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Review

The Effects of Lower Leg Compression Garments on Lower Extremity Sports Injuries, Subjective Fatigue and Biomechanical Variables: A Systematic Review with Meta-analysis

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ABSTRACT

International Journal of Exercise Science 17(6): 445-467, 2024. The objective of this study was to systematically review the literature on the effect of CGs versus non-CGs (such as regular socks) or versus placebo garments on 1) the incidence of lower extremity sports injuries and 2) subjective ratings of fatigue and biomechanical variables in athletes at participating in any sport that required any level of running performance, given that fatigue-related biomechanical alterations may increase the risk of sports injuries. This study was a systematic review with meta-analyses. PubMed, Embase, CINAHL, Cochrane, PEDro, and Scopus were searched for eligible studies until 7 July 2021. Two reviewers independently assessed the risk of bias using the Cochrane Collaboration's tool for risk of bias. Meta-analyses were performed using a random-effects model. The Grades of Recommendation, Assessment, Development and Evaluation (GRADE) approach was used to assess the certainty of evidence for all outcome measures. Twenty-three studies, all with a high risk of bias, were included. Nineteen studies were used in the meta-analyses. No studies focused on the effect of CGs on the incidence of lower extremity sports injuries in athletes. Seventeen studies investigated the effect of CGs on subjective ratings of fatigue, but meta-analysis showed no difference in effectiveness between CGs versus non-CGs (such as regular socks) and versus placebo CGs (low certainty evidence). Because of heterogeneity, pooling of the results was not possible for the biomechanical variables. Nonetheless, low certainty evidence showed no effect of CGs. We identified no evidence for a beneficial or detrimental effect of lower leg CGs on the occurrence of lower extremity sports injuries, subjective ratings of fatigue, or biomechanical variables in athletes at any level of running performance. Based on the variable use of running tests, definitions used for biomechanical variables, and reporting of CG characteristics and more standardized reporting is recommended for future studies evaluating CGs.

KEY WORDS: Prevention, sports injuries, running, fatigue, biomechanics

INTRODUCTION

Running is one of the most frequently practised leisure activities worldwide and its popularity is still growing.(46) Although running is associated with health benefits, it may also cause injuries, especially of the lower leg and knee (18,20,30,56). Recently, a systematic review reported that the incidence of Achilles tendinopathy (10.3%), medial tibial stress syndrome (9.4%), and plantar fasciitis (6.1%) was highest in runners (28). Runners who experience injuries look for ways to prevent these injuries (17,25). In one study, 47.7% of endurance athletes, mainly runners, wore CGs to prevent injury recurrence, mainly of the shin and calf (19). Furthermore, 13.6% of these endurance athletes used the CGs for primary prevention.

The cyclical nature of running causes repetitive loading of the lower extremity muscles and bones and an increasing intensity of impact load during the course of training or competition (14,15,36). Fatigue during running increases calcaneal eversion, mid- and forefoot load, and tibial and knee internal rotation (15,55). Consequently, the decreased ability of the muscles to dissipate the impact load gives rise to overuse injuries (15,42). Fatigue may also influence the kinematic and kinetic variables associated with lower extremity overuse injuries (43,57). Available systematic reviews, which investigated the effects of compression garments (CGs) on recovery and performance, reported that CGs may aid recovery from exercise-induced muscle damage, decrease muscle pain and inflammation, and slightly improve time to exhaustion (16,33). However, these effects may only be seen with low-intensity exercise because during high-intensity exercise (i.e. maximal heart rate [HRmax] ≥85%, ratings of perceived exertion [RPE] >16, all-out sprints) no improvements in VO_2max, $VO_2submax$, or RPE were found when CGs were compared with regular socks (47). Hypothetically, lower muscle fatigue might result in retained muscle function and therefore enable the calf muscles to better attenuate the impact load during low intensity exercise. This, in turn, could decrease the load on bone structures and help prevent (recurrence of) injuries.

To the authors' best knowledge, it is not known whether there is a causal relationship between the use of lower leg CGs and the incidence of lower leg sports injuries. Further, systematic reviews on this topic are not available. Therefore, the primary aim of this study was to systematically review the scientific literature regarding the effect of lower leg CGs versus non-CGs (such as regular socks) or versus placebo CGs on the incidence (recurrence and occurrence (1st injury) of injuries) of lower extremity sports injuries. A second aim was to investigate the effects of CGs on subjective ratings of fatigue and biomechanical variables, given that fatigue-related biomechanical alterations may increase the risk of sports injuries. A priori, we hypothesized that CGs would be more effective than CGs or non-CGs (such as regular socks) or placebo CGs for all of the aforementioned outcomes.

METHODS

This systematic review of the effects of CGs compared to non-CGs (such as regular socks) and placebo garments was carried out according to the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) statement (38), following the guidelines of the Cochrane Handbook for Systematic Reviews of Interventions (21).

Search strategy

The electronic databases PubMed, Embase, CINAHL, Cochrane, PEDro, and Scopus were searched for eligible studies up to 7 July 2021, using the following keywords: compression garments, compression stockings, compression socks, compression sleeves, compression clothing, athletes, running, runners, jogging. The complete search strategy can be found in Appendix 1. The reference lists of the included studies were searched to identify additional relevant studies. No language restrictions were applied.

Inclusion criteria

Studies were eligible for inclusion if: (1) a randomized controlled trial (RCT), controlled clinical trial, randomized block design (i.e., matched pairs), or crossover design was used; (2) study participants were aged > 18 years; (3) participants participated in any sport that required any level of running performance; (4) participants in the intervention group wore lower leg CGs (e.g., stockings, calf sleeves, socks) during running; (5) participants in the control group wore non-CGs (such as regular socks), or placebo garments (garments were considered to be placebo garments if they were non-compressive lower leg garments but athletes were told that they were CGs); and (6) the study included at least one outcome measure, namely, the incidence of lower extremity sports injuries, subjective ratings of fatigue or exertion, or biomechanical variables.

