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Graduated compression stockings: Physiological and perceptual responses during and after exercise

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Abstract

The aim of this study was to examine the effect of wearing graduated compression stockings on physiological and perceptual variables during and after intermittent (Experiment 1) and continuous (Experiment 2) running exercise. Fourteen recreational runners performed two multi-stage intermittent shuttle running tests with 1 h recovery between tests (Experiment 1). A further 14 participants performed a fast-paced continuous 10-km road run (Experiment 2). Participants wore commercially available knee-length graduated compression stockings (pressure at ankle 18–22 mmHg) beneath ankle-length sports socks (experimental trials) or just the latter (control trials) in a randomized counterbalanced design (for both experiments). No performance or physiological differences were observed between conditions during intermittent shuttle running. During the 10-km trials, there was a reduction in delayed-onset muscle soreness 24 h after exercise when wearing graduated compression stockings ($P < 0.05$). There was a marked difference in the frequency and location of soreness: two participants in the stockings trial but 13 participants in the control trial indicated soreness in the lower legs. Wearing graduated compression stockings during a 10-km road run appears to reduce delayed-onset muscle soreness after exercise in recreationally active men.

Keywords: *Heart rate, muscle soreness, performance, running, venous return*

Introduction

Graduated compression stockings have been used as a mechanical method of deep vein thrombosis prophylaxis for several years. They are preferred to other mechanical and pharmacological methods as they are both inexpensive and easy to use. Several studies have demonstrated an increase in mean deep venous velocity, reduced venous pooling, and an improved venous return in hospital patients who wore graduated compression stockings (e.g. Gandhi, Palmer, Lewis, & Schraibman, 1984; Lawrence & Kakkar, 1980; O'Donnell, Rosenthal, Callow, & Ledig, 1979). A possible improvement in venous return during and after exercise may facilitate the clearance of metabolites produced during exercise. Berry and McMurray (1987) hypothesized that reduced lactate concentrations with the use of compression stockings could be due to several factors: lower production of lactate, lactate being retained within the muscle, or the greater blood flow removing and oxidizing the lactate. Their results indicated blood lactate was reduced when wearing stockings but was probably due to the metabolite being retained in the muscle. The investigators used cycling as the mode of activity but running exercise may cause different reactions to graduated compression of the lower limbs.

Kraemer *et al.* (2000) assessed the use of graduated compression stockings on various physiological responses to standing fatigue in women. Following baseline measures, participants were required to perform 8 h of various tasks (i.e. to simulate the activity of a typical office worker) while wearing graduated compression stockings. Both during and immediately after the 8-h period, various measurements were taken. They reported a mediating effect of the stockings on oedema, venous pooling, and discomfort in the lower body and suggested that this could relate to reduced muscle damage (i.e. due to reduced concentrations of creatine kinase). Furthermore, Kraemer *et al.* (2001) showed that the use of compression sleeves during elbow flexion exercise reduced muscle soreness and creatine kinase

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production relative to a control condition. Consequently, a further benefit of wearing graduated compression stockings could be an amelioration of feelings of pain and soreness after exercise.

Although the use of graduated compression stockings by athletes has a rational basis, no rigorous scientific studies have been conducted to demonstrate improved performance, reduced soreness, improved venous return, or improved metabolic clearance after continuous or intermittent running exercise. The aim of this study, therefore, was to examine the influence of wearing graduated compression stockings on several physiological and perceptual responses during and after exercise.

Methods

Participants

Two distinct experiments were conducted as part of this study. Fourteen healthy males (age 22 ± 0.4 years, stature 1.74 ± 0.01 m, body mass 72.9 ± 2.0 kg, $\dot{V}O_{2max}$ 56.1 ± 0.4 ml · kg^{-1} · min^{-1}) volunteered to participate in Experiment 1, and 14 (age 23 ± 0.5 years, stature 1.76 ± 0.01 m, body mass 74.2 ± 2.1 kg, $\dot{V}O_{2max}$ 55.0 ± 0.9 ml · kg^{-1} · min^{-1}) participated in Experiment 2 (10 individuals participated in both experiments). The participants were involved in regular training and competition (and whose primary sport was based on running, e.g. soccer, tennis, rugby) and were recreational runners (i.e. performed at least two training runs of moderate to high intensity and of 30 – 60 min duration per week). All procedures were approved by Loughborough University's Ethics Committee and written informed consent was obtained from all participants.

