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REVIEW

Effects of Wearing Compression Stockings on Exercise Performance and Associated Indicators: A Systematic Review

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Gustavo R Mota[1]
Mário Antônio de Moura Simim[2]
Izabela Aparecida dos Santos[1]
Jeffer Eidi Sasaki[1]
Moacir Marocolo[3]

[1]Human Performance and Sport Research Group, Department of Sport Sciences, Institute of Health Sciences, Federal University of Triangulo Mineiro, Uberaba, MG, Brazil; [2]Research Group in Biodynamic Human Movement, Institute of Physical Education and Sports, Federal University of Ceará, Fortaleza, CE, Brazil; [3]Physiology and Human Performance Research Group, Department of Physiology, Federal University of Juiz de Fora, Juiz de Fora, MG, Brazil

Abstract: This systematic review investigated the effects of wearing below-knee compression stockings (CS) on exercise performance (or sports activity) and associated physiological and perceived indicators. We searched articles on PubMed using the following terms: "graduated compression stockings"; "compression stockings"; "graduated compression socks"; "compression socks" combined with "performance", "athletes", "exercise", "exercise performance", "fatigue", "sports" and "recovery", resulting in 1067 papers. After checking for inclusion criteria (e.g., original studies, healthy subjects, performance analysis), 21 studies were selected and analyzed. We conclude that wearing CS during exercise improved performance in a small number of studies. However, wearing CS could benefit muscle function indicators and perceived muscle soreness during the recovery period. Future research should investigate the chronic effect of CS on Sports Medicine and athletic performance.

Keywords: ergogenic aid, fatigue, sports, medicine, prevention, soccer, running

Introduction

The prevention of deep venous thrombosis is one of the first evidence-based benefits of wearing compression stockings (CS), demonstrated by a clinical experiment in which CS improved the venous return by increasing femoral vein blood flow velocity in hospitalized patients.[1] Over time, the interest from the basic medical area has expanded to other fields like Sports Medicine.[2] Nowadays, recreational and professional athletes have used CS as a tool for improving performance or accelerate recovery from training or competitions, and also to reduce lower limb volume,[3,4] relieve symptoms of muscle soreness, and fatigue.[3–6] Such popularity is probably boosted by the possibility to obtain potential ergogenic benefits with a simple and low-cost aid.

There are different types (e.g., shorts for thighs, full-leg) and application modes (e.g., using only after the exercise) for compression garments. However, using CS (bellow-knee) "only during" the exercise are probably more practical (than during recovery, after-exercise) for a significant number of sports/activities. For example, uniform issues would limit whole-body garments in some sports. Also, athletes living in tropical locations could be unmotivated to wear compression garments after training sessions once those garments usually promote higher skin temperatures.[7,8] Additionally, there is limited evidence regarding the effects of wearing CS (only)

Correspondence: Gustavo R Mota
Human Performance and Sport Research Group, Department of Sport Sciences/ Institute of Health Sciences, Federal University of Triângulo Mineiro, Av. Tutunas, 490 Uberaba/MG, Uberaba 38061-500, Brazil
Tel +55 34 3700-6633
Email grmotta@gmail.com

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during exercise/training/competition, which could be relevant for Sports Medicine professionals. Therefore, the purpose of this systematic review was to investigate the effect of wearing below-knee CS during exercise (or sports activity) on performance and associated physiological and perceptual indicators.

Methods

A systematic literature search was performed by two independent reviewers in PubMed. The following terms: (i) “graduated compression stockings”; (ii) “compression stockings”; (iii) “graduated compression socks”; (iv) “compression socks” were combined with “performance”, “athletes”, “exercise”, “exercise performance”, “fatigue”, “sports” and “recovery” (Figure 1).

Inclusion Criteria

The studies included in this review met the following inclusion criteria: 1) original studies; 2) comprised samples of adults (≥ 18 yr); 3) participants were healthy; 4) investigated the effects of wearing foot-to-knee (below knee) CS (during exercise) on exercise performance and physiological and perceptual indicators (e.g., muscle fatigue, muscle recovery, musle soreness); 5) compression stockings worn during the exercise/test/match; and 6) study protocol included exercise or effort tests and performance analysis.

The literature search occurred between January 01, 1900, until June 30, 2019. We excluded the following type of articles: conference abstracts, case reports, short communications, systematic reviews, meta-analyses, theses, letters to the editor, and protocol papers. Also, we excluded studies involving unhealthy participants: e.g., patients with morbid conditions such as obesity, chronic venous insufficiency, diabetes, hypertension (but not limited to).

