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Review

Do compression garments enhance running performance? An updated systematic review and meta-analysis

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Abstract

Background: Despite the wide use of compression garments to enhance athletic running performance, evidence supporting improvements has not been conclusive. This updated systematic review and meta-analysis of randomized controlled trials (RCTs) compared the effects of compression garment wearing with those of non-compression garment wearing (controls) during running on improving running performance.
Methods: A comprehensive search was conducted in the electronic databases (Web of Science, EBSCOhost, PubMed, Embase, Scopus, and Cochrane) for RCTs comparing running performance between runners wearing compression garments and controls during running, from inception to September 2024. Independent reviewers screened studies, extracted data, appraised risk of bias (RoB 2) and certainty of evidence (Grading of Recommendations Assessments, Development and Evaluation (GRADE)). Primary outcomes were race time and time to exhaustion. Secondary outcomes covered running speed and race pace, submaximal oxygen uptake, tissue oxygenation, and soft tissue vibration. Random-effects meta-analyses were conducted to generate pooled estimates, expressed in standardized mean difference (SMD). Subgroup differences of garment, race type, and contact surface were tested in moderator analyses.
Results: The search yielded 51 eligible studies comprising 899 participants, of which 33 studies were available for meta-analysis of primary outcomes. Runners wearing compression garments during running showed no significant improvement in race time (SMD = −0.07, 95%CI: −0.22 to 0.09; $p = 0.40$) or time to exhaustion (SMD = 0.04, 95%CI: −0.20 to 0.29; $p = 0.72$). Moderator analyses indicated no effects from garment type, race type, or surface. Secondary outcomes also showed no performance benefits, although compression garments significantly reduced soft tissue vibration (SMD = −0.43, 95%CI: −0.70 to −0.15; $p < 0.01$). Certainty of evidence was rated low to very low.
Conclusion: Data synthesis of current RCTs offers no updated evidence favoring the support of wearing compression garments during running as a viable strategy for improving running and endurance performance among runners of varying performance levels and types of running races.

Keywords: Runners; Performance enhancement; Sprint; Endurance

1. Introduction

Runners specializing in different running events or distances constantly seek new ways to improve, optimize, or boost their running experience and athletic performance as characterized by faster speed and better endurance.[1–3] One of the technology-driven strategies that has been used to transform running experience and performance is the wearing of compression garments, which typically include tights, socks, calf sleeves, and shorts commonly made from materials such as nylon and synthetic elastic fabrics or a combination thereof.[4,5] The idea underlying the various ergogenic and biomechanical effects of compression running gear is that the technology places an optimal amount of firm pressure on the runner's body, which may help increase peripheral blood flow,[6] reduce soft tissue vibration[7] and recovery time,[8]

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improve the control and stability of movement,[9,10] make efficient use of energy,[11] decrease exercise-induced muscle damage,[12] and enhance running efficiency.[13]

With continued advances and innovation in compression garment design and technology[14–16] and increasing market demands[17] for compression gear in sports running, there has been an increased number of empirical studies that focus on both the mechanisms and performance outcomes of wearing compression gear during or after running and/or exercising.[5,18] Randomized controlled trials (RCTs) examining the effects of wearing compression garments on running performance have, however, shown less than robust performance-enhancing results as evidenced by small effect sizes and inconsistent, often conflicting findings.[19–25] A 2018 meta-analysis of 23 RCTs revealed that, among many other outcomes, there were no beneficial effects of wearing compression garments on running performance compared to controls.[26] In contrast, a recent meta-analysis study reported significant performance gains in improving speed, endurance, and functional outcomes. However, heterogeneity in the inclusion of outcomes (motor *vs.* physical) and types of sporting events (running, swimming, cycling) in the latter study made the findings less generalizable to running.[27] Thus, as indicated by a few other reports,[5,28] the performance benefits of wearing compression garments during running remain unclear.

Both the equivocal findings from the current literature and the recent publication of additional trials necessitate a concerted effort to update current evidence on the performance-enhancing potential of wearing compression garments for running. In this systematic review and meta-analysis, we examine the effects of wearing compression garments during running on performance as it relates to race time and time to exhaustion. We also consider secondary outcomes, including running speed and race pace, submaximal oxygen uptake, tissue oxygenation, and soft tissue vibration. Given that there are multiple factors (garment type, contact surface, race type, and training level) that may influence performance, we conducted subgroup analyses to examine whether the effects on race time and time to exhaustion are influenced by characteristics of garment type, race type, contact surface type, and training level.

2. Methods

The Preferred Reporting Items for Systematic Reviews and Meta Analysis (PRISMA) guidelines[29] were followed in this systematic review. The protocol for this study was developed in June 2024 and was registered in International Prospective Register of Systematic Reviews (PROSPERO, CRD42024516589).

2.1. Literature search for identification of studies

To identify studies, a comprehensive literature search was conducted by 2 independent review authors (WW and QSL) using the electronic databases Web of Science, EBSCOhost, PubMed, Embase, Scopus, and Cochrane from inception to September 2024 (see Supplementary Table 1 for the search subject headings and text words or terms used for each database). The search with the predetermined keywords/terms was initially pilot tested on PubMed to identify target studies reviewed in the literature. Additional manual searches of journal articles and reference lists of existing review articles were used to capture any relevant studies that may not have been indexed in the databases at the time of the search. The search began in March 2024, with the last search conducted on September 6, 2024.