Studies were excluded if (1) study participants had a physical disorder (e.g., cardiovascular, metabolic, neurological, musculoskeletal) that could influence the outcome measures other than lower extremity sports injuries; (2) there were insufficient data on the incidence of lower extremity sports injuries, fatigue, or biomechanical variables (i.e., means, measures of variability, and/or *p* values were not reported), and (3) the article was not available in full text.

Study selection

After duplicate studies were removed, two reviewers (TF, HH) independently screened the eligibility of the titles and abstracts. Then, full-text versions of the studies with relevant abstracts were screened for final inclusion. If a full-text copy could not be found, the authors of the article were contacted and asked to provide it. Differences in study selection between the two reviewers were resolved by consensus. If no consensus could be achieved, a third reviewer (BH) was asked for a final decision.

Data extraction

Two reviewers (TF, HH) independently extracted data using a standardized data extraction form which was based on the Template for Intervention Description and Replication (TIDieR) guideline and checklist (24) and the guideline of the International Compression Club (ICC)(41).

The TIDieR guideline and checklist aim to stimulate the completeness of reporting and, ultimately, the replicability of interventions. We used the following items from the TIDieR checklist: (1) first author, publication year, and study design, (2) characteristics of study sample, (3) intervention characteristics (including the items from the ICC guideline), (4) control garment characteristics, (5) setting characteristics (i.e. by whom, how, where, and how much of which intervention or test was provided), (6) outcome measures, and (7) results.

The ICC guideline was established to help the design studies of CGs in patients with venous disorders. However, we think that the guideline can also be used in studies investigating the effects of sports CGs. We used the ICC guideline because there is no specific guideline for

sports CGs. The following data specific to CGs were extracted: type CG, fabric, pressure applied, type of material (flat or round knitted), stiffness of the material, timing, duration of use, and tailoring of the intervention (i.e. were CGs ready to wear or made to measure). If data were missing or further information was needed, the corresponding author was contacted to request for the missing data.
Follow-up periods were classified as: 1) during a test or race, 2) during the last minute or immediately after a test or race (i.e. up to 5 minutes after), 3) short term (from 5 minutes after the test up to 3 months), 4) mid-term (4–6 months), 5) long-term (>6 months).

Risk of bias assessment
Risk of bias was assessed independently by two reviewers (TF, HH) using the Revised Cochrane risk-of-bias (ROB2.0) tool for (cross-over) randomized trials (21,49), which evaluates the following domains: (1) randomization process, (2) deviations form intended interventions, (3) missing outcome data, (4) measurement of the outcome, (5) selection of the reported results, and (6) overall bias. Using the scores on the items from each of the domains and the predefined algorithm of the ROB2.0 tool each of the domains was judged as 'Low risk', 'Some concerns', or 'High risk'. Discrepancies between the two reviewers were resolved by discussion. If consensus could not be achieved, a third reviewer (BH) was asked for a final decision.

Data synthesis
In order to compare the effect of CGs to control interventions, random-effects meta-analyses were performed when multiple (≥ 2) studies were comparable regarding CGs used, control treatments, participant characteristics, and outcome measures.

For each study, effect sizes were calculated if these were not given in the article. Standardized mean differences (SMD) and 95% confidence intervals (CI) were calculated for continuous outcomes, using Hedges' *g* with an adjustment for small sample bias (13). Hedges' *g* was computed using the mean difference between the experimental and control groups divided by the pooled standard deviation (SD). If the SD was not reported, it was derived from the standard errors or the CI for group means. A Hedges' *g* effect size of <0.40 was defined as small, 0.40–0.70 as moderate, and >0.70 as large. Heterogeneity between the studies was estimated using the I^2 statistic and is classified as follows: 0-40% unimportant, 30-60% moderate, 50-90% substantial, and 75-100% considerable heterogeneity (21). Results were pooled in RevMan 5.4 software using the Inverse Variance Method.

Sensitivity analyses were performed to assess the robustness of the meta-analyses (13). If two or more studies were available for inclusion in a sensitivity analyses, we investigated whether there was an effect of different CGs characteristics or test characteristics, because to date no systematic reviews have assessed the characteristics of different types of CGs. Instead, previous reviews have combined multiple types of CGs with varying characteristics in meta-analyses. Based on the included studies we therefore chose to compare the effects of CGs to non-CGs (such as regular socks) and to placebo CGs, based on the characteristics of the CGs and the tests performed in the included studies.

Summary of findings and assessment of the certainty of the evidence

The Grades of Recommendation, Assessment, Development and Evaluation (GRADE) approach was used to assess the certainty of evidence (13). The GRADE approach consists of four levels of certainty, starting with a high certainty rating for randomized trial evidence. Randomized trial evidence can be downgraded to moderate, low, or very low certainty evidence, depending on the presence of five factors (i.e., risk of bias, indirectness, inconsistency, imprecision, and publication bias).

RESULTS

Characteristics of the studies

The initial search identified 802 articles. After the articles were screened and assessed for eligibility, 23 full-text articles were included (Figure 1). An overview of the characteristics of the included studies is presented in Appendix 2. The corresponding authors of three articles provided means and SDs for the intervention and control groups (12,40,45). Four studies consisted of two experiments each, so eight experiments in total. Data for these eight experiments were extracted and assessed separately (1,2,39,52). One study described three experiments (3).