Analysis

The heterogeneity of the selected studies was considerable: e.g., exercise protocols, fitness level of the participants, variables measured. Thus, we have decided not to evaluate the studies chosen from a statistical point of view. Instead, we performed a qualitative analysis, conducted by two authors focusing on the effects reported by the authors and potential practical implications. All other authors read this qualitative analysis carefully, and edits have been incorporated.

Results

Figure 1 shows the search, selection, and inclusion process. The search displayed a total of 1067 papers, which were reduced to 370 after exclusion of duplicate publications. Then, we discarded 39 articles written in non-English languages.[9] From the remaining 331 items, we excluded 261 by examining the title. Finally, from the remaining 70 articles, we selected 21 studies for this review according to our inclusion criteria (Figure 1).

Table 1 presents a summary of the studies examining the effects of wearing below-knee CS during exercise on performance and associated indicators. Running was the most common type of exercise in the selected studies (76%, 16 out of the 21 studies), followed by soccer (two studies; 10%), triathlon, calf-rise exercise and cycle ergometer (one study each one; 5%). All studies were performed using a randomized experimental design, with the majority employing a crossover design strategy (13 studies, 62%) (Table 1).

Table 2 presents those studies in which CS influenced at least one measurable variable (15 studies, 71%). Three studies (14%) found effects from wearing CS on at least two variables, and for all others (12 studies; 57%) CS affected only one variable (Table 2).

Only two studies found some beneficial effect of CS on performance, and a third study improved subsequent performance (Table 2). Two studies did not find performance effects of CS for the group mean, but the authors highlighted that CS promoted benefits for some individuals. The main effects of CS are presented with compressions between 20 and 30 mmHg. The range between the minimum compression values is 12 to 28 mmHg, while the maximum values range from 15 to 33 mmHg.

Discussion

This systematic review aimed to investigate the effect of wearing below-knee CS during exercise on performance and associated indicators. The main finding is that wearing this kind of CS during exercise (or physical activity) improved performance in a minor part of the studies selected (i.e., 3 out of 21). However, a reasonable number of studies have shown evidence that wearing CS could benefit muscle function or fatigue indicators (e.g., CMJ, specific physical tests) and perceived muscle soreness just after the exercise protocol and/or hours after the exercise bout (e.g., during 1 h, 24 h recovery).