2.2. Eligibility criteria

Eligibility criteria were developed based on the Population, Intervention, Comparison, Outcomes, and Study design (PICOS) guidelines[30] (Supplementary Table 2). Our prespecified eligibility criteria considered all RCTs that compared the performance effects of compression garment wearing during running with non-compression garment wearing (controls). Accordingly, we included RCTs that met the following criteria: (a) healthy runners of any sex, age, or performance level; (b) the use of compression garments covering the lower limbs (including whole-body compression garments); (c) inclusion of primary and/or secondary outcomes of interest (described below) in this study; and (d) original full-text papers in English and published in a peer-reviewed journal. Eligible comparators included the use of any non-compression garment placebo, sham, or control groups.

Studies were excluded if they: (a) applied compression garments as any form of treatment; (b) used compression garments along with other intervention strategies (e.g., nutrition, cold water immersion, stretching); or (c) included only upper-body compression garments.

2.3. Primary and secondary outcomes

Primary outcomes were race time and time to exhaustion. Race time was defined as the time (measured in seconds, minutes, or hours) it took for an individual to complete the race distance, whereas time to exhaustion was operationalized as the time (in seconds or minutes) for which an individual could maintain a specified running intensity before volitional fatigue or inability to continue occurred.[31] Secondary outcomes were running speed, race pace, submaximal oxygen uptake, tissue oxygenation, and soft tissue vibration during running. The list of these measures and their definitions can be found in Supplementary Table 3.

2.4. Data extraction

The titles and abstracts of all studies potentially fitting the inclusion and exclusion criteria were initially and independently screened by 2 review authors (WW and QSL). Studies deemed eligible for inclusion by both reviewers were advanced to the full-text screening phase, where full-text copies of all eligible papers were retrieved and assessed for eligibility. If the full text of the eligible articles could not be obtained online or in print, attempts were made to contact the author to obtain further details of the studies. The same 2-

stage screening process was applied to exclude ineligible studies, with reasons documented. Any disagreement between the 2 review authors was resolved through discussion or, if required, through consultation with a third review author (XL).

The same 2 review authors independently extracted data from the final list of included RCTs using a standardized data specification form that included information on study design components, baseline participant characteristics, intervention characteristics, and outcomes. Specifically, the form included: (a) the study design, with a description of experimental arms; (b) the number of participants, their sex, age, and runner status (i.e., healthy adults, recreational or competitive runners); (c) type of compression garments worn (i.e., shorts, tights, sleeves, stockings, or whole-body garments); (d) materials used for compression wear (e.g., polyamide, polyester, nylon, or elastane); (e) interface pressure applied (measured or manufacturer's guidelines in mmHg); (f) running protocols; (g) outcome measures; and (h) descriptive data involving means, standard deviation (SD), standard error, or 95% confidence interval (95%CI), and the numbers analyzed in each group.

WebPlotDigitizer software (Version 4.7; http://arohatgi.info/WebPlotDigitizer/; TX, USA) was used to extract means (SD) from figures when necessary. If relevant data were not reported, we contacted the corresponding author of the study via e-mail to request the data. All data were entered in an Excel spreadsheet (Version 2021; Microsoft, Redmond, WA, USA), and the files were checked by another author (QSL). Any disagreement was resolved through discussion or with a third reviewer (YZ) if necessary.

2.5. *Risk of bias and quality assessment*

Two review authors (WW and QTL) independently evaluated the risk of bias for each included trial using the Cochrane Risk of Bias 2 (RoB 2) tool (Cochrane Collaboration, London, UK) for randomized studies.[32] The methodological quality of the RCTs was determined using the Physiotherapy Evidence Database (PEDro).[33] Judgements about the risk of bias of included studies were made based on the recommendations outlined in the Cochrane Handbook for Systematic Reviews of Interventions.[34] Disagreements were resolved by discussion or by involving a third review author (YW) to adjudicate if necessary.

The Cochrane RoB 2 tool assesses risk of bias in 5 domains: (a) randomization process, (b) deviations from intended interventions, (c) missing outcome data, (d) measurement of the outcome, and (e) selection of the reported result. Per the guidelines, a study is judged to have a "low risk of bias" overall if it scores low in all 5 quality domains; the risk of bias is of "some concern" if the study is judged to raise some concerns in at least one domain (as long as it does not reach a high level of concern); and there is a "high risk of bias" if the study is judged to be of high concern in at least one domain or to generate a lower level of concern in multiple domains in a way that substantially lowers confidence in the results. The evaluation in this study focused on all outcomes and was completed using an RoB 2 Excel tool[35] then visualized via risk-of-bias plots.[36]

