.61]
Goto and Morishima [22]	Resistance	24 h	Bench	1.14 [0.12, 2.15]
Hill et al. [21]	Running	0	MVC_{knee}	0.57 [-0.25, 1.39]
Hill et al. [21]	Running	24 h	MVC_{knee}	0.35 [-0.46, 1.16]
Hill et al. [21]	Running	48 h	MVC_{knee}	0.35 [-0.46, 1.16]
Hill et al. [21]	Running	72 h	MVC_{knee}	0.22 [-0.58, 1.03]
Jakeman et al. [38]	Resistance	1 h	MVC_{knee}	0.52 [-0.45, 1.49]
Jakeman et al. [38]	Resistance	24 h	MVC_{knee}	3.15 [1.61, 4.69]
Jakeman et al. [38]	Resistance	48 h	MVC_{knee}	7.11 [4.22, 10.00]
Jakeman et al. [38]	Resistance	72 h	MVC_{knee}	5.82 [3.39, 8.25]
Jakeman et al. [38]	Resistance	96 h	MVC_{knee}	5.33 [3.07, 7.58]
Kraemer et al. 2001 [49]	Resistance	24 h	MVC_{elbow}	-0.16 [-1.04, 0.71]
Kraemer et al. 2001 [49]	Resistance	48 h	MVC_{elbow}	0.76 [-0.16, 1.67]
Kraemer et al. 2001 [49]	Resistance	96 h	MVC_{elbow}	1.18 [0.21, 2.14]
Kraemer et al. 2001 [49]	Resistance	72 h	MVC_{elbow}	1.18 [0.21, 2.14]
Kraemer et al. 2001 [49]	Resistance	120 h	MVC_{elbow}	1.60 [0.57, 2.64]
Kraemer et al. 2001 [19]	Resistance	24 h	MVC_{elbow}	0.08 [-0.94, 1.09]
Kraemer et al. 2001 [19]	Resistance	48 h	MVC_{elbow}	2.39 [0.97, 3.81]
Kraemer et al. 2001 [19]	Resistance	72 h	MVC_{elbow}	2.56 [1.09, 4.03]
Martorelli et al. [61]	Resistance	30 min	MVC_{bench}	0.18 [-0.54, 0.89]
Pruscino et al. [59]	Running	48 h	CMJ	-0.05 [-1.03, 0.93]
Pruscino et al. [59]	Running	1 h	Squat jump	-0.08 [-1.06, 0.90]
Pruscino et al. [59]	Running	24 h	Squat jump	-0.29 [-1.27, 0.70]
Pruscino et al. [59]	Running	48 h	Squat jump	-0.35 [-1.34, 0.64]
Pruscino et al. [59]	Running	1 h	CMJ	0.02 [-0.96, 1.00]
Pruscino et al. [59]	Running	24 h	CMJ	-0.38 [-1.37, 0.61]
Test for overall effect: z = 5.30 (p < 0.001)				**0.62 [0.39, 0.84]**