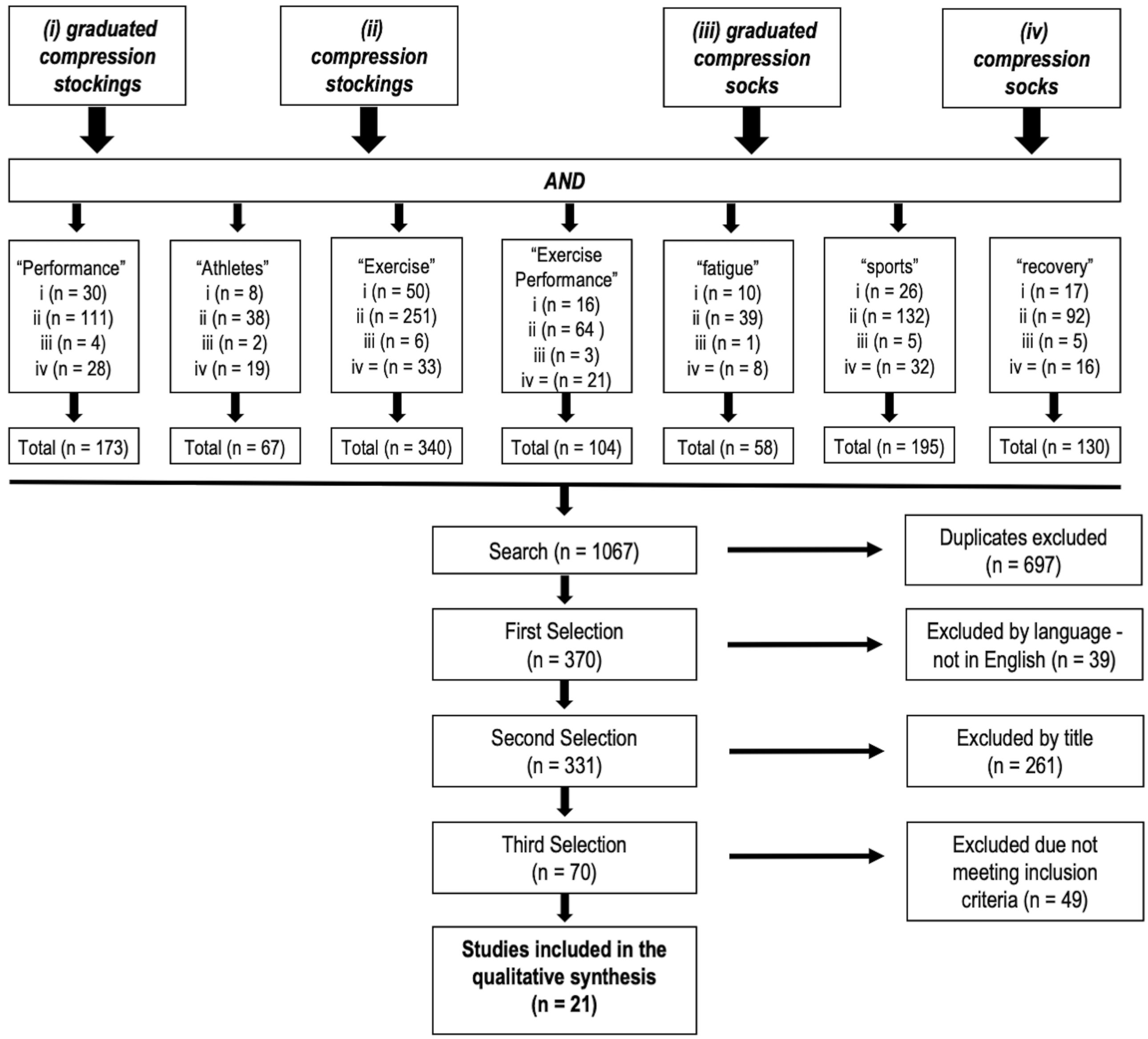

Figure 1 Flow chart for search and selection of articles.

CS and Performance Improvement

One of the main reasons for wearing CS during exercise is probably the expectation of performance enhancement due to potential physiological effects.[2] This includes better venous return which hasten metabolic removal from the exercising muscles[31] and reduce cardiac load,[26] improved proprioceptive feedback and better movement accuracy,[32] reduced muscle oscillations, lower muscle damage, inflammation, and soreness.[6,31] In the current review, only three studies found some CS-induced benefit on performance but did not present adirect mechanistic explanation. For example, astudy concluded that wearing CS (during two soccer matches, 72 hin-between) resulted in higher distances covered in high-intensity activities which are decisive for soccer. Also, CS promoted alower perceived muscle soreness in thesecond match.[17] Although the authors did not measure any direct muscle damage marker, they suggested that CS probably protected the eccentric actions common in soccer matches,[33] mechanically (i.e., smaller muscle oscillation).[6] In this regard, the oscillating forces experienced by the muscle resulted in reduced muscle fatigue. Thus, the CS might offer a mechanical advantage reducing muscle oscillation and countering fatigue in high-intensity activities (e.g., intermittent acceleration, changing directions).[34,35]

Table 1 Characteristics of the Studies Examining the Effects of Wearing CS Below-Knee During the Exercise Performance and Related Indicators

Date-Author	Subjects	Age	Aim	Experimental Design	CP (mmHg)	Type of Exercise	Exercise Protocol/ Details	Findings
Ali et al 2007[10] (Experiment 1)	14 recreational runners (men)	22±0.4	To examine the influence of wearing graduated CS on physiological and Perceptual responses during and after exercise	Randomized crossover	18–22	Intermittent running	2 x multi-stage fitness shuttle running test, with 1 h recovery between tests	CS had no effects on distance covered, HR, perceived soreness, RPE and comfort
Experiment 2	10 individuals participated in both experiments	23±0.5		Randomized crossover	18–22	Continuous running	10 km time-trial	CS decreased muscle soreness 24 h after the 10 km, but not performance, HR, RPE
Ali et al 2011[11]	12 well-trained runners (men and women)	33±10	To examine the effects of wearing different grades of CS on 10 km running performance and to assess the effects on physiological and perceptual responses after exercise	Randomized crossover	Control - 0 Low 12–15 Med 18–21 Hi 23–32	Running	10 km time-trial	CS worn did not affect performance; Low and Med CS resulted in greater maintenance of leg power after 10 km
Areces et al 2015[12]	34 experienced runners (30 men and 4 women)	42±7.8 control 41.2±8.9 CS	To investigate the benefits of CS for running pace, prevention of muscle damage, and maintenance of muscle performance during a real marathon	Randomized Controlled trial	20–25	Running	Marathon race (42,195 m)	CS did not improve marathon race time, muscle function, RPE or markers of muscle damage
Berry et al 1987[13]	6 high fit men college students	22.5±5.4	To determine the effects of CS on maximal oxygen consumption, time to exhaustion, and blood lactate during recovery	Randomized crossover	8–18	Running	Incremental treadmill test until exhaustion	CS had no effect on VO2max, recovery of VO2max. Blood lactate was lower on recovery period