The PEDro scale yields a maximum score of 10 points for each study. The first criterion was omitted from the overall scoring because it relates to participant eligibility criteria. Scores and their respective rank in terms of methodological quality were then categorized as "excellent" (9−10), "good" (6−8), "moderate" (4−5), or "poor" (<4).[6,37] The PEDro scale is considered a valid and reliable tool for assessing the quality of RCTs related to compression garments.[5,6,38]

The certainty of the evidence for effect estimates was assessed by 2 independent reviewers (WW and QTL) using the Grading of Recommendations Assessments, Development and Evaluation (GRADE).[39−41] A third reviewer (YZ) was engaged to resolve any discrepancies when consensus was not reached. The GRADE evaluation system rates the quality of evidence as high (i.e., further research is very unlikely to change our confidence in the estimate of effect), moderate (i.e., further research is likely to have an important impact on our confidence in the estimate of effect and may change the estimate), low (i.e., further research is very likely to have an important impact on our confidence in the estimate of effect and is likely to change the estimate), or very low quality (i.e., any estimate of effect is very uncertain).

2.6. *Statistical analysis*

2.6.1. *Assessing intervention effects*

A random effects meta-analysis was performed on the extracted trial data to examine whether compression garment wearing differed statistically from controls in the primary and secondary running performance outcomes. The pooled standardized mean differences (SMD) of change scores (post−pre values) and their corresponding 95%CIs were calculated for the primary and secondary study outcomes using the prespecified meta-analysis of a restricted maximum likelihood random-effects model with the inverse variance weighting method. SMD is defined as trivial (0.00−0.19), small (0.20−0.49), medium (0.50−0.79), or large (≥0.80).[42] If the descriptive data in the original studies were presented in the form of median, interquartile, 95%CI, or standard error of estimate (SE), they were converted to SD per the guidelines.[43]

2.6.2. *Assessing heterogeneity*

Between-trial heterogeneity was assessed using the χ^2 test and the I^2 statistic, with additional visual inspection of the forest plot. Heterogeneity among studies is considered low when the value of the I^2 statistic is <25%; heterogeneity is moderate when I^2 is 25%−75% and high when I^2 is ≥75%.[44]

2.6.3. *Assessing reporting biases*

Possible publication bias and small-study effects were assessed with visual inspection of funnel plots of comparisons with 10 or more trial studies and statistically using Egger's test ($p < 0.05$).[45,46]

2.6.4. Sensitivity analysis

Several sensitivity analyses were conducted. First, we reappraised the estimates of the primary outcomes using a fixed-effect model. Second, we evaluated whether the estimates generated were dependent on quality (PEDro scores of <6 *vs.* ≥ 6), sample sizes (<20 *vs.* ≥ 20 subjects), and performance level (healthy adult runners *vs.* recreational and competitive runners).

2.6.5. Subgroup meta-analysis

To evaluate the dependability of the findings, we planned prespecified subgroup meta-analyses, independent of heterogeneity, to examine the effects of possible modifiers on the primary outcomes. These variables included garment type (shorts, tights, sleeves, stockings, and whole-body garments), race type (10−400 m, 5−10 km, 15−24 km, and marathon), and contact surface type (tarmac road, outdoor course, treadmill, and mountainous terrain). We planned subgroup meta-analysis procedures only when there were at least 3 studies available for each outcome.

Statistical tests were 2-tailed, and the statistical significance threshold was $p < 0.05$. Analyses were conducted using R (Version 4.3.3; R Foundation, Vienna, Austria) with the Meta, robvis, ggplot2, and forestploter packages.[47] Data analyses were performed from June 12, 2024 to September 10, 2024.

3. Results

3.1. Search results

The PRISMA flow diagram describing the search, selection process, and results is presented in Fig. 1. Our electronic search of the literature identified and retrieved 414 research records. After initial screening, 314 ineligible records were excluded (188 duplicates, 118 ineligibles, and 8 with no full-text article). A further full-text evaluation identified 49 ineligible records that were subsequently removed, and 51 studies published between 1987 and 2024 were deemed eligible and included.

3.2. Study designs and inclusion of outcomes

Of the 51 eligible studies included, 8 (16%) employed a parallel trial design[13,23,24,48−52] whereas 43 (84%) used a crossover design.[10,19−22,25,53−89] Twenty-two studies (43%) provided data on race time,[20,25,50−52,54−58,60,68−73,77,78,85,87,88] and 11 (22%) included data on time to exhaustion,[10,19,21−23,48,53,62−64,66] thus they were included in the meta-analysis. Regarding the secondary outcomes, 7 studies (14%) included measures of running speed and race pace,[19,24,49,61,63,78,84] 18 (35%) measured submaximal oxygen uptake,[13,21,48,59,62−65,67,75,76,79−81,83,86,88,89] 4 (8%) measured tissue oxygenation,[62,71,78,82] and 4 (8%) measured soft tissue vibration.[74,81,83,86]

3.3. Characteristics of included studies

The total number of participants in the 51 RCTs included was 899 (683 men, 184 women, and 32 undescribed) (Supplementary Table 4), with the sample sizes of these studies ranging from 6 to 67 (median = 13). Of the 899 participants included, primary outcome measures were available from 500 participants and secondary outcomes were available from 399 participants. The ages of the participants ranged from 18 to 60 years old (median = 30.5 years old). Two studies (4%)