In total, 520 athletes were involved in the 23 studies, with a mean sample size ± standard deviation (SD) of 20.8±17.3 participants. The athletes were recreational (1,4,9,12,22,27,29,31,32,34,35,39,40,52,53), competitive (2,3), cross-country (44,45), marathon runners (5,7), triathletes (48), or athletes whose sport was based on running (i.e. soccer, tennis, rugby) and performed at least two recreational runs per week (1). Eleven studies included both men and women (2,3,5,7,31,32,39,40,44,45,52), eleven included only men (1,4,9,12,27,29,34,35,48,50,53), and one included only women (51). Overall, more than three times as many men (n= 404) than women (n=116) participated in the included studies.

Risk of bias assessment

Table 1 and Appendix 3 show the results of the risk of bias assessment for each study and the distribution of the risk of bias per domain, respectively. All studies were considered to have a high risk of bias overall, which arose mainly because of a high risk of bias in the domains ‘selection of the reported results’ (100% of the studies), ‘deviations from the intended interventions’ (87.5%), and ‘measurement of the outcome’ (83.3%).

Characteristics of the compression garments

Table 2 shows the characteristics of the CGs used in the intervention groups of the 23 studies. Compression socks, i.e. CGs that cover the entire foot, were used in 16 studies (1–3,5,7,12,27,31,32,39,40,44,45,48,51,52). The actual pressure provided by the CGs was measured in only three studies (2,12,29). Sixteen studies did not measure the pressure but reported the pressure as provided by the manufacturer (1,3–5,7,9,27,31,32,34,39,40,44,45,48,50). None of the studies reported whether the CGs were flat or round knitted or the stiffness of the materials used, and 10 studies did not report the type of fabric(s) used to make the CGs. Overall, the studies reported a mean of 70% of the CG characteristics mentioned in the ICC guideline.

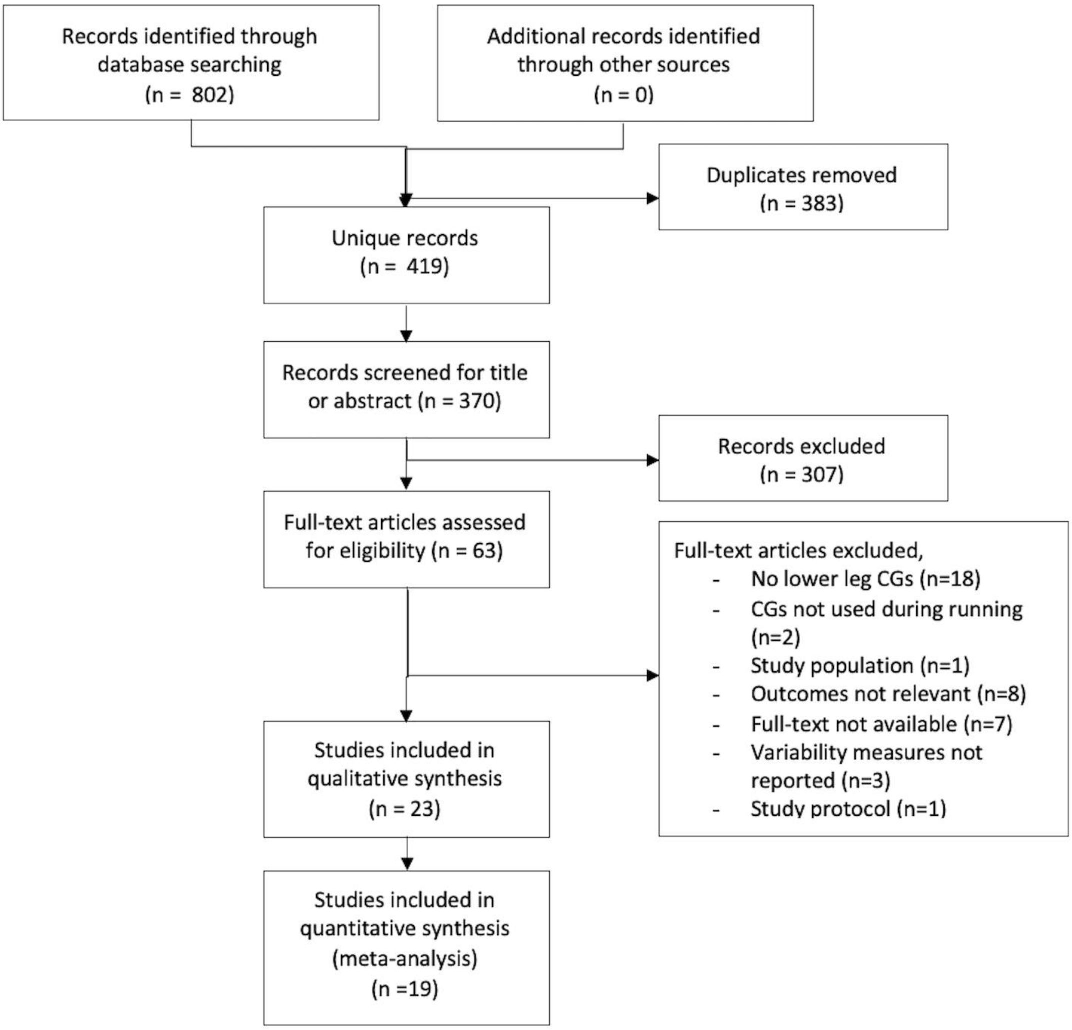

Figure 1. Prisma flowchart.

Table 1. Risk of bias assessment per domain per study.