Bieuzen et al 2014[14]	11 highly trained men runners	34.7±9.8	To examine the effect of wearing CS on indices of exercise-induced muscle damage in a trail-running context	Randomized crossover	25	Running (simulated trail race)	15.6 km total distance, being 3 laps of 5.2 km In mountainous terrain. Each lap had a climbing (2.2 km, ~ 13%) Followed by a downhill (3 km, ~ –9%).	CS improved post-exercise recovery (perceived leg soreness and muscle function); No benefits on markers of muscle damage/ inflammation
Brophy-Williams et al 2019[15]	12 well-trained men runners	30.5±8.1	To assess the effect of wearing CS during a 5 km running time-trial on physiological, perceptual and performance-based parameters, and subsequent performance	Counter-balanced crossover experiment	37 ± 4 mmHg at the maximal calf girth, 31 ± 4 mmHg at the upper ankle and 23 ± 4 mmHg at the lower ankle	Running	Maximal 5 km time-trial on treadmill (CS or control). A subsequent 5 km time-trial was performed 60 min later (without CS)	CS did not affect immediate performance, but had a positive impact on subsequent performance (less decrement from first to the second 5 km time-trial)
Del Coso et al 2014[16]	36 experienced triathletes	35.8±6.3 control 35.0±5.3 CS	To investigate the effects CS to prevent muscular damage and to preserve muscular performance during a half-ironman competition	Matched for age, anthropometric And training status and randomly assigned to CS or control	Not mentioned	Half-ironman Triathlon	Half-ironman Triathlon competition (1.9 km of swimming, 75 km of cycling and 21.1 km of running)	CS did not improve performance, and did not prevent the reduction in lower-limb muscle function, as well as did not reduce post-race muscle damage markers
Gimenes et al 2019[17]	20 under-20 soccer players (men)	18.3±0.5 control 18.4±0.4 CS	To evaluated the effects of using CS on the match-based physical performance indicators, HR and perceptual responses during 2 matches	Randomized (balanced by the playing position)	20–30	Soccer matches	Two soccer matches separated by 72 h	CS minimized the increment of local muscle soreness in the 2nd match; promoted higher distance covered in high-intensity activities

(*Continued*)

Table 1 (Continued).

Date-Author	Subjects	Age	Aim	Experimental Design	CP (mmHg)	Type of Exercise	Exercise Protocol/ Details	Findings
Kemmler et al 2009[18]	21 moderately trained men runners	39.3 ±10.7	To determine the effect of CS on parameters of running performance	Randomized crossover	24	Running	Stepwise Speed-incremented treadmill test to voluntary maximum (every 5 min, speed was increased)	CS improved running performance at various metabolic stages: total work and time under load**, maximum speed, parameters at the anaerobic thresholds
Menetrier et al 2011[19]	14 moderatey trained athletes	21.9±0.7	To determine the effects of calf compression sleeves on running performance and on calf tissue oxygen saturation (sto2) at rest before exercise and during recovery period.	Randomized crossover	18–30	Running	Running time to exhaustion	CS did not improve times to exhaustion performed; However, the StO2 results argue for further interest of this garment during effort recovery.
Miyamoto et al 2011[20]	14 healthy men	25.6±3.7	To examine the effects of wearing a CS, with different pressure profiles during a fatiguing calf-raise exercise session, on the torque generating capacity after exercise.	Randomized crossover	18 and 30	Calf-raise exercise	15 sets of 10 repetitions of calf-raise exercise - 30 s rest between sets	CS with adequate pressure at the calf region relieves muscle fatigue of the triceps surae induced by calf-raise exercise.
Pavin et al 2019[21]	20 amateur female soccer players	20.6±3.9	To evaluate the effect of CS use during an amateur female soccer match on match-induced fatigue indicators	Randomized (balanced by the playing position)	20–30	Soccer match	A single soccer match	CS positively influenced agility and lower limb muscular endurance (standing heel-rise) performances following the match
Rider et al 2014[22]	10 cross-country runners (men and women)	Men 21 ±1.3 Women 18.7±0.6	To determine the effect of CS on physiological variables associated with running performance	Randomized Crossover	15–22	Running	Maximal treadmill test	CS did not improve running performance, but could lend credence to certain manufacturers claims of improved recovery through lower BLa values after exercise