Heterogeneity: $\chi^2 = 141$, ($p < 0.001$); $I^2 = 64\%$



Study	Challenge	Time	Measure	Effect size (mean ± 95% CI)
Argus et al. [62]	Metabolic	30 min	Bike 30 s sprint	0.14 [-0.69, 0.98]
Argus et al. [62]	Metabolic	1 h	Bike 30 s sprint	0.19 [-0.64, 1.03]
Bieuzen et al. [47]	Running	1 h	CMJ	0.59 [-0.27, 1.45]
Bieuzen et al. [47]	Running	48 h	CMJ	0.79 [-0.09, 1.66]
Bieuzen et al. [47]	Running	24 h	CMJ	0.48 [-0.37, 1.33]
Born et al. [55]	Running	30 min	30 m sprint	-1.11 [-1.98, -0.24]
Born et al. [55]	Running	20 min	30 m sprint	-0.88 [-1.73, -0.04]
Born et al. [55]	Running	30 min	30 m sprint	0.13 [-0.67, 0.93]
Born et al. [55]	Running	20 min	30 m sprint	-0.07 [-0.87, 0.73]
Davies et al. [33]	Resistance	48 h	CMJ	0.07 [-0.77, 0.90]
Davies et al. [33]	Resistance	48 h	20 m sprint	-0.30 [-1.14, 0.54]
Davies et al. [33]	Resistance	48 h	10 m sprint (505)	0.37 [-0.47, 1.22]
Davies et al. [33]	Resistance	48 h	10 m sprint	-0.30 [-1.14, 0.54]
Davies et al. [33]	Resistance	48 h	5 m sprint	-0.48 [-1.33, 0.37]
Duffield and Portus [56]	Running	10 min	10 m sprint	0.13 [-0.75, 1.01]
Duffield and Portus [56]	Running	24 h	Throw	0.10 [-0.78, 0.98]
Duffield and Portus [56]	Running	10 min	20 m sprint	-0.04 [-0.91, 0.84]
Duffield et al. [57]	Running	0	Scrum	0.17 [-0.57, 0.91]
Duffield et al. [57]	Running	0	20 m sprint	-0.02 [-0.76, 0.72]
Duffield et al. [57]	Running	24 h	20 m sprint	-0.15 [-0.89, 0.60]
Duffield et al. [57]	Running	24 h	Scrum	0.41 [-0.34, 1.16]
Duffield et al. [58]	Running	9 min	20 m sprint 10	0.01 [-0.82, 0.85]
Duffield et al. [58]	Running	10 min	Bound 2	-0.06 [-0.90, 0.77]
Duffield et al. [58]	Running	7 min	20 m sprint 8	-0.12 [-0.96, 0.71]
Duffield et al. [58]	Running	8 min	20 m sprint 9	0.01 [-0.82, 0.85]
Duffield et al. [58]	Running	10 min	Bound 5	-0.03 [-0.86, 0.81]
Duffield et al. [58]	Running	10 min	Bound 6	0.15 [-0.69, 0.98]
Duffield et al. [58]	Running	10 min	Bound 3	0.04 [-0.79, 0.88]
Duffield et al. [58]	Running	10 min	Bound 4	0.17 [-0.67, 1.00]
Duffield et al. [58]	Running	1 min	20 m sprint 2	0.40 [-0.45, 1.24]
Duffield et al. [58]	Running	2 min	20 m sprint 3	0.53 [-0.32, 1.38]
Duffield et al. [58]	Running	5 min	20 m sprint 6	0.14 [-0.70, 0.98]
Duffield et al. [58]	Running	6 min	20 m sprint 7	-0.04 [-0.88, 0.80]
Duffield et al. [58]	Running	3 min	20 m sprint 4	0.15 [-0.69, 0.99]
Duffield et al. [58]	Running	4 min	20 m sprint 5	0.18 [-0.66, 1.01]
Duffield et al. [58]	Running	10 min	Bound 10	0.64 [-0.22, 1.50]
Duffield et al. [58]	Running	10 min	Bound 9	0.16 [-0.68, 1.00]
Duffield et al. [58]	Running	10 min	Bound 8	0.20 [-0.64, 1.03]
Duffield et al. [58]	Running	10 min	Bound 7	0.09 [-0.74, 0.93]
Jakeman et al. [38]	Resistance	48 h	CMJ	4.68 [2.64, 6.71]
Jakeman et al. [38]	Resistance	24 h	CMJ	3.18 [1.63, 4.73]
Jakeman et al. [38]	Resistance	1 h	CMJ	0.27 [-0.69, 1.23]
Jakeman et al. [38]	Resistance	96 h	Squat jump	5.92 [3.46, 8.38]
Jakeman et al. [38]	Resistance	96 h	CMJ	0.00 [-0.95, 0.95]
Jakeman et al. [38]	Resistance	72 h	CMJ	3.83 [2.08, 5.58]
Jakeman et al. [38]	Resistance	72 h	Squat jump	3.36 [1.76, 4.96]
Jakeman et al. [38]	Resistance	48 h	Squat jump	6.35 [3.73, 8.96]
Jakeman et al. [38]	Resistance	24 h	CMJ	8.30 [4.98, 11.63]
Jakeman et al. [38]	Resistance	1 h	Squat jump	2.45 [1.11, 3.79]
Kraemer et al. 2001 [49]	Resistance	72 h	MVC_{elbow}	-0.11 [-0.99, 0.77]
Kraemer et al. 2001 [49]	Resistance	96 h	MVC_{elbow}	-0.16 [-1.04, 0.72]
Kraemer et al. 2001 [49]	Resistance	120 h	MVC_{elbow}	0.11 [-0.77, 0.99]
Kraemer et al. 2001 [49]	Resistance	48 h	MVC_{elbow}	-1.53 [-2.56, -0.51]
Kraemer et al. 2001 [49]	Resistance	24 h	MVC_{elbow}	-0.13 [-1.01, 0.75]
Kraemer et al. 2001 [19]	Resistance	48 h	MVC_{elbow}	1.16 [0.04, 2.29]
Kraemer et al. 2001 [19]	Resistance	72 h	MVC_{elbow}	2.71 [1.19, 4.22]
Kraemer et al. 2001 [19]	Resistance	24 h	MVC_{elbow}	0.51 [-0.53, 1.55]
Martorelli et al. [61]	Resistance	5 min	Bench set 3 pk	-0.21 [-0.93, 0.50]
Martorelli et al. [61]	Resistance	7 min 30 s	Bench set 4 pk	-0.05 [-0.77, 0.66]
Martorelli et al. [61]	Resistance	10 min	Bench set 5 pk	0.20 [-0.52, 0.92]
Martorelli et al. [61]	Resistance	12 min 30 s	Bench set 6 pk	0.20 [-0.52, 0.92]
Martorelli et al. [61]	Resistance	7 min 30 s	Bench set 4 mean	0.09 [-0.63, 0.81]
Martorelli et al. [61]	Resistance	10 min	Bench set 5 mean	-0.21 [-0.93, 0.51]
Martorelli et al. [61]	Resistance	12 min 30 s	Bench set 6 mean	0.16 [-0.56, 0.88]
Martorelli et al. [61]	Resistance	2 min 30 s	Bench 2 pk	0.35 [-0.37, 1.08]
Martorelli et al. [61]	Resistance	2 min 30 s	Bench set 2 mean	0.21 [-0.51, 0.92]
Martorelli et al. [61]	Resistance	5 min	Bench set 3 mean	0.14 [-0.58, 0.86]
Montgomery et al. [6]	Running	72 h	CMJ (post)	-0.26 [-1.14, 0.62]
Montgomery et al. [6]	Running	72 h	CMJ (pre)	-0.19 [-1.07, 0.69]
Montgomery et al. [6]	Running	72 h	25 m sprint	-0.33 [-1.21, 0.55]
Montgomery et al. [6]	Running	72 h	CCT	-1.12 [-2.08, -0.17]
Montgomery et al. [6]	Running	72 h	20 m acc	-1.38 [-2.38, -0.38]
Montgomery et al. [6]	Running	72 h	LD	1.70 [0.64, 2.75]
Montgomery et al. [6]	Running	48 h	CMJ (pre)	-0.34 [-1.22, 0.55]
Montgomery et al. [6]	Running	24 h	CMJ (pre)	0.08 [-0.79, 0.96]
Pruscino et al. [59]	Running	24 h	CMJ	-0.23 [-1.22, 0.75]
Pruscino et al. [59]	Running	1 h	CMJ	-0.05 [-1.03, 0.93]
Pruscino et al. [59]	Running	48 h	CMJ	-0.40 [-1.39, 0.59]
Rugg et al. [60]	Running	15 min	CMJ	0.33 [-0.42, 1.08]
Test for overall effect: z = 2.64 (p = 0.008)				**0.23 [0.06, 0.41]**

Heterogeneity: χ^2 = 229, (p < 0.001); I^2 = 66%



◀ **Fig. 7** Forest plot illustrating the effects of compression garments (CG) compared with control on power recovery at all time points. The results represent part of a comparison with strength and endurance performance, and are weighted accordingly. *Square boxes* represent the standardized mean effect for each study, with *lines* demonstrating 95% CIs. A *diamond* represents the overall standardized mean effect. *0* post-exercise, *505* agility test, *acc* acceleration, *bench* bench press, *bound* double leg bound, *CI* confidence interval, *CMJ* countermovement jump, *CCT* (basketball) court coverage time, *elbow* elbow flexion, *LD* (basketball) line drill, *metabolic* cardiovascular exercise with minimal eccentric component, *MVC* maximal voluntary contraction, *pk* peak, *post* post-match, *pre* pre-match, *resistance* resistance exercise with eccentric component, *scrum* peak scrum power, *throw* maximal throwing distance

4.1 Performance Outcomes

These data demonstrate that CG exert a preferential effect on strength recovery. Whilst previous analyses have reported a tendency for CG to exert greater relative effects on power recovery [9, 64], these analyses were less extensive. Hill et al. [21] reported a tendency towards larger effects for power recovery compared with strength, following the analysis of 17 power outcomes from six studies and 16 strength outcomes from five studies (a total of eight studies and 33 data points). Similarly, Marques-Jimenez et al. [64] recently reported a tendency towards comparatively greater effects on power recovery after analysing 30 power outcomes from five studies and 45 strength outcomes from eight studies (nine studies and 75 data points in total). However, the present results from the analysis of 136 data points demonstrate a significantly larger effect from CG on strength compared with power, while very likely benefits were apparent for strength outcomes only (Figs. 6, 12). Analysing the recovery from specific exercise challenges seems to mirror these findings, as CG were most effective following resistance or plyometric exercise (Figs. 9, 10, 13). This finding is supported by numerous studies that demonstrate that CG serve to attenuate symptoms of muscle damage [17, 19, 20]. Furthermore, CG demonstrated large, very likely benefits on strength recovery at >24 h, when muscle damage and associated force decrements are greatest [27, 28]. This suggests that compression enhances force recovery by ameliorating EIMD.