	STUDY ID	RANDOMIZATION PROCESS	DEVIATIONS FROM INTENDED INTERVENTIONS	MISSING OUTCOME DATA	MEASUREMENT OF THE OUTCOME	SELECTION OF THE REPORTED RESULT	OVERALL
1	Ali et al.[1] experiment 1	-	+	+	-	?	-
2	Ali et al.[1] experiment 2	-	+	-	-	?	-
3	Ali et al.[2] experiment 1	?	-	+	+	?	-
4	Ali et al.[2] experiment 2	?	-	+	+	?	-
5	Ali et al.[3] experiment 1	?	-	-	+	?	-
6	Ali et al.[3] experiment 2	?	-	-	+	?	-
7	Ali et al.[3] experiment 3	?	-	-	+	?	-
8	Allaert et al.[5]	-	-	-	-	?	-
9	Allaert et al.[4]	-	-	-	-	?	-
10	Areces et al.[7]	?	-	+	?	?	-
11	Bieuzen et al.[9]	?	-	-	-	?	-
12	Brophy Williams et al.[12]	-	-	-	-	?	-
13	Jefrey et al.[26]	?	-	+	-	?	-
14	Kerherve et al.[29]	?	-	+	-	?	-
15	Lucas-Cuevas et al.[31]	?	-	-	-	?	-
16	Lucas-Cuevas et al.[32]	?	-	-	-	?	-
17	Menetrier et al.[35]	?	-	-	-	?	-
18	Menetrier et al.[34]	?	-	-	-	?	-
19	Moreno-Perez et al.[39] experiment 1	?	-	-	-	?	-
20	Moreno-Perez et al.[39] experiment 2	?	-	-	-	?	-
21	Priego Quesada et al.[40]	?	-	-	-	?	-
22	Rider et al.[44]	?	-	-	-	?	-
23	Rivas et al.[45]	?	-	-	-	?	-
24	Sperlich et al.[48]	?	-	-	-	?	-
25	Stickford et al.[50]	?	-	-	-	?	-
26	Treseler et al.[51]	?	+	+	-	?	-
27	Varela-Sanz et al.[52] experiment 1	?	-	+	-	?	-
28	Varela-Sanz et al.[52] experiment 2	-	-	+	-	?	-
29	Vercruyssen et al.[53]	?	-	-	-	?	-

Note: ?, some concerns; +, low risk of bias; -, high risk of bias.

Table 2. Characteristics of compression garments used in the included studies.

Reference	Type of CG	Kind of material Flat or round knitted?	Stiffness of the material	Constant or graduated pressure	Pressure gradient reported	Pressures gradient measured by investigators or provided by manufacturer	Ready to wear or made to measure	Percentage reported
Ali et al.[1]	Knee length stocking			Graduated	18-22mmHg, 22 mmHg at ankle level, decreasing to 70% at the top of the stocking.	Provided by manufacturer	Ready to wear	71%
Ali et al.[2]	Below knee socks			Graduated	Low pressure grade group 15 mmHg at ankle, 12 mmHg at knee High pressure grade group 32 mmHg at ankle, 23 mmHg at knee	Measured by investigators	Ready to wear	71%
Ali et al.[33]	Below knee socks			Graduated	Below-knee GCs Low grade 15 mmHg at ankle 12 mmHg at knee Medium grade 21 mmHg at ankle, 18 mmHg at knee High grade 32 mmHg at ankle, 23 mmHg at knee	Provided by manufacturer	Ready to wear	71%
Allaert et al.[5]	Compression socks				18-21 mmHg	Provided by manufacturer		43%
Allaert et al.[4]	Compression sleeves			Graduated	15-20 mmHg at the level of the calf muscles	Provided by manufacturer	Ready to wear	71%

Areces et al.[7]	Below-knee GCs	77% polyamide, 13% elastane, and 10% polyester	Graduated	25 mmHg at the foot and malleolus to 20 mmHg below the knee	Provided by manufacturer	Ready to wear	86%
Bieuzen et al.[9]	Sleeve from the lateral malleolus to below the knee.	constant 94% polyamide and 6% elastane	Constant	25 mmHg	Provided by manufacturer		71%
Brophy Williams et al.[12]	Below knee compression socks		Graduated	23 ±4 mmHg at the lower ankle, 31±4 mmHg at the upper ankle, 37 ± 4 mmHg at the maximal calf girth.	Measured by investigators	Ready to wear	71%
Jefrey et al.[27]	Below knee compression socks	85% nylon, 15% spandex		20-30 mmHg	Provided by manufacturer	Ready to wear	71%
Kerhervé et al.[29]	Degressive calf compression sleeves between the ankle and the knee joint			23 ± 2 mmHg in between of medial and lateral heads of the gastrocnemius muscle.	Measured by investigators		43%
Lucas-Cuevas et al.[31]	Below-knee stockings	85 % polyamide and 15 % elastane (Lycra)	Graduated	24 mmHg at ankle 21 mmHg at calf	Provided by manufacturer	Ready to wear	86%
Lucas-Cuevas et al.[32]	Below-knee stockings	85 % polyamide and 15 % elastane	Graduated	24 mmHg at the ankle, 21 mmHg at the calf	Provided by manufacturer	Ready to wear	86%
Menetrier et al.[35]	Calf compression sleeves	72 % nylon and 28 % elasthane	Graduated	15 mmHg at medial ankle 27 mmHg at top of gastrocnemius	Provided by manufacturer	Ready to wear	86%

Menetrier et al.[34]	Calf compression sleeves			≈20 mmHg at the level of the gastrocnemius muscle			29%
Moreno-Perez et al. [39]	Below-knee graduated compression stockings	88% polyamid, 12% elasthane	Graduated	15-20 mmHg at the ankle	Provided by manufacturer	Ready to wear	86%
Priego Quesada et al.[40]	Below-knee compression stockings	85% Polyamide and 15% Elastane	Graduated	20-25 mmHg at ankle 15-10 mmHg under the knee	Provided by manufacturer	Ready to wear	86%
Rider et al.[44]	Below-knee compression stockings	67% dri-release polyester, 26% nylon, and 7% spandex	Graduated	20 mmHg at the ankle and 15 mmHg at the calf	Provided by manufacturer	Ready to wear	86%
Rivas et al.[45]	Below-knee compression socks		Graduated	12-15 mmHg at ankle and 9-12 mmHg over the calf	Provided by manufacturer	Ready to wear	71%
Sperlich et al.[48]	Compression socks	94% Polyamide, 6% Lycra		20 mmHg	Provided by manufacturer	Ready to wear	71%
Stickford et al.[50]	Calf compression sleeve from ~2cm above the ankle to ~4cm below the knee		Graduated	15-20 mmHg	Provided by manufacturer	Ready to wear	71%
Treseler et al.[51]	Below-knee compression stockings		Graduated	18-21 mmHg at the ankle 12.6-14.7 mmHg at the knee		Ready to wear	57%