Rimaud et al 2010[23]	8 healthy trained males	21.7±0.9	To investigate if wearing CS during exercise and recovery could affect lactate profile in sportsmen	Randomized crossover	12–22	Cycle ergometer	Incremental cycle ergometer test	CS during graded exercise lead to a significant higher blood lactate value at exhaustion, probably due to a higher lactate accumulation related to a greater overall contribution of anaerobic glycolysis in the energy supply when subjects wore CS during exercise
Sperlich et al 2010[24]	15 well-trained endurance athletes	27.1±4.8	To test three types of compression clothing on well-trained athletes to assess physiological responses and effects on performance	Randomized crossover	20	Running	Incremental test in treadmill	CS did not improved time to exhaustion or resulted in any altered oxygen uptake response, lactate concentration, or ratings of perceived exertion and muscle soreness during maximal and submaximal exercise
Treseler et al 2016[25]	19 recreationally active women	20±1	To examine the physiological and perceptual responses to wearing below-the-knee CS after a 5-km running performance	Randomized crossover	12.6–21	Continuous running	5 km time-trial	CS had no effects on 5 km time and HR, but resulted in less muscle soreness in lower extremities and higher RPE
Varela-Sanz et al 2011[26] (Experiment 1)	16 endurance trained athletes (men and women)	34.7± 6.3	To examine the effect of gradual-elastic compression stock- ings (gcss) on running economy	Randomized repeated-measures design	15–22	Continuous running	4 bouts of 6-min half-marathon pace treadmill running	CS had no effects on running economy and RPE
Experiment 2	12 endurance trained athletes (men and women) *These individuals also participated in experiment 1	Not described	To examine the effect of gcss on kinematics, and running performance	Randomized non–crossover design	15–22	Continuous running	Treadmill running until exhaustion at 105% of the athlete's recent 10-km time and 1% grade	CS resulted in lower $\%HR_{max}$. No effects of the CS were observed for time to fatigue, HR_{peak}, lactate, RPE, $VO_{2\ peak}$, speed, $\%VO_{2\ max}$, and RE

(*Continued*)

Table 1 (Continued).

Date-Author	Subjects	Age	Aim	Experimental Design	CP (mmHg)	Type of Exercise	Exercise Protocol/ Details	Findings
Vercruyssen et al 2012[27]	11 male trained runners	34.7±9.8	To investigate the effects of CS on performance indicators and physiological responses during prolonged trail running	Randomized crossover	18	Continuous running	15.6 km trail-running	CS had no effects on run time, HR, blood lactate concentration and RPE
Wahl et al 2012[28]	9 well-trained, male endurance athletes	22.2±1.3	To test if different levels of sock compression affect erythrocyte deformability and metabolic parameters during sub-maximal and maximal running	Randomized repeated-measures design	0, 10, 20, and 40	Continuous running	30 min sub-maximal running and time to exhaustion thereafter using a ramp test (increase in incline of 1% every minute)	CS had no effects on erythrocyte deformability, heart rate, pO2 and lactate concentration. However, exercise itself significantly increased erythrocyte deformability, with high CS attenuating this effect.
Zadow et al 2018[29]	67 marathon runners (men and women)	46.7 ±10.3	To investigate the effect of wearing compression socks on coagulation and fibrinolysis following a marathon	Randomized controlled trial	Not described	Continuous running	Marathon race (42,195 m)	CS significantly reduced post-marathon D-Dimer concentrations
Zaleski et al 2018[30]	20 runners (men and women)	Control: 35.5±8.0 CS: 36.9 ±8.4	To examine the influence of CS worn during a marathon on creatine kinase levels	Randomized controlled trial	19–25	Continuous running	Marathon race (42,195 m)	CS had no effects on CK levels at baseline, immediately following, or 24h after a marathon race.

Notes: **Time under load means the maximal amount of minutes performed at a submaximal speed (i.e., 9 to 11 km.h^{-1}) to ensure over 30 mins running.
Abbreviations: CP, compression pressure; CMJ, countermovement jumps; CK, creatine kinase; CS, compression stockings; ES Cohen's d, effect size; RPE, rating of perceived exertion.