4.2 Compression, Muscle Damage and Strength Recovery

Within the studies reviewed, the greatest levels of muscle damage were observed following resistance exercise. The greatest circulating levels of CK, for example, were reported to reach 1350 $U \cdot L^{-1}$ following two sets of 50 bicep curls with 12 maximal eccentric contractions [19]. In contrast, far lower [CK] values of 353 $U \cdot L^{-1}$ [58] and 305 $U \cdot L^{-1}$ [47] were elicited by repeated sprint protocols. These findings are consistent with existing literature that suggests that resistance exercise typically leads to greater levels of muscle damage than running [65–67], while non-load-bearing exercise is subject to even less eccentric load [12]. Although running can result in comparable levels of EIMD to resistance exercise, for example, following a marathon [21], levels of EIMD reported throughout the literature are generally lower than those from resistance training [68].

The large benefits of CG on both strength recovery and recovery from resistance exercise are concordant with a role in ameliorating muscle damage. The results of this meta-analysis support this theory in three main ways. Firstly, force recovery is intimately linked to muscle damage, being impaired to a greater extent by EIMD than

Study	Challenge	Time	Measure	Effect size (mean ± 95% CI)
Ali et al. [53]	Running	1 h	MSFT	-0.28 [-1.02, 0.47]
Armstrong et al. [54]	Running	14 d	TTE	0.45 [-0.25, 1.15]
de Glanville and Hamlin 2012 [35]	Metabolic	24 h	40 km TT	1.05 [0.25, 1.85]
Driller and Halson [44]	Metabolic	1 h	15 min TT	0.69 [-0.22, 1.60]
Sperlich et al. [63]	Metabolic	6 min	Ski 3 min sprint	0.15 [-0.73, 1.02]
Sperlich et al. [63]	Metabolic	12 min	Ski 3 min sprint	0.37 [-0.51, 1.26]
Test for overall effect: $z = 2.04$ ($p = 0.04$)				**0.39 [0.02, 0.77]**
Heterogeneity: $\chi^2 = 6.43$, ($p = 0.27$); $I^2 = 22\%$				

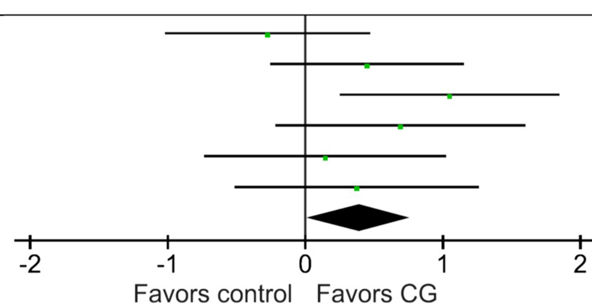
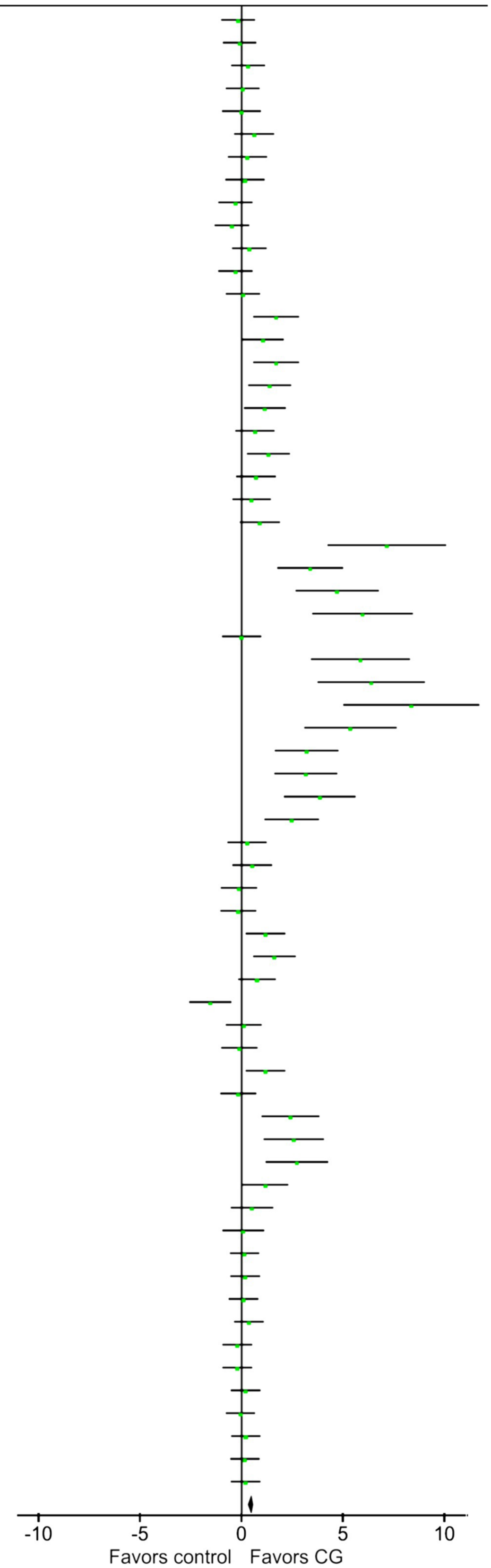


Fig. 8 Forest plot illustrating the effects of compression garments (CG) compared with controls on recovery of endurance performance at all time points. The results represent part of a comparison with strength and power performance, and have been weighted accordingly. *Square boxes* represent the standardized mean effect for each study, with *lines* demonstrating 95% CIs. A *diamond* represents the overall standardized mean effect. *CI* confidence interval, *metabolic* cardiovascular exercise with minimal eccentric component, *MSFT* multi-stage fitness test, *ski* skiing ergometer, *TT* time trial, *TTE* graduated time to exhaustion test (treadmill)