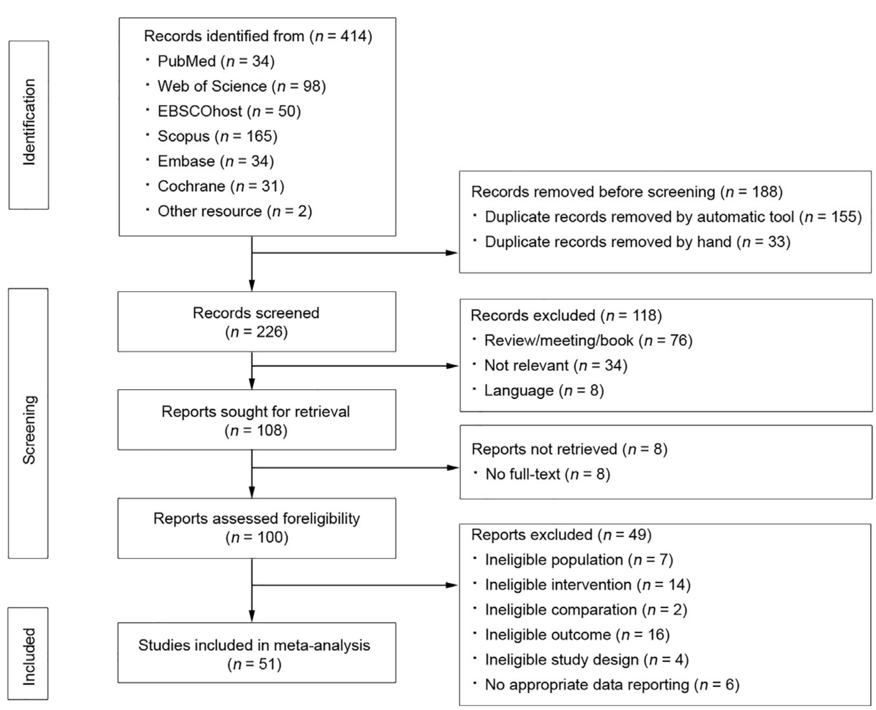

Fig. 1. Preferred reporting items for systematic reviews and meta-analysis (PRISMA) flow diagram of the literature screening and selection process.