Table 2 Studies That Found Effects from Wearing CS During Exercise

Study Potential Benefited Variable	Summary	Effects from CS	No Effects from CS
Ali et al 2007[10] Muscle soreness	Experiment 2: CS decreased muscle soreness following each exercise bout, and 24 h after the 10 km time-trial; Performance was not influence by CS (P=0.15)	Experiment 2: Lower perceived muscle soreness potential Individual improvements: 10 of the 14 Participants ran faster ~ 20 s	Experiment 1: Distance covered on the multi-stage fitness Shuttle running test HRmean Perceived muscle soreness RPE Experiment 2: Time to complete 10 km time-trial (mean) Time to complete 1st and 2nd 5 km partial time RPE
Ali et al 2011[11] Muscle fatigue	CS worn (low and medium compression) resulted in greater maintenance of leg power after 10 km, but performance on 10 km did not	Vertical jump height higher (from pre-to post-10 km running) when wearing Low (12–15 mm Hg) and Med (18–21 mm Hg) CS	Time to complete 10 km RPE HRmean High (23–32 mm Hg) CS had no benefit for vertical jump post-10 km
Berry et al 1987[13] Lactate recovery	CS did not affect the VO2max, recovery of VO2max, but blood lactate was lower on the recovery period when CS was worn during incremental treadmill test until exhaustion	Lower blood lactate after the incremental test (at 15 min of the recovery period)	VO2max Time to exhaustion recovery of VO2max
Bieuzen et al 2014[14] Muscle soreness Muscle fatigue-recovery	CS improved post-exercise recovery (perceived leg soreness and muscle function); CS did not influence the performance (15.6 km in mountainous terrain) and markers of muscle damage/ inflammation	Lower perceived muscle soreness Higher isometric peak torque and MVC (knee extensors) at 1 h (ES small) and 24 h post-run All recovery periods on CMJ (ES large)	Time to complete 15.6 km RPE HR responses CK and interleukin-6 levels
Brophy-Williams et al 2019[15] Subsequent performance	CS did not affect immediate performance, but had a positive impact on subsequent performance (1 h later)	Lower decrement from TT1 to TT2 (~9.5 s vs control) on time to complete 5 km	Time to complete TT1 (5 km) Time to complete TT2 (5 km) Oxygen consumption Blood lactate Cross sectional area of calf RPE Perceived muscle soreness Perceived fatigue Perceived recovery
Gimenes et al 2019[17] Muscle soreness Acute performance	CS minimized the increment of local muscle soreness in the 2nd match (two soccer matches with 72 h in-between); CS also improved performance in high-intensity activities during the matches	Minimized the increment of muscle soreness on match 2; Higher distances covered > 19.1 $km.h^{1}$ and ≥ 23 $km.h^{-1}$ on match 1 higher distances covered between 19.1 and 22.99 $km.h^{-1}$ on match 2	Match 1 Perceived soreness and recovery RPE HRmean, HRpeak Internal load (RPE x minutes played) Sprints repetitions Distances covered in total and below 19.1 $km.h^{-1}$ Match 2 Perceived recovery RPE HRmean, HRpeak Internal load (RPE x minutes played) Sprints repetitions Distances covered in total and below 19.1 $km.h^{-1}$

(*Continued*)

Table 2 (Continued).

Study Potential Benefited Variable	Summary	Effects from CS	No Effects from CS
Kemmler et al 2009[18] Acute performance Anaerobic threshold	CS improved running performance and metabolic indicators (anaerobic threshold)	Time under load** (ES 0.40) Total work (ES: 0.30) Running at the anaerobic (ES: 0.22) And aerobic thresholds (ES: 0.28)	VO2max Maximal lactate concentration HRmax Pulmonary ventilation Ventilator equivalent Respiratory exchange ratio
Menetrier et al 2011[19] Oxygen saturation at recovery	CS did not improve performance, however CS increased calf tissue oxygen saturation at rest and during recovery from exercise	Increased calf tissue oxygen saturation at rest (before exercise): + 6.4±1.9% And during recovery: + 7.4±1.7% and + 10.7 ± 1.8% at 20th And 30th min of the last recovery period, respectively	Times to exhaustion performed HRmean HRmax RPE
Miyamoto et al 2011[20] Muscle fatigue	CS had no effect on the decline of MVC, but the extent of reduction of the evoked triplet torque was smaller when wearing CS with a high compression pressure	The decline of the MPF in the CS 30 mmHg was significantly smaller than that in 0 mmHg (control)	Reduction of the MVC torque after the calf-raise among 0 (control), 18 and 30 mmHg CS EMG amplitude during the MVC was decreased, the extent to which was not significantly different among the three Conditions both for the medial gastrocnemius and soleus M-wave amplitude (evoked contraction)
Pavin et al 2019[21] Muscle fatigue	CS positively influenced agility and lower limb muscular endurance performances following a soccer match	After-match kept the time to complete *T*-test Agility (control performed slower) from baseline Control presented greater decrement after-match (ES = 1.27 control vs. CS) in the heel-rise test repetitions from baseline	Distance covered in the Yo-Yo intermittent endurance level 2 after match HRmean, peak and %peak RPE
Rider et al 2014[22] **worst acute performance Lactate recovery	CS did not improve running performance, but seem to improve recovery after exercise	Time to fatigue lower in CS (**negative) Blood lactate lower during recovery (1 and 5 min)	HR blood lactate (during the maximal treadmill test) lactate threshold VO2max Respiratory exchange ratio RPE
Rimaud et al 2010[23] Lactate recovery	CS did not improve performance during graded maximal exercise but lead to a higher contribution of anaerobic glycolysis and improved lactate removal during passive recovery. However, CS efficacy is highly limited	Higher blood lactate value at exhaustion Lactate removal ability was improved (during passive recovery)	Submaximal/maximal HR VO2 Performance (W on VO2max) SBP RPE
Treseler et al 2016[25] Muscle soreness	CS decreased muscle soreness (24 h post-run) in lower extremities, (but not for calf) and presented higher RPE (feelings of working harder with CS); CS did not influence 5 km performance (P=0.74)	Lower perceived muscle soreness 24 h later Potential individual improvement (10 of 19 participants ran faster ~10 s)	Time to complete 5 km time-trial (mean) HR responses Rate of perceived recovery

(*Continued*)

Table 2 (Continued).