Varela-Sanz et al.[52]	Below-knee compression stockings	88% Polyamid; 12% Elasthane	Graduated	15-22 mmHg pressure at the ankle, pressure at the calf/below knee level not reported	57%
Vercruyssen et al.[53]	Below-knee compression socks from the lateral malleolus to below the knee	94% Polyamide, 6% Lycra	Constant	18 mmHg	57%

Note: cm, centimter; mmHg, milimeters of mercurcy; GCs, graduated compression stockings.

Effectiveness of compression garments

The evidence for the effectiveness of CGs versus non-CGs (such as regular socks) or versus placebo CGs was assessed using the following outcome measures; 1) incidence of lower extremity sports injuries, 2) subjective ratings of fatigue, and 3) biomechanical outcome variables (Table 3).

Table 3. GRADE evidence table for compression garments (CGs) versus non-CGs (such as regular socks) and versus placebo CGs.

Certainty assessment							**№ of patients**		**Effect**	**Certainty**
№ of studies	**Study design**	**Risk of bias**	**Inconsistency**	**Indirectness**	**Imprecision**	**Other considerations**	**Intervention**	**Control**	**Absolute (95% CI)**	
Subjective ratings of fatigue- CGs vs non-CGs (such as regular socks) (assessed with: rated perceived exertion)										
17	randomised cross-over trials	very serious [a]	serious[b]	not serious	serious [c]	none	382	382	SMD **0.08 higher** (0.33 lower to 0.18 higher)	⊕◯◯◯ VERY LOW
Subjective ratings of fatigue - CGs vs placebo CGs, (assessed with: rated perceived exertion)										

Certainty assessment							№ of patients		Effect	Certainty
№ of studies	**Study design**	**Risk of bias**	**Inconsistency**	**Indirectness**	**Imprecision**	**Other considerations**	**Intervention**	**Control**	**Absolute (95% CI)**	
5	randomised cross-over trials	very serious[a]	not serious	not serious	serious [b]	none	180	180	SMD **0.01 SD lower** (0.22 lower to 0.20 higher)	⊕◯◯◯ VERY LOW
Muscle Fatigue - CGs vs no-CGs (such as regular socks) (assessed with: visual analogue scale)										
2	randomised cross-over trials	very serious[a]	serious[b]	not serious	serious [c]	none	55	55	SMD **0.3 lower** (0.96 lower to 0.37 higher)	⊕◯◯◯ VERY LOW
Muscle Fatigue - CGs vs placebo CGs (assessed with: visual analogue scale)										
1	randomised cross-over trials	very serious[a]	not serious	serious	serious [c]	None	14	14	-	⊕◯◯◯ VERY LOW
Biomechanical variables - CGs vs non-CGs (such as regular socks) (assessed with: step frequency, contact time, step length, swing time)										
2	randomised cross-over trials	very serious[a]	serious	not serious	serious [c]	None	32	32	-	⊕◯◯◯ VERY LOW
Biomechanical variables - CGs vs placebo CGs, (assessed with: contact time, aerial time, step frequency, step length, peak force, duty factor, lower limb stiffness, vertical stiffness, and impact acceleration parameters)										
2	randomised trials	very serious[a]	serious	serious	serious [c]	none	54	54	-	⊕◯◯◯ VERY LOW

Note: CI, Confidence interval; CGs, Compression garments; SMD, Standardised mean difference; vs, versus
Explanations: a. high risk of bias, b. moderate to substantial heterogeneity, c. insufficient sample size per study.

Incidence of lower extremity sports injuries

None of the included studies investigated the effects of CGs on the incidence of lower extremity sports injuries.

So, no evidence for the effectiveness of lower leg CGs on the incidence of lower leg sport injuries in athletes participated in any sport that required any level of running performance was found.

Subjective ratings of fatigue

Studies that assessed the effect of CGs relative to non-CGs (such as regular socks) and placebo CGs reported two outcome measures: 1) RPE and 2) perceived muscle fatigue.

Seventeen studies (21 experiments) reported on RPE with CGs versus non-CGs (such as regular socks) were included (1,2,5,7,9,12,31,34,39,40,44,45,48,51–53). All 21 experiments were included in the meta-analysis on RPE and reported on the effectiveness of CGs during the last minute of the test, directly after the race or test (1,2,4,5,7,9,31,34,39,40,45,48,51–53), or three minutes after the race or test (12,44). There was no difference in RPE between CGs versus non-CGs (Standardized Mean Difference [SMD], -0.08 (95% confidence interval [CI] -0.33; 0.18), p-value $p=0.55$, heterogeneity $I^2=65\%$) (Figure 2). Eight sensitivity analyses were performed that compared the effects of wearing different types of CGs to non-CGs (such as regular socks). CGs with a 1) pressure 15-21 mmHg at ankle level, 2) graduated pressure gradient, 3) constant pressure, 4) sock form, 5) sleeve form all compared to non-CGs (Appendix 4). Additionally, CGs were compared to non-CGs when worn during 6) submaximal tests performed on a treadmill, 7) maximal tests performed on a treadmill, and 8) tests performed outside on the road or trail. The only significant difference in RPE was seen in favour of CGs in the comparison constant pressure CGs versus non-CGs (-0.43 (-0.74; -0.11), $p=0.008$, $I^2=0\%$).