Preliminary measurements

During the preliminary session, stature, body mass, ankle and calf girth, and perimeter of lower leg immediately below the knee were measured. These measurements were used to determine the correct size of graduated compression stockings for each participant in accordance with the manufacturer's instructions. Participants were briefed on the correct method of wearing the stockings and practised doing so under the supervision of the investigators. They were also fully habituated with the various rating scales and measurement procedures used during the experiments.

The participants were informed that they would be involved in two separate experiments. However, because of injury and other commitments, only 10 completed both. Experiment 1 was conducted initially and, after a 2-week break, Experiment 2 was completed as a separate but related study.

Experiment 1 (intermittent exercise)

Participants completed two trials separated by at least 3 days in a crossover design; that is, the participants acted as their own controls and were randomly assigned to either experimental (graduated compression stockings, GCS) or control (non-GCS) groups and performed each trial in pairs. They were asked to record their food and drink consumption for the day before exercise and to maintain similar intakes for the subsequent trial. The participants were also instructed to abstain from exercise from the day before the trials until the 24 h post-exercise measurements were obtained.

During the intervention trials (INT-GCS), the participants wore commercially available knee-length graduated compression stockings (Venosan, 4001, St. Galen, Switzerland). These stockings provide graduated compression, which is highest at the ankle (18 – 22 mmHg), with the pressure decaying by 70% to the top of the stocking. Standard (non-compression) ankle-length athletic socks were worn over the top of the compression garment to prevent slippage within the running shoe. During the control trials, the participants wore only the ankle-length socks (INT-CON). These garments were chosen for control purposes, as the participants routinely wore this type of sock when running. The graduated compression stockings (and/or ankle-length socks) were worn after baseline measurements were taken and before the first exercise bout and were removed after measurements were taken following the second exercise bout (Figure 1). The stockings were not worn during the following 24-h recovery period, as we wanted to determine the effects of wearing the graduated compression stockings *during* exercise on subsequent recovery.

The participants reported to the laboratory after a 10 – 12 h overnight fast. Ambient temperature was measured using a whirling hygrometer (Brannan Thermometers Ltd, Cumberland, UK) immediately before the first multi-stage fitness shuttle running test (Ramsbottom, Brewer, & Williams, 1988). The protocol of this test requires participants to complete 20-m shuttles at a progressive pace. The test begins at a low speed of 2.22 m · s^{-1} and gradually increases by 0.14 m · s^{-1} every minute. The participants were required to place one foot on or over a taped line in time with an audible signal (i.e. a "beep"); each taped line was exactly 20 m away from the other. Participants dropped out or were withdrawn from the test by the investigators when they failed to keep up with three successive bleeps. Nude body mass was determined using a beam balance scale (Avery Ltd, model 3306 ABV, Birmingham, UK) before exercise and after the second recovery period (Figure 1). Heart rate was monitored continuously