Study	Outcome	Time	Measure	Effect size (mean ± 95% CI)
Carling et al. [50]	Strength	48 h	MVC_{elbow}	-0.17 [-0.99, 0.65]
Carling et al. [50]	Strength	10 min	MVC_{knee}	-0.09 [-0.91, 0.72]
Carling et al. [50]	Strength	24 h	MVC_{elbow}	0.33 [-0.50, 1.15]
Carling et al. [50]	Strength	72 h	MVC_{elbow}	0.05 [-0.77, 0.87]
Cerquiera et al. [51]	Strength	96 h	MVC_{elbow}	0.00 [-0.95, 0.95]
Cerquiera et al. [51]	Strength	24 h	MVC_{elbow}	0.62 [-0.35, 1.60]
Cerquiera et al. [51]	Strength	48 h	MVC_{elbow}	0.28 [-0.67, 1.24]
Cerquiera et al. [51]	Strength	72 h	MVC_{elbow}	0.17 [-0.78, 1.12]
Davies et al. [33]	Power	48 h	10 m sprint	-0.30 [-1.14, 0.54]
Davies et al. [33]	Power	48 h	5 m sprint	-0.48 [-1.33, 0.37]
Davies et al. [33]	Power	48 h	10 m sprint (505)	0.37 [-0.47, 1.22]
Davies et al. [33]	Power	48 h	20 m sprint	-0.30 [-1.14, 0.54]
Davies et al. [33]	Power	48 h	CMJ	0.07 [-0.77, 0.90]
Goto and Morishima [22]	Strength	3 h	Bench	1.69 [0.57, 2.81]
Goto and Morishima [22]	Strength	8 h	MVC_{knee}	1.05 [0.05, 2.05]
Goto and Morishima [22]	Strength	5 h	Bench	1.69 [0.57, 2.81]
Goto and Morishima [22]	Strength	8 h	Bench	1.38 [0.32, 2.43]
Goto and Morishima [22]	Strength	24 h	Bench	1.14 [0.12, 2.15]
Goto and Morishima [22]	Strength	1 h	MVC_{knee}	0.65 [-0.30, 1.61]
Goto and Morishima [22]	Strength	1 h	Bench	1.31 [0.27, 2.36]
Goto and Morishima [22]	Strength	24 h	MVC_{knee}	0.71 [-0.25, 1.67]
Goto and Morishima [22]	Strength	3 h	MVC_{knee}	0.49 [-0.45, 1.43]
Goto and Morishima [22]	Strength	5 h	MVC_{knee}	0.90 [-0.09, 1.88]
Jakeman et al. [38]	Strength	48 h	MVC_{knee}	7.11 [4.22, 10.00]
Jakeman et al. [38]	Power	72 h	Squat jump	3.36 [1.76, 4.96]
Jakeman et al. [38]	Power	48 h	CMJ	4.68 [2.64, 6.71]
Jakeman et al. [38]	Power	96 h	Squat jump	5.92 [3.46, 8.38]
Jakeman et al. [38]	Power	96 h	CMJ	0.00 [-0.95, 0.95]
Jakeman et al. [38]	Strength	72 h	MVC_{knee}	5.82 [3.39, 8.25]
Jakeman et al. [38]	Power	48 h	Squat jump	6.35 [3.73, 8.96]
Jakeman et al. [38]	Power	24 h	CMJ	8.30 [4.98, 11.63]
Jakeman et al. [38]	Strength	96 h	MVC_{knee}	5.33 [3.07, 7.58]
Jakeman et al. [38]	Power	24 h	CMJ	3.18 [1.63, 4.73]
Jakeman et al. [38]	Strength	24 h	MVC_{knee}	3.15 [1.61, 4.69]
Jakeman et al. [38]	Power	72 h	CMJ	3.83 [2.08, 5.58]
Jakeman et al. [38]	Power	1 h	Squat jump	2.45 [1.11, 3.79]
Jakeman et al. [38]	Power	1 h	CMJ	0.27 [-0.69, 1.23]
Jakeman et al. [38]	Strength	1 h	MVC_{knee}	0.52 [-0.45, 1.49]
Kraemer et al. 2001 [49]	Power	24 h	MVC_{elbow}	-0.13 [-1.01, 0.75]
Kraemer et al. 2001 [49]	Power	96 h	MVC_{elbow}	-0.16 [-1.04, 0.72]
Kraemer et al. 2001 [49]	Strength	72 h	MVC_{elbow}	1.18 [0.21, 2.14]
Kraemer et al. 2001 [49]	Strength	120 h	MVC_{elbow}	1.60 [0.57, 2.64]
Kraemer et al. 2001 [49]	Strength	48 h	MVC_{elbow}	0.76 [-0.16, 1.67]
Kraemer et al. 2001 [49]	Power	48 h	MVC_{elbow}	-1.53 [-2.56, -0.51]
Kraemer et al. 2001 [49]	Power	120 h	MVC_{elbow}	0.11 [-0.77, 0.99]
Kraemer et al. 2001 [49]	Power	72 h	MVC_{elbow}	-0.11 [-0.99, 0.77]
Kraemer et al. 2001 [49]	Strength	96 h	MVC_{elbow}	1.18 [0.21, 2.14]
Kraemer et al. 2001 [49]	Strength	24 h	MVC_{elbow}	-0.16 [-1.04, 0.71]
Kraemer et al. 2001 [19]	Strength	48 h	MVC_{elbow}	2.39 [0.97, 3.81]
Kraemer et al. 2001 [19]	Strength	72 h	MVC_{elbow}	2.56 [1.09, 4.03]
Kraemer et al. 2001 [19]	Power	72 h	MVC_{elbow}	2.71 [1.19, 4.22]
Kraemer et al. 2001 [19]	Power	48 h	MVC_{elbow}	1.16 [0.04, 2.29]
Kraemer et al. 2001 [19]	Power	24 h	MVC_{elbow}	0.51 [-0.53, 1.55]
Kraemer et al. 2001 [19]	Strength	24 h	MVC_{elbow}	0.08 [-0.94, 1.09]
Martorelli et al. [61]	Power	5 min	Bench set 3 mean	0.14 [-0.58, 0.86]
Martorelli et al. [61]	Strength	30 min	MVC_{bench}	0.18 [-0.54, 0.89]
Martorelli et al. [61]	Power	7 min 30 s	Bench set 4 mean	0.09 [-0.63, 0.81]
Martorelli et al. [61]	Power	2 min 30 s	Bench set 2 pk	0.35 [-0.37, 1.08]
Martorelli et al. [61]	Power	10 min	Bench set 5 mean	-0.21 [-0.93, 0.51]
Martorelli et al. [61]	Power	5 min	Bench set 3 pk	-0.21 [-0.93, 0.50]
Martorelli et al. [61]	Power	12 min 30 s	Bench set 6 pk	0.20 [-0.52, 0.92]
Martorelli et al. [61]	Power	7 min 30 s	Bench set 4 pk	-0.05 [-0.77, 0.66]
Martorelli et al. [61]	Power	2 min 30 s	Bench 2 mean	0.21 [-0.51, 0.92]
Martorelli et al. [61]	Power	12 min 30 s	Bench set 6 mean	0.16 [-0.56, 0.88]
Martorelli et al. [61]	Power	10 min	Bench set 5 pk	0.20 [-0.52, 0.92]
Test for overall effect: $z = 8.09$ ($p < 0.001$)				**0.49 [0.37, 0.61]**