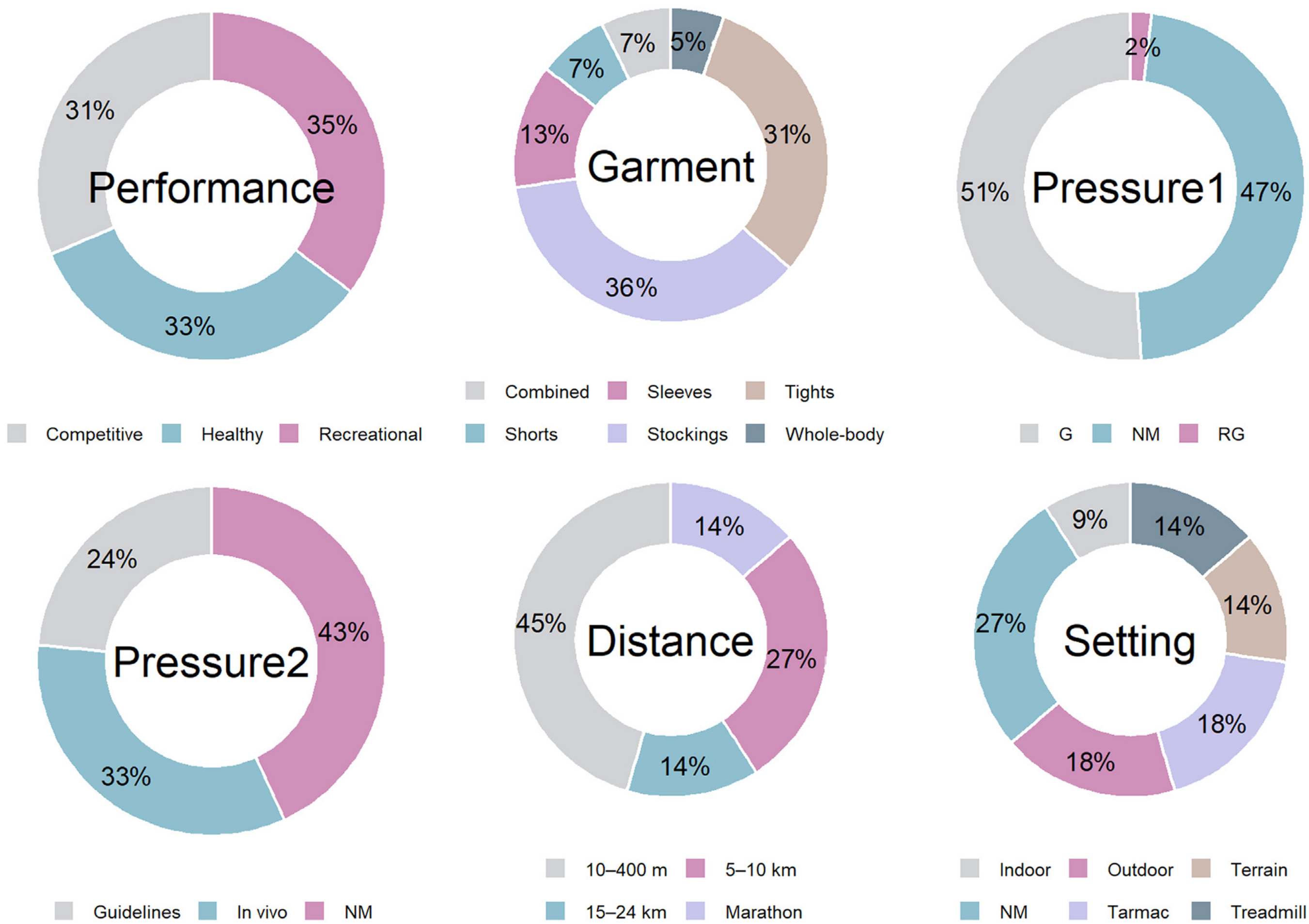

Fig. 2. Characteristics of study outcomes included in this systematic review and meta-analysis. Performance = performance level; Pressure1 = pressure characteristics; Pressure2 = pressure measurement method. G = gradual; NM = not mentioned; RG = reverse gradual. Percentages may not add up to 100% due to rounding.

included only female participants,[71,77] 28 studies (55%) exclusively enrolled male participants,[10,13,19,21,25,49,53,56,58,61–70,72,73,76,78,79,81,83,88,89] and 18 studies (35%) included both genders.[8,20,22–24,48,50–52,54,55,59,74,75,79,82,84,85] The remaining 3 studies (6%) did not provide information on sex.[57,60,80] With respect to performance level, participants were classified as healthy adults ($n = 357$, 40%),[10,19,23,24,51–53,55,56,68,72,77,78,82,83,86,87] recreational runners ($n = 283$, 31%),[13,21,25,50,58,60,61,63,64,66,67,69,71,74,75,85,88,89] or competitive runners ($n = 259$, 29%).[20,22,48,49,54,57,59,62,65,70,73,76,79–81,84]

Six different types of compression garments were identified in the studies included. These were shorts (covering from the waist to the thigh),[54,55,80,81] tights (covering from above the ankle to the waist),[10,13,57,60,62–65,68,69,71,72,83,85–87,89] stockings (covering from the foot to the knee or below the knee),[19–23,25,48,50–53,59,62,67,74,75,77,79,82,88] sleeves (covering from or above the ankle to the knee or below the knee),[49,66,70,73,76,78,84] whole-body garments (a combination of tights and a long-sleeved top),[56,61,62] and combined garments (shorts and stockings, shorts and sleeves).[58,69,80,81] In terms of pressure, 17 studies (33%) measured pressure *in vivo*,[10,13,21,59,61,63–65,67–69,71,72,78,82,87,88] 12 (24%) reported pressure measured according to the manufacturer's guidelines,[20,22,23,51,66,70,76,77,80,81,83,85] and 22 (43%) provided no mention of this measure.[19,24,25,48–50,52–58,60,62,73–75,79,84,86,89] Twenty-six studies (51%) reported exerting gradual pressure on the body,[10,13,19,20,22,23,25,48–51,53,59,61,65,67,68,74–79,81,84,85] while 1 (2%) implemented reverse gradual pressure[66] (Fig. 2). Compression garments were found to be made primarily of polyamide/nylon or polyester, some with a combination of elastane (e.g., Lycra) (Supplementary Table 4). Of the time-trial studies, 10 (45%) reported short distances (range: 10 m–400 m)[54–58,60,69,71,72,87] and 12 (55%) involved long distances (range: 5–41.2 km).[20,25,50–52,68,70,73,77,78,85,88] Included studies were conducted in different settings: 3 (14%) were performed with treadmills,[68,85,88] 2 (9%) used indoor tracks,[71,72] 4 (18%) used outdoor tracks,[20,56,69,77] 4 (18%) used tarmac roads,[25,50–52] 3 (14%) were on mountainous terrain,[70,73,78] and 6 (27%) did not mention the setting[54,55,57,58,60,87] (Fig. 2).

Table 1
Compression garments compared to controls for running performance.