Perceived muscle fatigue was measured in two studies that compared CGs to non-CGs (such as regular socks) directly after a marathon race (5) and three minutes after a running time trial (12). There was no difference in perceived muscle fatigue between CGs versus non-CGs (-0.30 (-0.96; 0.37)), $p=0.38$, $I^2=55\%$) (Figure 3).

Two studies (4 experiments) compared the effects of CGs to placebo CGs (Figure 4) (3,32). Meta-analysis of these 4 experiments showed no significant difference in RPE between CGs and placebo CGs (0.12 (-0.20; 0.44)), $p=0.47$, $I^2=0\%$). Two sensitivity analyses comparing CGs with varying pressure gradients (15–21 mmHg and 23–32 mmHg at the ankle) to placebo CGs found no significant difference in RPE. Only one study(29), which investigated CGs versus placebo CGs, used a visual analogue scale (VAS) to measure perceived muscle fatigue. Thus, a meta-analysis could not be performed. The study reported that perceived fatigue of the thigh muscles was significantly lower in the CG group than in the placebo group after a run (CG group 5.93 ± 3.00 vs placebo group 6.71 ± 1.44, $p=0.041$, effect size $\eta^2_p = 0.28$).

Owing to the high risk of bias, inconsistency (moderate-substantial heterogeneity) and imprecision (insufficient sample size), the evidence was low certainty. There is little confidence in the estimate of the effects of CGs versus non-CGs (such as regular athletic socks) or versus placebo CGs on RPE or perceived muscle fatigue in athletes participating in any sport, which required any level of running performance.

Biomechanical outcome variables

Two studies investigating CGs versus non-CGs (such as regular socks) reported on biomechanical variables such as 1) step frequency, 2) contact time, 3) step length, and 4) swing time (50,52). No univocal definitions for the aforementioned biomechanical variables and exercise protocols were used in these studies. As to CGs vs placebo GCs, two studies measured a variety of biomechanical variables (29,32). Only step frequency was measured by both studies. However, as these studies used different definitions for step frequency and used dissimilar tests no meta-analysis could be performed. Although no meta-analysis was performed the studies were included in the GRADE assessment. Because of the high risk of bias, inconsistency, and imprecision (insufficient sample size) the evidence downgraded and judged as low quality evidence. Thus, there is little confidence in the evidence for the effect of CGs on biomechanical variables compared to either non-CGs (such as regular socks) or to placebo CGs for athletes in any sport for which any level of running performance was needed.

	CG			Regular socks				Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
1.1.1 CGs vs non-CGs or regular socks								
Ali et al. 2007.Experiment 1	17	0.5	14	17	0.4	14	5.5%	0.00 [-0.74, 0.74]
Ali et al. 2007.Experiment 2	17	0.5	14	17	0.5	14	5.5%	0.00 [-0.74, 0.74]
Ali et al. 2010. A	13.9	1.1	10	13.4	1.2	10	4.7%	0.42 [-0.47, 1.30]
Ali et al. 2010. B	13.8	1	10	13.4	1.2	10	4.8%	0.35 [-0.54, 1.23]
Allaert et al. 2011	44	21	43	57	25	43	7.2%	-0.56 [-0.99, -0.13]
Allaert et al. 2017	9.8	0.2	35	10.1	0.2	35	6.6%	-1.48 [-2.02, -0.95]
Areces et al. 2015	16	2	17	16	2	17	5.9%	0.00 [-0.67, 0.67]
Bieuzen et al. 2014	16	3	11	17	2	11	5.0%	-0.38 [-1.22, 0.47]
Brophy Williams et al. 2019	18.2	1.2	12	18	1.3	12	5.2%	0.15 [-0.65, 0.96]
Lucas Cuevas et al. 2017	14.7	1.3	36	14.2	1.4	36	7.0%	0.37 [-0.10, 0.83]
Menetrier et al. 2011.A	4.7	0.4	14	4.3	0.2	14	5.1%	1.23 [0.41, 2.05]
Priego Quesada et al. 2015	14.6	2.3	44	14	2.2	44	7.3%	0.26 [-0.16, 0.68]
Rider et al. 2014	19	0.9	10	19.5	0.5	10	4.7%	-0.66 [-1.56, 0.25]
Rivas et al. 2017	16	2	13	16	2	13	5.3%	0.00 [-0.77, 0.77]
Sperlich et al. 2010	18.3	1	15	18.6	1.1	15	5.6%	-0.28 [-1.00, 0.44]
Treseler et al. 2016	15.3	2	19	14.6	1.8	19	6.0%	0.36 [-0.28, 1.00]
Varela Sanz et al. 2011	9.71	0.48	6	9.5	0.83	6	3.7%	0.29 [-0.85, 1.43]
Vercruyssen et al. 2014	17.1	2.5	11	17.5	1.6	11	5.0%	-0.18 [-1.02, 0.65]
Total (95% CI)			**334**			**334**	**100.0%**	**-0.03 [-0.32, 0.26]**

Heterogeneity: Tau² = 0.26; Chi² = 54.53, df = 17 (P < 0.00001); I² = 69%
Test for overall effect: Z = 0.20 (P = 0.84)
Test for subgroup differences: Not applicable

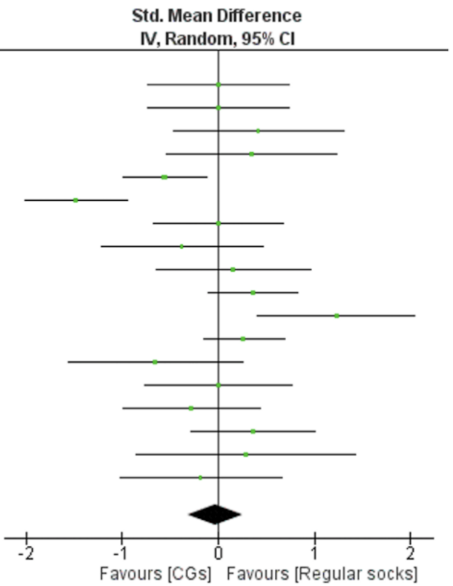

Figure 2. Meta-analysis for CGs vs no-CGs or regular socks on rate of perceived exertion.