Heterogeneity: $\chi^2 = 301$ ($p < 0.001$); $I^2 = 79\%$



◀ **Fig. 9** Forest plot illustrating the effects of compression garments (CG) compared with control on all recovery measures following resistance exercise at all time points. The results represent part of a comparison with running and non-running endurance (metabolic) exercise challenges, and have been weighted accordingly. *Square boxes* represent the standardized mean effect for each study, with *lines* demonstrating 95% CIs. A *diamond* represents the overall standardized mean effect. *505* agility test, *bench* bench press, *CI* confidence interval, *CMJ* countermovement jump, *elbow* elbow flexion, *knee* knee extension, *MVC* maximal voluntary contraction, *pk* peak

either running [69] or power outcomes [19, 20, 70] from 24 to 48 h. Secondly, the observed time course of recovery for both resistance exercise and strength performance lends further weight to the idea that CG ameliorate muscle damage. Apart from the 2–8 h time point, very likely benefits to recovery for both strength performance [ES = 1.03 (95% CI 0.48, 1.57)] and following resistance exercise [ES = 1.33 (95% CI 0.80, 1.85)] were only apparent at >24 h. A delayed recovery from resistance exercise is a common feature of EIMD [27], while impairments to strength are known to persist for longer than impairments to power [70, 71]. Strength recovery at time points >24 h post-exercise will depend upon the attenuation of EIMD [70, 71]. Finally, markers of muscle damage, although not quantified in this meta-analysis, were greatly attenuated by CG in studies on strength recovery and resistance exercise. Where measured, reductions in CK activity were reported in parallel with both improved strength performance and DOMS [17, 19, 20], while four studies that demonstrated significant benefits from CG also reported lower levels of swelling compared with controls [19, 22, 44, 49]. Interestingly, oedema has been suggested to play a mechanistic role in the progression of muscle damage, rather than simply representing a symptom of EIMD. It is thought that the infiltration of fluid into muscle cells increases osmotic pressure, leading to further cell lysis and muscle damage [30, 32]. CG may therefore enhance recovery by ameliorating swelling to limit the progression of EIMD [17, 19, 20].

In contrast to the long-term benefits of compression, some of the greatest effects of CG on strength recovery were demonstrated at 2–8 h. All data were extracted from a single trial, which assessed the effects of CG over 24 h recovery from resistance training [22]. The authors reported faster recovery of upper body strength [chest-press 1 repetition maximum (RM)] over the first 8 h ($p < 0.05$). However, the mechanisms of action over these time points were unclear as the CG and control groups displayed similar levels of lactate, muscle damage (myoglobin and CK), anabolic hormones (insulin like growth factor-1 and free testosterone), and inflammation, as shown by interleukin 6 and interleukin 1 [22]. It is interesting that whilst the effects of muscle temperature on strength and power performance are well established [72], and may explain both detrimental [73] and ergogenic [74] effects of recovery interventions, the effects of temperature as a mediating factor on compression have yet to be defined. Other mechanisms proposed to explain the short-term recovery benefits of CG include proprioceptive or neuromuscular effects [75], improved lactate clearance [18, 58, 61, 63] and increased oxygen saturation [76].

4.3 Compression, Power Recovery, and Running

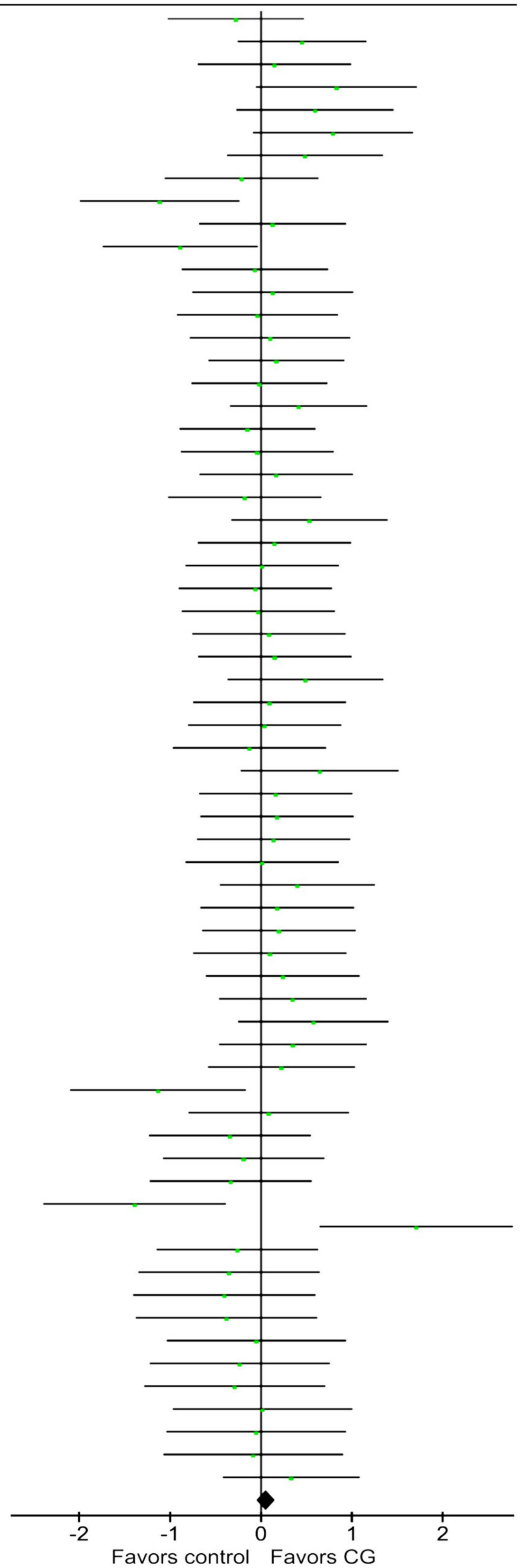
In contrast to resistance exercise, no likely recovery benefits from CG were demonstrated following running. This finding is in agreement with previous research, with a recent review of 32 trials using CG during or after running reporting insignificant effects on recovery [37]. An earlier review of 23 peer-reviewed papers, 11 of which were studies on recovery from running, also found insignificant effects from CG [39]. The mechanisms by which load-bearing exercise retards recovery are complex and varied, and include muscle damage and the depletion of endogenous energy substrates [77], the accumulation of metabolic by-products [78, 79] and impaired neuromuscular function [80]. It is therefore unsurprising that ameliorating muscle damage alone is often insufficient to aid recovery from running [33, 81], as this milieu of degenerative processes is unlikely to be wholly addressed by a single recovery method. Generating power, too, depends on a varied combination of physiological factors, including neuromuscular [70], coordinative [82] and tendon-mediated components [83]. This will reduce the relative influence of muscle damage and, potentially, the benefits of CG. Compression may have also failed to provide very likely benefits on power recovery due to the wide variation in the performance measures studied. The current analysis grouped together power outputs for squat jumps, countermovement jumps, numerous resistance exercises (at various loads and velocities), and various running and ergometer-based sprint protocols. The large number of outcomes analysed here (79 data points) compared with previous meta-analyses (17 and 30 data points for the analyses of Hill et al. and Marques-Jimenez et al., respectively) may further explain the conflict between results [6, 33, 38, 47, 55–62]. As the recovery rates of these different movements are unique to their neuromuscular profiles [84, 85], any positive impacts from CG that stem purely from attenuating muscle damage will vary according to outcome measures.