Outcomes	Summary of results		Certainty of the evidence (GRADE)						Comments
	No. of participants (studies)	SMD (95%CI)	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	Certainty	
Race time	629 (22 RCTs)	−0.07 (−0.22 to 0.09)	very serious[a]	not serious	serious[b]	serious[c]	none	⊕○○○ Very low	Compared with controls, the pooled estimate examining the effect of compression garment wearing on race time was not statistically significant.
Time to exhaustion	261 (11 RCTs)	0.04 (−0.20 to 0.29)	very serious[d]	not serious	not serious	serious[e]	none	⊕○○○ Very low	Compared with controls, runners who wore compression garments exhibited no performance change in time to exhaustion.
Running speed and pace	366 (7 RCTs)	0.17 (−0.04 to 0.38)	very serious[f]	not serious	serious[g]	serious[h]	none	⊕○○○ Very low	Compared with controls, compression garment wearing showed a non-significant effect on running speed.
Submaximal oxygen uptake	508 (18 RCTs)	−0.02 (−0.20 to 0.15)	very serious[i]	not serious	not serious	serious[j]	none	⊕○○○ Very low	Compared with controls, compression garment wearing showed a non-significant effect on submaximal oxygen uptake.
Tissues oxygen index	128 (4 RCTs)	−1.06 (−3.15 to 1.03)	very serious[k]	serious[l]	serious[m]	serious[n]	none	⊕○○○ Very low	Compared with controls, compression garment wearing showed a non-significant effect on tissue oxygenation.
Soft tissues vibration	206 (4 RCTs)	−0.43 (−0.7 to −0.15)	serious[o]	not serious	not serious	serious[p]	none	⊕⊕○○ Low	There was a small but significant effort on soft tissue vibration.

Note: Population means runners; intervention refers to compression garments; comparison indicates controls.
[a] Three studies were rated as low risk, 2 studies had some concerns, and the remaining studies were high risk. The RCTs suffered from inadequate concealment of allocation, unblinded assessment of outcome and reporting trial results. The quality of the evidence was downgraded by 2 levels due to these study quality limitations.
[b] The main purpose of 10 of 22 studies was not to measure performance. The quality of the evidence was downgraded by 1 level.
[c] The sample size was small (range: 8−67), and 95%CIs were wide.
[d] All studies were rated as high risk. The RCTs suffered from inadequate concealment of allocation, unblinded assessment of outcome and reporting trial results.
[e] The sample size was small (range: 6−33), and 95%CIs were wide.
[f] All studies were rated as high risk. The RCTs suffered from inadequate concealment of allocation, unblinded assessment of outcome and reporting trial results.
[g] The main purpose of 3 of 7 studies was not to measure running speed and pace.
[h] The sample size was small (range: 8−36), and 95%CIs were wide.
[i] One study was rated as low risk, 7 studies had some concerns, and the remaining 10 studies were high risk. The RCTs suffered from inadequate concealment of allocation, unblinded assessment of outcome and reporting trial results.
[j] The sample size was small (range: 9−26), and 95%CIs were wide.
[k] All studies were rated as high risk. The RCTs suffered from inadequate concealment of allocation and unblinded assessment of outcome.
[l] $I^2 = 90\%$.
[m] The main outcome of 2 of 4 studies is not tissues oxygen.
[n] The sample size was small (range: 14−20).
[o] Two studies were rated as high risk, and 2 studies had some concerns. The RCTs suffered from inadequate concealment of allocation and unblinded assessment of outcome.
[p] The sample size was small (range: 11−40), and 95%CIs were wide.
Abbreviations: 95%CI = 95% confidence interval; GRADE = Grading of Recommendations Assessments, Development and Evaluation; RCTs = randomized controlled trials; SMD = standardized mean difference.

3.4. Risk of bias, quality assessment, and certainty of evidence

Applying the RoB 2 tool criteria, we found that 38 (75%) of the studies had a high risk of bias. Of the remaining 13 studies, 4 (8%) were rated as having a low risk of bias and 9 (17%) as having some concerns (Supplementary Fig. 1). Among the 5 domains of quality assessment, "randomization process" was identified among 38 (75%) studies as having "high" bias, thereby raising concerns about study participant and assessor blinding, outcome assessment, and allocation concealment. This was followed by the domain of "Selection of the report results", where 44 studies (86%) showed "some concerns" of bias in reporting trial results. The average PEDro score (mean ± SD) was 6.00 ± 0.69 (range: 4−9) for all 51 studies (Supplementary Table 5), indicating moderate quality of the included studies. All outcomes in the included studies had low to very low ratings for certainty per the GRADE guidelines (Table 1).

3.5. Primary outcomes

The pooled estimate examining the effect of compression garment wearing during running, compared with controls, on race time was not statistically significant (SMD = −0.07, 95%CI: −0.22 to 0.09, $p = 0.40$). The heterogeneity statistic I^2 is 0%, indicative of no between-trial heterogeneity (Fig. 3 and

Characteristics	Studies	Participants (%)	SMD (95%CI)	p (intervention)	I^2 (%)
Garments type				0.70	0
Shorts	3	90 (14.3)	0.01 (−0.41 to 0.42)	0.97	0
Stockings	7	235 (37.4)	−0.02 (−0.27 to 0.24)	0.89	0
Tights	8	212 (33.7)	−0.16 (−0.43 to 0.11)	0.26	0
Sleeves	3	72 (11.4)	0.07 (−0.39 to 0.53)	0.76	0
Whole-body garments	1	20 (3.2)	−0.54 (−1.44 to 0.35)	NA	0
Race type				0.71	0
10–400 m	10	270 (42.9)	−0.17 (−0.41 to 0.07)	0.17	0
5–10 km	6	158 (25.1)	−0.02 (−0.33 to 0.29)	0.91	0
15–24 km	3	80 (12.7)	0.09 (−0.35 to 0.53)	0.69	0
Marathon	3	121 (19.2)	−0.01 (−0.37 to 0.35)	0.96	0
Surface type				0.94	0
Indoor track	2	50 (7.9)	−0.09 (−0.64 to 0.47)	0.75	0
Tarmac road	4	149 (23.7)	−0.02 (−0.35 to 0.30)	0.88	0
Treadmill	3	76 (12.1)	0.05 (−0.40 to 0.50)	0.83	0
Outdoor course	4	104 (16.5)	−0.14 (−0.52 to 0.25)	0.49	0
Mountainous terrain	3	72 (11.4)	0.07 (−0.39 to 0.53)	0.76	0
NM	6	178 (28.3)	−0.17 (−0.46 to 0.13)	0.27	29
Race time	22	629 (100)	−0.07 (−0.22 to 0.09)	0.40	0