Study Potential Benefited Variable	Summary	Effects from CS	No Effects from CS
Varela-Sanz et al 2011[26] (experiment 2) Acute lower cardiac stress	CS resulted in lower cardiac stress during a test at competition pace, but none effects for performance and other physiological and perceptual indicators	Lower HR response during a test at competition pace (ie, 105% best 10 km run)	Time to fatigue HR_{peak} Blood lactate RPE $VO_{2\ peak}$ speed $\%VO_{2\ max}$ Running economy
Zadow et al 2018[29] Lower fibrinolytic activity	CS significantly reduced post-marathon fibrinolytic activity	Lower D-Dimer concentrations post-marathon	Marathon finishing times Thrombin–anti-thrombin complex tissue factor Tissue factor pathway inhibitor

Notes: **Time under load means the maximal amount of minutes performed at a submaximal speed (ie, 9 to 11 $km.h^{-1}$) to ensure over 30 mins running.
Abbreviations: CMJ, countermovement jumps; CS, compression stockings; ES Cohen's d, effect size; HR, heart rate; MVC, maximal voluntary contraction; RPE, rating of perceived exertion; TT, time-trial.

Another study showed CS-induced ergogenic effects on performance. The authors found an improvement in running performance concomitantly with anaerobic and aerobic thresholds when participants wore CS.[18] The benefits of CS-ergogenic effects on performance are attributed to enhanced biomechanical support of the muscles, leading to higher efficiency and lower metabolic costs at given workloads,[18,36] reduction of muscular microtrauma,[6] and enhanced the proprioception.[32] During a 5 km running time-trial (Brophy-Williams et al[15]) the wearing CS did not affect immediate performance. However, CS generated a positive impact on subsequent 5 km running (i.e., less performance decrement from time-trial 1 to time-trial 2). Again, the underlying mechanism of such benefit is unclear but may be related to increased oxygen delivery, lower muscle oscillation, and better running mechanics.[15]

Despite the current results, the literature does not indicate robust evidence favoring the use of CS during exercise (i.e., only three studies found benefits on performance). Researchers should be careful in drawing conclusions. Considering that each specific study has (or had) a particular experimental design (e.g., exercise protocol, duration, intensity, variables measured, fitness level of the participants), it becomes difficult to generalize the results from the different studies. Thus, it is essential to consider the risk of bias and heterogeneity of the studies. As the same protocol does not conduct different studies, they will vary in the characteristics of the included population, interventions, diagnostic methods to access outcomes, etc. (clinical heterogeneity). Thus, these studies may be biased.[37] Additionally, two studies did not find CS-induced effects on group mean performance, but the authors highlighted the individual improvements: 10 of 19 runners ran the 5 km time-trial approximately 10 s faster,[25] and 10 of the 14 runners ran the 10 km time-trial[10] approximately 20 s faster. Therefore, individual responses should be carefully evaluated in practical settings.

CS, Muscle Function and Perceived Muscle Soreness

Some studies in the current review have shown that CS can induce lower muscle fatigue after an exercise protocol with the same workload than a control condition.[11,14,20,21] The lower after-exercise fatigue may suggest a preserved muscle function. Overall, such studies show the maintenance (based on baseline values) of muscle function by a smaller decrement of performance (or none) in specific muscular tests performed after the exercise protocol (e.g., running time-trial, soccer match). On the same reasoning, the lower perceived muscle soreness found in the current review is also a potential beneficial outcome from CS. The smaller muscle soreness may be particularly relevant for more prolonged periods with multiples exhausting physical activities performed with a short recovery period in-between.[17]

In one of the studies, competitive runners (VO_2max ~69 mL.kg.min) completed four 10 km time-trial wearing control CS (0 mm Hg) and CS with different pressures in a randomized, counterbalanced order.[11] The runners performed CMJ tests before and after running as a muscle function indicator. The results showed that CMJ height decreased after control running. However, CMJ performance was improved after running wearing CS (low and medium pressure), suggesting a better maintainance of muscle function.