Note: CI, confidence interval; CG, compression garments; vs, versus; SD, standard deviation.

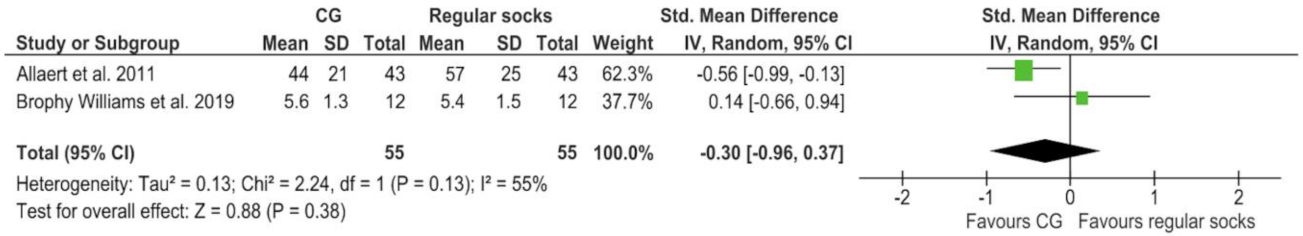

Figure 3. Meta-analysis for CGs vs no-CGs or regular socks on muscle fatigue (assessed with a Visual Analogue Scale).
Note: CI, confidence interval; CG, compression garments; vs, versus; SD, standard deviation.

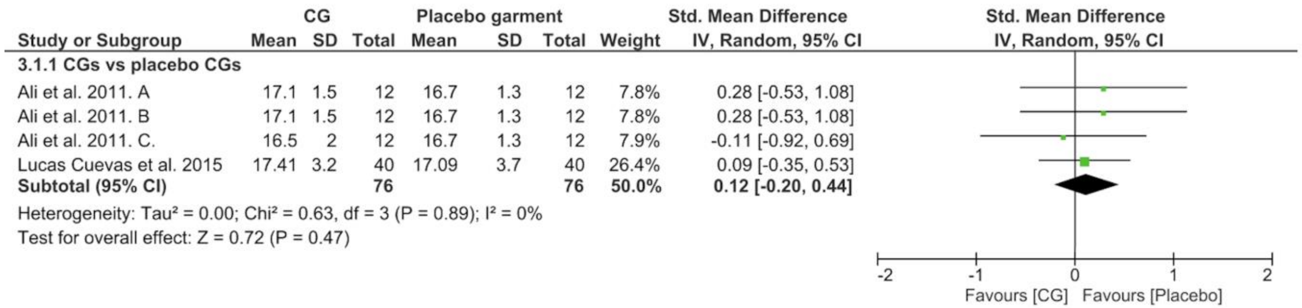

Figure 4. Meta-analysis for CGs vs placebo CGs on subjective ratings of fatigue (assessed with rate of perceived exertion).
Note: CI, confidence interval; CG, compression garments; vs, versus; SD, standard deviation.

DISCUSSION

The aim of this study was to systematically review the literature on the effects of lower leg CGs on the incidence of lower extremity sports injuries and secondary measures, subjective rating of fatigue and biomechanical variables. No studies were found that investigated the incidence of lower extremity sports injuries. As such, we cannot state if CGs have a beneficial or detrimental effect on the incidence of lower extremity sports injuries, because absence of evidence does not mean evidence of absence (6). We did identify multiple studies investigating the effect of CGs on subjective ratings of fatigue and biomechanical variables, but we found no evidence for a beneficial or detrimental effect of CGs compared to non-CGs (such as regular socks) or placebo CGs in athletes participating in any sport involving any level of running performance.

A clear gap of knowledge in the scientific literature was identified as no studies were found that investigated the effects leg CGs on (secondary) lower extremity sports injury prevention. Even though, we very broadly defined lower extremity sports injuries within this systematic review, as a priori we hypothesized that the scientific literature would be scarce, we did not identify any studies on the effects of CGs on lower extremity sports injuries and injury prevention. It is important to investigate whether there is a causal relationship between using CGs and the occurrence of lower extremity injuries, because almost half of the athletes who wear CGs use them to prevent injury recurrence (19). The systematic review of Bisciotti et al. (2020), which included two RCTs, one cross-sectional study, and one case series, theorized that compression clothing reduces pain and symptoms in athletes with adductor-related groin pain syndrome (10). The authors suggested that compression shorts might reduce activation of the adductor longus muscle and thus the load on the adductor longus enthesis and the symphysis. Translating this hypothesis to lower leg CGs, might suppose that pressure on lower leg muscles provided by CGs might reduce activation of the plantar flexor muscles, leading to diminished traction on the tendinous insertion of the muscles and on the tibial periosteum. Traction on the tibial periosteum is a suggested pathophysiological mechanism of medial tibial stress syndrome (MTSS) (8,11,37). Future research should investigate whether the use of lower leg CGs prevents the occurrence of lower extremity injuries such as MTSS.