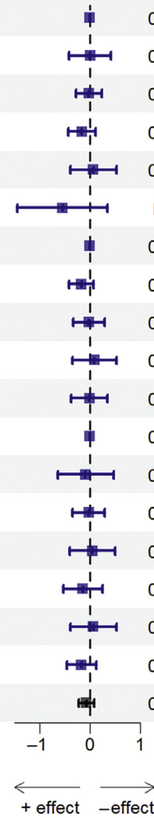

Fig. 3. The forest plot showing the effect of compression garment wearing on race time, as compared with controls. The black square represents the pooled SMD and its 95%CI. Estimates were calculated using a random-effects model meta-analysis. 95%CI = 95% confidence interval; NM = not mentioned; SMD = standardized mean difference.

Supplementary Fig. 2). Likewise, compared with the controls, runners who wore compression garments exhibited no performance change in time to exhaustion (SMD = 0.04, 95%CI: −0.20 to 0.29, $p = 0.72$, $I^2 = 0\%$) (Fig. 4).

Results from the sensitivity analyses showed no deviations in the estimates generated by a fixed-effect model compared to those produced by the random-effects model on both primary outcomes. Similarly, the estimates were shown to not be impacted by quality assessment (as measured by PEDro scores), sample sizes, or performance level when compared to the overall analyses (Supplementary Fig. 3).

Subgroup analyses revealed no effect on race time by garment type (shorts, tights, sleeves, stockings, or whole-body garments, and combined garments), race type (10−400 m, 5−10 km, 15−24 km, or marathon), or contact surface type (tarmac road, indoor track, outdoor course, treadmill, or mountainous terrain) (Figs. 3 and 4).

3.6. Secondary outcomes

Compared with controls, compression garment wearing showed a non-significant effect on running speed (SMD = 0.17, 95%CI: −0.04 to 0.38, $p = 0.10$, $I^2 = 0\%$), submaximal oxygen uptake (SMD = −0.02, 95%CI: −0.20 to 0.15, $p = 0.78$, $I^2 = 0\%$), and tissue oxygenation (SMD = −1.06, 95%CI: −3.15 to 1.03, $p = 0.32$, $I^2 = 94\%$). However, there was a small but significant effect on soft tissue vibration (SMD = −0.43, 95%CI: −0.70 to 0.15, $p < 0.01$, $I^2 = 0\%$) (Supplementary Fig. 4).

An inspection of the funnel plot for the trial time outcome showed only 1 of the 45 studies (2%) having effect estimates that fell outside the expected distribution for their size (or precision), and the Egger's p value was non-significant ($p = 0.06$). The distribution was shown to be symmetrical for the outcomes of time to exhaustion and submaximal oxygen uptake ($p > 0.05$ on Egger's tests) (Supplementary Fig. 5 and Supplementary Table 6).

4. Discussion

In this updated systematic review and meta-analysis, we showed, from the pooled results of 33 RCTs with 500 participants, no evidence that wearing compression garments provided benefits for improving athletic performance as measured by race time and time to exhaustion in runners. Our sensitivity analyses showed little indication that the estimates generated were influenced by the estimation methods or other selected characteristics such as quality of the study or training level. There was little heterogeneity in variation across studies, as indexed by the I^2 statistic, suggesting that the true effects

Characteristics	Studies	Participants (%)	SMD (95%CI)	p (intervention)	I^2 (%)
Garments type				0.99	0
Stockings	7	167 (64.0)	0.03 (−0.27 to 0.34)	0.84	0
Tights	3	66 (25.3)	0.06 (−0.43 to 0.54)	0.82	0
Sleeves	1	28 (10.7)	0.08 (−0.66 to 0.82)	NA	
Time to exhaustion	11	261 (100)	0.04 (−0.20 to 0.29)	0.72	0

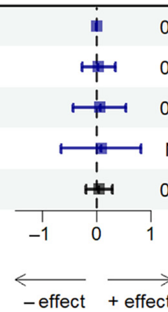

Fig. 4. The forest plot showing the effect of compression garment wearing on time to exhaustion, as compared with controls. The black square represents the pooled SMD and its 95%CI. Estimates were calculated using a random-effects model meta-analysis. 95%CI = 95% confidence interval; SMD = standardized mean difference.

(i.e., the null findings) on both outcomes were uniformly distributed across all the studies included in this review. The quality of the included trials was judged as low to modest on average, suggesting a lack of rigorous, high-quality studies examining the associations between compression garments and running performance.