4.4 Compression, Metabolic Exercise and Endurance Performance

Compression-mediated recovery following metabolic exercise, and prior to endurance performance, were subject to only small, significant but unlikely benefits (Figs. 8, 11,

Study	Outcome	Time	Measure	Effect size (mean ± 95% CI)
Ali et al. [53]	Endurance	1 h	MSFT	-0.28 [-1.02, 0.47]
Armstrong et al. [54]	Endurance	14 d	TTE	0.45 [-0.25, 1.15]
Bieuzen et al. [47]	Strength	1 h	MVC_{knee}	0.15 [-0.69, 0.98]
Bieuzen et al. [47]	Strength	24 h	MVC_{knee}	0.83 [-0.05, 1.70]
Bieuzen et al. [47]	Power	1 h	CMJ	0.59 [-0.27, 1.45]
Bieuzen et al. [47]	Power	48 h	CMJ	0.79 [-0.09, 1.66]
Bieuzen et al. [47]	Power	24 h	CMJ	0.48 [-0.37, 1.33]
Bieuzen et al. [47]	Strength	48 h	MVC_{knee}	-0.21 [-1.05, 0.63]
Born et al. [55]	Power	30 min	30 m sprint	-1.11 [-1.98, -0.24]
Born et al. [55]	Power	30 min	30 m sprint	0.13 [-0.67, 0.93]
Born et al. [55]	Power	20 min	30 m sprint	-0.88 [-1.73, -0.04]
Born et al. [55]	Power	20 min	30 m sprint	-0.07 [-0.87, 0.73]
Duffield and Portus [56]	Power	10 min	10 m sprint	0.13 [-0.75, 1.01]
Duffield and Portus [56]	Power	10 min	20 m sprint	-0.04 [-0.91, 0.84]
Duffield and Portus [56]	Power	24 h	Throw	0.10 [-0.78, 0.98]
Duffield et al. [57]	Power	0	Scrum	0.17 [-0.57, 0.91]
Duffield et al. [57]	Power	0	20 m sprint	-0.02 [-0.76, 0.72]
Duffield et al. [57]	Power	24 h	Scrum	0.41 [-0.34, 1.16]
Duffield et al. [57]	Power	24 h	20 m sprint	-0.15 [-0.89, 0.60]
Duffield et al. [58]	Power	6 min	20 m sprint 7	-0.04 [-0.88, 0.80]
Duffield et al. [58]	Power	10 min	Bound 4	0.17 [-0.67, 1.00]
Duffield et al. [58]	Strength	0	MVC_{ham}	-0.18 [-1.01, 0.66]
Duffield et al. [58]	Power	2 min	20 m sprint 3	0.53 [-0.32, 1.38]
Duffield et al. [58]	Power	10 min	Bound 6	0.15 [-0.69, 0.98]
Duffield et al. [58]	Power	8 min	20 m sprint 9	0.01 [-0.82, 0.85]
Duffield et al. [58]	Power	10 min	Bound 2	-0.06 [-0.90, 0.77]
Duffield et al. [58]	Power	10 min	Bound 5	-0.03 [-0.86, 0.81]
Duffield et al. [58]	Strength	2 h	MVC_{ham}	0.09 [-0.75, 0.93]
Duffield et al. [58]	Power	3 min	20 m sprint 4	0.15 [-0.69, 0.99]
Duffield et al. [58]	Strength	2 h	MVC_{knee}	0.49 [-0.36, 1.34]
Duffield et al. [58]	Power	10 min	Bound 7	0.09 [-0.74, 0.93]
Duffield et al. [58]	Power	10 min	Bound 3	0.04 [-0.79, 0.88]
Duffield et al. [58]	Power	3 min	20 m sprint 8	-0.12 [-0.96, 0.71]
Duffield et al. [58]	Power	10 min	Bound 10	0.64 [-0.22, 1.50]
Duffield et al. [58]	Power	10 min	Bound 9	0.16 [-0.68, 1.00]
Duffield et al. [58]	Power	4 min	20 m sprint 5	0.18 [-0.66, 1.01]
Duffield et al. [58]	Power	5 min	20 m sprint 6	0.14 [-0.70, 0.98]
Duffield et al. [58]	Power	9 min	20 m sprint 10	0.01 [-0.82, 0.85]
Duffield et al. [58]	Power	1 min	20 m sprint 2	0.40 [-0.45, 1.24]
Duffield et al. [58]	Strength	0	MVC_{knee}	0.18 [-0.66, 1.02]
Duffield et al. [58]	Power	10 min	Bound 8	0.20 [-0.64, 1.03]
Duffield et al. [58]	Strength	24 h	MVC_{knee}	0.10 [-0.74, 0.93]
Duffield et al. [58]	Strength	24 h	MVC_{ham}	0.24 [-0.60, 1.08]
Hill et al. [21]	Strength	48 h	MVC_{knee}	0.35 [-0.46, 1.16]
Hill et al. [21]	Strength	0	MVC_{knee}	0.57 [-0.25, 1.39]
Hill et al. [21]	Strength	24 h	MVC_{knee}	0.35 [-0.46, 1.16]
Hill et al. [21]	Strength	72 h	MVC_{knee}	0.22 [-0.58, 1.03]
Montgomery et al. [6]	Power	72 h	CCT	-1.12 [-2.08, -0.17]
Montgomery et al. [6]	Power	24 h	CMJ (pre)	0.08 [-0.79, 0.96]
Montgomery et al. [6]	Power	48 h	CMJ (pre)	-0.34 [-1.22, 0.55]
Montgomery et al. [6]	Power	72 h	CMJ (pre)	-0.19 [-1.07, 0.69]
Montgomery et al. [6]	Power	72 h	25 m sprint	-0.33 [-1.21, 0.55]
Montgomery et al. [6]	Power	72 h	20 m acc	-1.38 [-2.38, -0.38]
Montgomery et al. [6]	Power	72 h	LD	1.70 [0.64, 2.75]
Montgomery et al. [6]	Power	72 h	CMJ (post)	-0.26 [-1.14, 0.62]
Pruscino et al. [59]	Strength	48 h	Squat jump	-0.35 [-1.34, 0.64]
Pruscino et al. [59]	Power	48 h	CMJ	-0.40 [-1.39, 0.59]
Pruscino et al. [59]	Strength	24 h	CMJ	-0.38 [-1.37, 0.61]
Pruscino et al. [59]	Strength	48 h	CMJ	-0.05 [-1.03, 0.93]
Pruscino et al. [59]	Power	24 h	CMJ	-0.23 [-1.22, 0.75]
Pruscino et al. [59]	Strength	24 h	Squat jump	-0.29 [-1.27, 0.70]
Pruscino et al. [59]	Strength	1 h	CMJ	0.02 [-0.96, 1.00]
Pruscino et al. [59]	Power	1 h	CMJ	-0.05 [-1.03, 0.93]
Pruscino et al. [59]	Strength	1 h	Squat jump	-0.08 [-1.06, 0.90]
Rugg et al. [60]	Power	15 min	CMJ	0.33 [-0.42, 1.08]
Test for overall effect: $z = 1.20$ ($p = 0.23$)				**0.06 [-0.04, 0.17]**