While multiple studies on the effect of CGs on subjective ratings of fatigue were included in our meta-analyses, we found CGs not to have a significant effect on subjective ratings of fatigue compared to non-CGs (such as regular socks) or placebo CGs, except in one sensitivity analysis. With low certainty evidence, the sensitivity analysis showed that athletes using constant pressure CGs had a lower RPE immediately after a test compared with athletes using non-CGs. As such, indicating that CGs with a constant pressure might help reduce fatigue after a running test. In their meta-analysis, Engel et al. (2016) reported, based on 16 original studies, small but positive effects of wearing lower extremity CGs during running on perceived exertion in recreational, well trained, and elite runners (Hedges' g = 0.28±0.38 mean±SD; range -0.31 to 1.21) (16). However, their review did not distinguish between different types of CGs (i.e. shorts, tights, and socks) and included them in a single meta-analysis, whereas we focused purely on lower leg CGs. Moreover, in the sensitivity analyses we distinguished between sock and sleeve CGs. Except for the aforementioned sensitivity analysis, no significant effects were found. The systematic review from da Silva et al. (47). corroborated our findings, as they also reported no effects of lower leg CGs on RPE specifically during high intensity exercise. Hill et al. and Hu et al. have investigated the post training use of CGs on recovery from sports (23,26). They reported that using CGs post training might help decrease recovery from exercise induced muscle damage or even heart rate variability as a proxy for automatic nervous system modulation. Future studies might consider further exploring if post training or match use of CG improves recovery and consequently decreases the risk of a sports injury occurring. We identified multiple studies investigating the effect of CGs on subjective ratings of fatigue and biomechanical variables, but we found no evidence for a beneficial or detrimental effect of CGs compared to non-CGs (such as regular socks) or placebo CGs in athletes participating in any sport involving any level of running performance.

We aimed to provide an overview of the characteristics of the CGs from the included studies using the ICC guideline (41). However, the poor reporting of the characteristics of the CGs used meant that we were unable to provide a proper overview. On average, 70% of the characteristics of the CGs were reported, but information such as the 'kind of material' and 'stiffness' were poorly reported. The 'kind of material' used, i.e. the (elastic) fabric of the CG, is important because it greatly affects the extensibility and the elastic recovery of the CG (41,58). These two characteristics are what enables CGs to exert pressure on the lower limb. Extensibility is the extent to which the CG can lengthen and elastic recovery reflects the extent and speed with which a fabric regains its original length and shape after being stretched to less than its breaking point (54). Stiffness is defined as the change of compression exerted by a garment when the girth is increased or decreased. This information is essential to include in studies investigating whether CGs actually contribute to sports injury prevention. Clear reporting of the CGs used facilitates pooling of similar interventions in future meta-analyses.

We could not perform a meta-analyses of biomechanical variables because studies used varying definitions and measurements of these variables. For example, Stickford et al. measured step frequency at 233, 268, and 300 m/min (50), whereas Varela-Sanz et al. measured step frequency during the first third and last third of a time to exhaustion test on a treadmill at a 1% gradient with a speed of 105% of a recent 10-km time (52), and Kerherve et al. used an outdoor running test, part tarmac and part trail running through hilly terrain (29). The aforementioned variations in measurement of biomechanical variables explain why pooling these studies is not recommendable. This lack of uniformity of definition and measurements show why it is important to develop a consensus-based standardized treadmill protocol for future studies. Furthermore, the certainty of the evidence for the biomechanical variables was low because of a high risk of bias, inconsistency, and imprecision in the included studies.

Limitations

A clear limitation in the generalizability of our findings is the low certainty of the evidence found, mainly because all the included studies had a high risk of bias, as assessed with the revised Cochrane risk-of-bias tool for randomized trails (RoB 2) (49). This version of the risk of bias assessment tool enables authors to evaluate bias in several domains and then determine the domain score by following a predefined algorithm. The domains 'deviations from the intended intervention' and 'measurement of the outcome' were judged as being at high risk of bias most frequently because participants often were aware of the assigned intervention and this could affect the assessment of outcome measures. A test version of the risk of bias assessment tool specifically for cross-over trials was published by Cochrane in March 2021, after the meta-analysis for this study was completed (49). The adapted version of the risk of bias assessment includes items specific to cross-over trials regarding period and carry-over effects. However, as all studies had high risk of bias in other domains, the use of this new version would not have affected our risk of bias assessment.

Another limitation in the generalizability of our findings is that the included studies included nearly three times as many men (n= 404) as women (n=116). Eleven studies included both men and women (2,3,5,7,31,32,39,40,44,45,52), eleven only men (1,4,9,12,27,29,34,35,48,50,53), and one only women (51). Further, our study did not investigate if the effects of CGs varies for different types subgroups of athletes and different lower extremity injury definitions. Per example, it is known that more experienced athletes or athletes with previous injuries might wear their CGs more consequently as in their perception CGs help prevent injuries (19). Future studies on the effects of CGs on (the prevention of) lower extremity injuries should investigate if the effects of CGs vary for specific groups of athletes and injury definitions.

Conclusion

Our study systematically reviewed the scientific literature for any evidence for an effect of lower leg CGs versus non-CGs (such as regular socks) and versus placebo garments, used by athletes who participated in any sport that involved any level of running performance. We did not find a single study that investigated whether lower leg CGs had a positive or negative effect on the incidence of (recurring) lower extremity injuries in athletes. Our meta-analyses regarding subjective ratings of fatigue did not find any evidence favouring either CGs or non-CGs (such as regular socks) or placebo garments during or directly after the running test, in the short-, mid-, or long-term. Only one of the ten sensitivity analyses found significant results (low-certainty evidence) showing that athletes who used constant pressure gradient CGs had a lower RPE immediately after the running test compared to non-CGs. Because of the heterogeneity in running tests, outcome definitions, and CG characteristics, we were unable to perform meta-analyses of the effects of CGs on biomechanical variables. Further, based on the variable reporting of CG characteristics standardized reporting is recommended for future studies evaluating CGs. Consensus based standardized reporting could be achieved using Delphi methodology. As athletes use CGs to prevent (recurring) sports injuries, studies investigating the effectiveness of lower leg CGs in preventing lower extremity sports injuries are needed.

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