The updated findings from this study are generally in line with previous meta-analysis studies, which consistently showed no meaningful effects of wearing compression garments on running performance. For example, an early meta-analysis of 10 trials showed only a small positive effect (Hedges' $g = 0.15$) of wearing compression garments on extending time to exhaustion and improving race time performance.[28] Another meta-analysis of 19 trials found no significant effects on race time and only a small positive effect on time to exhaustion.[5] A meta-analysis of 23 trials evaluating lower limb compression garments reported no significant performance-enhancing effects.[26] In contrast, a more recent study revealed, among many outcomes, positive effects of wearing compression garments on speed and endurance.[27] However, the point estimates pooled across a wide range of skills (motor *vs.* physical) and sport events (running, swimming, cycling) have made the assessment of true performance effects on running outcomes difficult if not impossible. Our study integrated the latest evidence from RCTs focusing on compression garments within the context of running. The primary outcomes, race time and time to exhaustion, were carefully selected as the most relevant performance metrics[31] for assessing the effectiveness of compression garments. However, due to the null findings, it is premature to make definitive recommendations at this stage, and the use of compression garments in running should be reconsidered by coaches and athletes.

There was also no evidence from our planned subgroup analyses that both outcomes were moderated by garment type, race type, contact surface, or training level. Meta-analysis of the available data on the secondary outcomes indicated no superior effect of wearing compression gear versus controls on running speed and pace, submaximal oxygen uptake, or tissues oxygen index, while wearing compression gear was associated with a significant decrease in soft tissue vibration. These null effects from our subgroup analyses were not unsurprising given the lack of heterogeneity observed in both race time and time to exhaustion.

The null findings related to the effects of wearing compression garments on running outcomes have been echoed by a recent scoping review[18] in which the authors conclude that there is insufficient evidence supporting many of the relevant running performance-enhancing factors, including kinetic and kinematic outputs, strength, sprinting, or agility. Although biomechanical and neuromuscular mechanisms underlying the null results for running performance variables are not well understood, factors such as optimal level of compression applied by garments to the body or muscles,[20,70,77,78] level of professional training,[20,78] thermal sensation during wearing,[64,68] and the user's belief about the benefits of compression garment wearing[76,90] may have the potential to impact, either positively or negatively running performance. Therefore, these mechanisms should be targeted in future studies.

Some major methodological weaknesses in the existing RCTs on wearing compression garments are noted. Many studies were exploratory in nature, without explicitly stated hypotheses that could be evaluated or tested. In the included trials, methodological quality, as indexed by PEDro, was generally deemed mediocre, with a lack of rigor or transparency in trial protocol, blinding of experimenters or assessors, randomization, and data treatment and analysis. The sample sizes employed in these studies were small (ranging from 6 to 67, median = 13) and not always as adequately or statistically powered as they should be.

A notable strength of this study is the inclusion of RCTs on running performance published to date. This is important in light of evolving technologies in compression garment engineering and design.[87,91,92] Another strength is that we followed a stringent and rigorous review process during article screening, data abstraction, risk of bias appraisal, and statistical analyses. From an applied perspective, this study focused on evaluating the most tangible outcomes to determine the scientific and practical merit of wearing compression garments as it relates to running performance.

However, this study also has several limitations. First, non-English studies were not included in this review, which may compromise the representation of all compression garment trials in the literature. Second, running performance outcomes in some studies were excluded because they lacked sufficient data or usable information that could be directly meta-analyzed. Third, coding of the 2 primary performance outcomes was undertaken using the information presented in the published articles; therefore, there is the potential for inaccurate interpretation. Finally, we were unable to evaluate the safety and potential harm of wearing compression garments because almost all RCTs failed to monitor or report adverse events during and after running.

5. Conclusion

In this systematic review and meta-analysis, data synthesis of current RCTs offered no updated evidence supporting the wearing of compression garments as a viable strategy for improving running and endurance performance among runners of varying performance levels. Additional studies are needed in the future, however, given the rapid technological advances in the manufacture of compression garments and the practical need for understanding the mechanisms of compression garments that may help enhance running performance. Future studies should also have enhancements in their design and methodologies, including assurances on the quality of randomization, adequately powered sample sizes, and improved transparency in trial reporting in order to ensure a rigorous evaluation of the potential merit and efficacy of wearing compression garments for improving running performance.

Authors' contributions

WW completed the selection, data extraction and analysis, wrote the first draft of manuscript and revised the manuscript; YZ participated in data extraction and revised the manuscript; DS revised the manuscript; QSL and XL participated in the selection, data extraction and analysis; QTL and YW assessed the Risk of Bias and quality; LH conceptualized the review; SW revised the manuscript; YL supervised the work and revised the manuscript. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Competing interests

The authors declare that they have no competing interests.

Availability of data and materials

All data analyzed and reported in this systematic review and meta-analysis are available from the corresponding author on reasonable request.

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Supplementary materials

Supplementary materials associated with this article can be found in the online version at doi:10.1016/j.jshs.2025.101028.

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