The authors speculated that improvements in proprioception to jump and reduced muscle oscillations due to CS probably collaborated with lower muscle fatigue.[11]

In other included study, highly trained runners participated in 3 simulated trail races (15.6 km, including uphill and downhill) in a randomized crossover trial.[14] Authors measured indicators of muscle function (and also muscle perceived soreness) at baseline, 1, 24, and 48 h after-run. Muscle function decreased after the race, suggesting the appearance of fatigue, which was partially counteracted by CS. More specifically, a beneficial effect from wearing CS was found for isometric peak torque at 1 h and 24 h post-run and for CMJ throughout the 48 h recovery period. Perceived muscle soreness was also lower when runners wore CS during trail running compared with the control condition (1 h and 24 h post-run). Specific muscle contractions during trail running (e.g., eccentric on the downhill portion) might result in more extensive muscle oscillation and soreness. Thus, CS probably reduced the perceived muscle soreness due to the higher preservation of muscle function.[14]

Miyamoto et al[20] showed that CS promoted a smaller extent of reduction (- 6.4 ± 8.5% for CS vs. −16.5 ± 9.0% for control) of the evoked triplet torque, after a fatiguing protocol (15 sets X 10 repetitions) of calf-raise exercise. The authors suggested that mitigation of muscle fatigue observed in their study could be related to increased venous flow velocity and prevention of the lowering of the intramuscular pH.[20]

Positive CS-induced benefits on muscle fatigue was also described after a soccer match. Female players of both teams (50% each team, randomly wore CS or control socks) performed tests (agility T, standing heel-rise, and YoYo Intermittent Endurance II) 48 h before (baseline) and immediately after the game. CS resulted in less match-induced fatigue for agility *T*-test performance (maintenance for CS and decrement in control players) and heel-rise test (both groups had a decrement on the number of repetitions, but higher in control).[21]

In the current review, some researchers found a beneficial CS-effect on the perceived muscle soreness in lower extremities after the following exercises: high-intensity continuous 10 km road-running,[10] 15.6 km trail in mountainous terrain,[14] in the second match of soccer (72 h between the first game),[17] and 24 h post 5 km time-trial.[25] Overall, those studies suggested a lower perception of muscle soreness due to less extensive muscle damage (lower muscle oscillation), and better proprioception. However, we cannot rule out a potential placebo effect, once it is hard to control such bias due to the nature of compressive CS versus control socks.

CS, Other Potential Benefits, and Final Considerations

Besides performance, muscle soreness, and muscle function indicators, 15 out of the 21 studies selected in this review presented other variables influenced by CS: lower blood lactate levels,[13,22,23] and fibrinolytic activity,[29] higher oxygen saturation,[19] after the exercise protocol (recovery). Also, lower cardiac stress during exercise has been found.[26]

Mitigation of exercise-induced muscle damage is a possible effect according to authors that found benefit from wearing CS in this review. However, none of them measured blood markers of muscle damage (e.g., creatine kinase - CK, lactate dehydrogenase - LDH). Curiously, only three studies measured such markers after-exercise: a marathon race,[12] a 15.6 km trail-running,[14] and half-ironman triathlon competition,[16] and found no effect from CS. The lack of measurements of muscle damage markers on several studies herein included may be due to the experimental design and the fact of "only" wearing the CS during the exercise (i.e., more focus on performance than recovery). Longer time-points of measurement after the activity (e.g., time-course of CK for at least 24 h after-exercise) could be necessary to detect a significant change in CK,[38] for example.

Finally, we highlight that in a real-world scenario, athletes probably will not use a promising ergogenic aid to improve performance (e.g., CS) only once, as the majority of studies included here. Athletes would perhaps try it in a couple of training session and one competition before to make a final decision. Also, in practical terms, athletes usually may combine different strategies to improve performance and later recovery, such as ischemic preconditioning,[39,40] myofascial release, and cold water immersion.[41] Currently, the effects of such strategies (isolated or combined) with CS are unknown. Therefore, the interpretation of our findings should have in mind "to see also the forest, not just the leaf".

Conclusions

Wearing below-knee CS during exercise (or sport/physical activity) improved the actual performance in a small number of the studies analyzed. However, there is some evidence that wearing CS could benefit muscle fatigue indicators and muscle soreness immediately after and hours after an exercise bout (e.g., better recovery until 48 h). Lower muscle fatigue and muscle soreness might be helpful in subsequent exercises or more extended periods of intervention (e.g., several months). Thus, Sports Medicine professionals should consider the individual responses for performance and a potential placebo (or nocebo) effect. Future studies should evaluate longer experimental designs (e.g., several weeks) wearing CS on exercise performance and physiological indicators, once the chronic effects are unknown.

Disclosure

The authors report no conflicts of interest in this work.

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