Heterogeneity: $\chi^2 = 62.0$, ($p = 0.58$); $I^2 = 0\%$



◀**Fig. 10** Forest plot illustrating the effects of compression garments (CG) compared with control on all recovery measures following running-based exercise at all time points. The results represent part of a comparison with eccentric exercise and non-running endurance exercise challenges, and have been weighted accordingly. *Square boxes* represent the standardized mean effect for each study, with *lines* demonstrating 95% CIs. A *diamond* represents the overall standardized mean effect. *0* post-exercise, *acc* acceleration, *bound* double leg bound, *CCT* (basketball) court coverage time, *CI* confidence interval, *CMJ* countermovement jump, *ham* hamstring flexion, *knee* knee extension, *LD* (basketball) line drill, *MSFT* multi-stage fitness test, *MVC* maximal voluntary contraction, *post* post-match, *pre* pre-match, *scrum* peak scrum power, *throw* maximal throwing distance, *TTE* graduated time to exhaustion test (treadmill)

12, 13). As studies featuring metabolic exercise modalities subjected participants to minimal eccentric load, muscle damage would have been far lower in this group than for load-bearing exercise [12]. Subsequent endurance performance is also known to be far less affected by EIMD than strength [69]. The trivial recovery benefits of CG for endurance training are therefore consistent with a role in ameliorating muscle damage.

Although large, very likely beneficial effects of CG were apparent at 24 h following metabolic exercise or prior to endurance performance, no recovery benefits following endurance exercise were apparent at 0–2 h. Such a finding is perhaps surprising given reports of CG enhancing metabolite clearance throughout repeated sprints [63] and immediately post-exercise [34]. It is likely that variations in athlete training status, the duration of recovery, and the specific demands of individual exercise challenges are responsible for inconsistencies in short-term effects [86, 87]. For instance, although enhanced lactate clearance from CG failed to improve recovery of repeated ski performance over 3 × 3-min bouts in competitive endurance athletes [63], the reported peak lactate ($[La]_{pk}$) values of

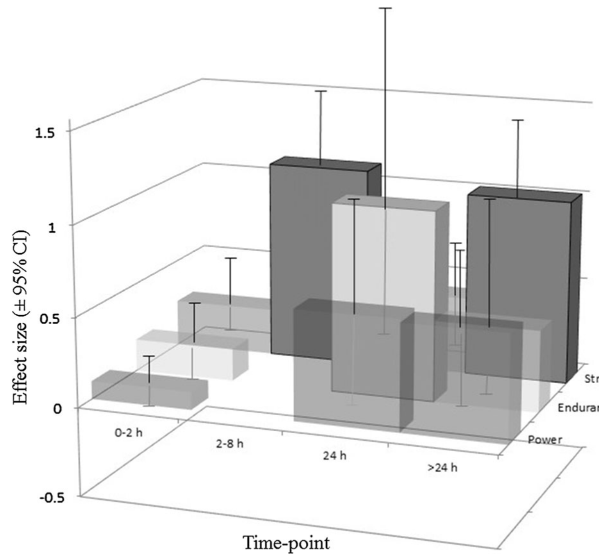


Fig. 12 A comparison of the effects of compression garments with controls on all measures of performance recovery at all time points. *Columns* represent the standardized mean effect at each time point, with *error bars* demonstrating 95% CIs. The threshold values for standardized changes were as follows: ≤0.2 (trivial), >0.2 (small), >0.5 (moderate) and >0.8 (large). Effects were deemed very likely if the 95% CI did not cross below the threshold for the smallest worthwhile effect (*filled columns with solid borders*). *Transparent columns without borders* indicate that the 95% CI transected the threshold for the smallest worthwhile effect. *CI* confidence interval

2.8–3.0 mmol/L would have been unlikely to limit performance. Such levels are well below the $[La]_{pk}$ values of 13.5 ± 0.9 mmol/L [88] and 7.28 ± 1.85 mmol/L [89] previously reported in collegiate and elite cross-country skiers, respectively. Conversely, CG were associated with both improvements in post-exercise lactate and improved recovery in the second of two 30-min cycling time trials separated by 1 h [44]. The reported mean post-exercise

Study	Outcome	Time	Measure	Effect size (mean ± 95% CI)
Argus et al. [62]	Power	30 min	Bike 30 s sprint	0.14 [-0.69, 0.98]
Argus et al. [62]	Power	1 h	Bike 30 s sprint	0.19 [-0.64, 1.03]
de Glanville and Hamlin 2012 [35]	Endurance	24 h	40 km TT	1.05 [0.25, 1.85]
Driller and Halson [44]	Endurance	1 h	15 min TT	0.69 [-0.22, 1.60]
Sperlich et al. [63]	Endurance	12 min	Ski 3 min sprint	0.37 [-0.51, 1.26]
Sperlich et al. [63]	Endurance	6 min	Ski 3 min sprint	0.15 [-0.73, 1.02]
Test for overall effect: $z = 2.49$ ($p = 0.01$)				**0.44 [0.09, 0.79]**
Heterogeneity: $\chi^2 = 3.79$, ($p = 0.58$); $I^2 = 0\%$				

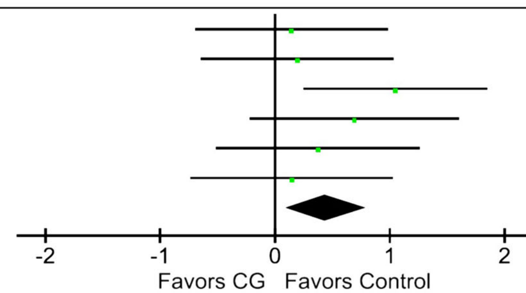


Fig. 11 Forest plot illustrating the effects of compression garments (CG) compared with controls on all recovery measures following metabolic (non-running endurance) exercise at all time points. The results represent part of a comparison with running-based and resistance exercise, and have been weighted accordingly. *Square boxes* represent the standardized mean effect for each study, with *lines* demonstrating 95% CIs. A *diamond* represents the overall standardized mean effect. *CI* confidence interval, *ski* skiing ergometer, *TT* time trial

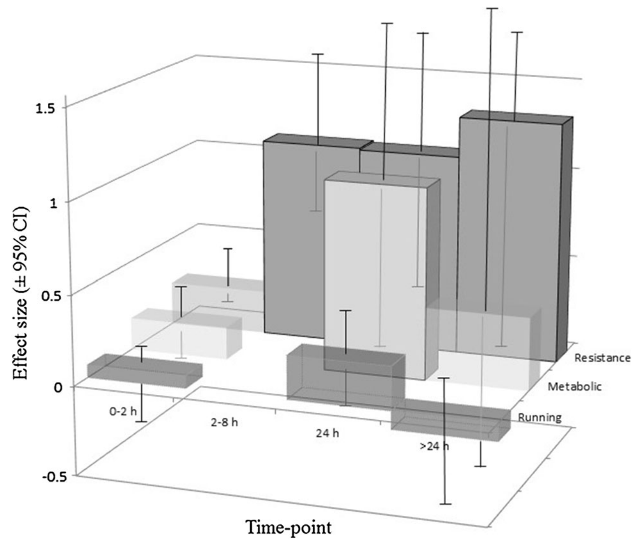


Fig. 13 A comparison of the effects of compression garments with controls on recovery from all exercise challenges at all time points. *Columns* represent the standardized mean effect at each time point, with *error bars* demonstrating 95% CIs. The threshold values for standardized changes were as follows: ≤0.2 (trivial), >0.2 (small), >0.5 (moderate) and >0.8 (large). Effects were deemed very likely if the 95% CI did not cross below the threshold for the smallest worthwhile effect (*filled columns with solid borders*). *Transparent columns without borders* indicated that the 95% CI transected the threshold for the smallest worthwhile effect. *CI* confidence interval, *metabolic* cardiovascular exercise with minimal eccentric component, *resistance* resistance training or drop-jumps

$[La]_{pk}$ value of 10.3 ± 2.2 mmol/L would have been physiologically relevant to recovery and subsequent performance at 1 h. In contrast, the significant and very likely benefits of CG at 24 h in metabolic trials cannot be attributed to improved lactate metabolism. No benefits on post-exercise $[La]_{pk}$ were reported following either of two bouts when CG were worn throughout each of two daily 40-km time trials and the intervening 24 h [35].

As with trials of resistance exercise, positive effects of CG on endurance have also been reported alongside reductions in swelling [44]. A significant attenuation of the post-exercise increase in thigh circumference was reported alongside improved subsequent performance in the CG group (15-min time trial), 1 h after the initial 30-min cycling bout [44]. However, no measures of leg circumference were taken in the only trial that assessed recovery of endurance performance at 24 h [35]. It is therefore impossible to confirm whether CG served to enhance next-day recovery by ameliorating swelling. Conversely, compression-mediated reductions in post-exercise swelling were not significant in any of the running studies, in line with the lack of CG efficacy in this group [6, 33]. The conditions for optimal CG efficacy may be influenced by likelihood of post-exercise swelling at a specific time point.

4.5 Pressure

The effects of CG on recovery were not different between trials applying garment pressures more or less than 15 mmHg ($p = 0.06$, $\chi^2 = 3.46$). However, only 24 data points from eight trials were identified where garment pressures had been measured directly. The apparent trend towards poorer recovery in the higher pressure group likely reflects the fact that all of these studies reported endurance measures. In comparison, data from the lower pressure trials will have been skewed by the inclusion of studies on resistance exercise and strength recovery, which displayed a preferential treatment effect from CG. Although greater pressures have been demonstrated to be more beneficial for reducing T2 relaxation times throughout recovery [90], to date, no evidence exists to suggest an enhanced effect on the recovery of performance. Methodological inconsistencies in measuring pressure, as well as variations between exercise protocols, continue to obscure the effects of garment pressure on recovery [34, 39]. More research is required to quantify the effects of CG in relation to the pressures they apply.

4.6 Training Status

The results of this analysis would suggest that the effects of CG are not dependent on training status. However, the definition of training status is prone to subjective bias, not least due to heterogeneity in the populations studied. The participants studied by Jakeman et al. [38], for example, exercised a minimum of three times per week and included representatives of competitive university teams (personal communication, John Jakeman). However, athletes were excluded if actively involved in lower body resistance or plyometric training, despite including athletes competing regularly and participating in sprint training. Therefore, this cohort could theoretically have included both high-performance athletes that routinely sustained muscle damage from load-bearing exercise as well as recreational exercisers with no prior experience of running or resistance training (for example, swimmers and cyclists). Further bias may have resulted from the fact that all of the participants in the untrained group belonged to just four trials of resistance exercise [17, 19, 50, 51]. This exercise modality was associated with the largest recovery benefits from CG. The potential for training status to influence the efficacy of CG is still unknown, but a case could be made for a preferential effect in either group. As the repeated bout effect minimises subsequent levels of DOMS and performance decrements in trained participants [41, 91], it could be feasible that untrained individuals stand to gain the most from CG. However, it is also possible that this greater degree of muscle damage could mask anything other than very large benefits from compression. There is a lack of studies analysing the effects of CG in untrained participants in activities other than resistance exercise. More trials with untrained participants are required that provide direct measurements of garment pressures.

4.7 Limitations

The strength of the conclusions drawn from this analysis is limited to a large degree by methodological differences amongst the trials reviewed. Both performance outcomes and exercise protocols were subject to heterogeneity, with power outcomes in particular being subject to varied mechanical, neuromuscular and technical requirements [33, 55–58].

Meaningful interpretation of these results, as well as assessment of the quality of included studies, was made difficult by inconsistencies in data reporting. No trials gave information on randomization, and whilst compression trials are inherently prone to control issues, none reported data on the effectiveness of blinding (Fig. 2). Whilst this analysis focused on performance recovery, more consistent reporting of physiological measures would also help to clarify the mechanisms responsible. This would help strengthen recommendations on the particular exercise modalities and subsequent performance outcomes for which CG are most effective. Consistent reporting of swelling, CK and DOMS, as well as skin temperature, lactate concentration and neuromuscular function, could help elucidate the mechanisms responsible for specific recovery benefits. Furthermore, the subjective and inconsistent nature of reporting participant characteristics among the studies reviewed also obscured the effects of training status.

Particular analyses were also limited by the small numbers of eligible studies. For example, drawing valid conclusions on the effects of pressure was not possible, as only eight trials directly recorded compression pressures [21, 35, 36, 53, 55, 59, 62, 63]. Finally, the large, very likely benefits reported for strength recovery at 2–8 h following resistance exercise [22] and for next-day cycling performance [35], respectively, were both based on the results of single studies. More research on recovery in these scenarios, as well as the physiological mechanisms involved, could help confirm the optimal conditions for compression.

5 Conclusions

Compression would seem to be most effective for improving long-term (>24 h) recovery from exercise that elicits a large degree of muscle damage, such as resistance or plyometric exercise. Regarding performance outcomes, CG confer the largest benefits to strength from 2 to 8 h [22] or >24 h. A large, very likely beneficial effect also exists for next-day cycling performance. These findings could provide effective guidance on the use of CG to optimize performance recovery following training or competition.

From this meta-analysis, CG would be recommended to aid the recovery of:

- Maximal strength at least 24 h post-exercise (for example, in strength and power athletes undertaking resistance training programmes).
- Strength and power performance following resistance training or eccentric exercise.
- Next-day cycling performance.

Further investigation of the mechanisms involved for recovery from specific forms of exercise is required to provide further guidance on the effective use of CG.

Compliance with Ethical Standards

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Conflicts of interest Freddy Brown, Conor Gissane, Glyn Howatson, Ken van Someren, Charles Pedlar and Jessica Hill declare that they have no conflicts of interest relevant to the content of this review.

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