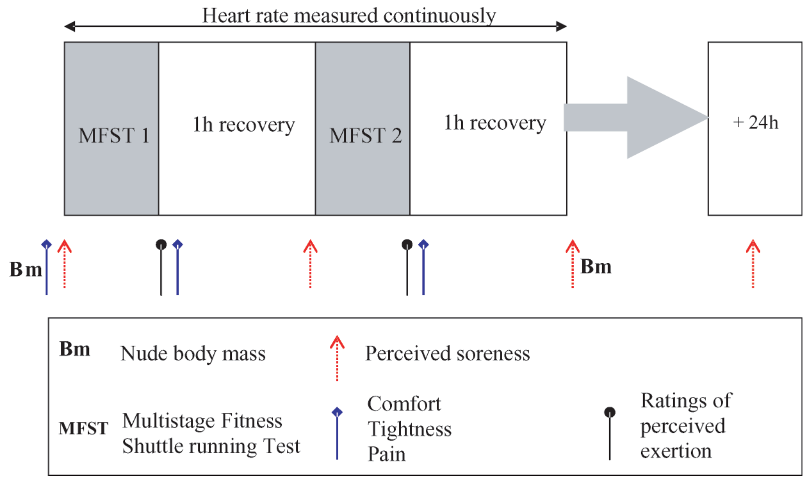

Figure 1. Schematic representation of the protocol for Experiment 1.

throughout the trials by short-range telemetry (Vantage NV, Polar, Finland) and downloaded using the appropriate software. The participants ingested water *ad libitum* on the first trial and the same amount was administered during the second trial.

Ratings of perceived soreness and labelling of the musculature to indicate the location of soreness were gauged pre-exercise, following each exercise bout and 24 h after exercise. These methods are described in more detail elsewhere (see Thompson, Nicholas, & Williams, 1999). Briefly, the participants were given a coloured pen to indicate the location of soreness on a figure depicting various muscle groups. Furthermore, they indicated whole-body soreness using an 11-point scale that ranged from 0 = "not sore" to 10 = "very, very sore".

To monitor the comfort and feel of wearing the graduated compression stockings, three 11-point rating scales were used to assess "comfort", "tightness" (of fit), and any "pain" associated with wearing the stockings. The anchors on the scale ranged from 0 = "very uncomfortable" to 10 = "very comfortable", 0 = "very slack" to 10 = "very tight", and 0 = "no pain" to 10 = "very painful" respectively. These scales were administered following the initial wearing of the graduated compression stockings and after each exercise bout (GCS-INT only). Ratings of perceived exertion (RPE) were determined immediately after each exercise bout.

Experiment 2 (continuous exercise)

The participants completed two randomized trials separated by at least 3 days. They reported to the laboratory after fasting for at least 3 h and were instructed not to perform any physical activity in the 24 h before or after exercise.

Before the main trials, the participants were required to complete the previously established 10-km tarmac route at least once and the times(s) obtained were used to determine the running pace for the main trials. A field-based rather than laboratory-based treadmill protocol was chosen so as to examine the effects of wearing the graduated compression stockings during typical training runs (i.e. to maintain ecological validity). It is well established that treadmill running reduces the peak impact force experienced by the runner compared with overground running on stiff surfaces such as tarmac. The pace was maintained for the participants by one of the investigators riding beside them on a bicycle throughout the trial. Time checks were made at regular and frequent intervals around the course to ensure the pacing was genuinely consistent throughout the whole of the run. Participants wore the graduated compression stockings under ankle-length sports socks in the experimental trial (10 km-GCS) but only the sports socks in the control trial (10 km-CON). Ambient temperature was measured before the start of exercise and was found to be consistent between conditions. Nude body mass was measured both before and after exercise. Heart rate was measured continuously during exercise. Ratings of perceived soreness and location of soreness were measured before and immediately after exercise as well as 24 h after exercise. The scales used to monitor the comfort and feel of the stockings were administered before and after exercise (10 km-GCS only). Ratings of perceived exertion were determined immediately after exercise.

Statistical analyses

The data were examined using a two-factor (treatment × time of measurement) analysis of variance

(ANOVA), with repeated measures for correlated data (SPSS version 10). Mauchly's test of sphericity was used to determine whether the assumption of sphericity was being violated by the data. When this was the case, the Huynh-Feldt correction was applied (SPSS). When differences were found, paired t-tests with Bonferroni adjustment were used to ascertain where the differences lay. Student's t-test for correlated data was also used to examine differences between trials. The data are presented as means ± standard errors of the mean. Statistical significance was set at $P < 0.05$.

Results

There were no trial order effects for any of the variables measured and so any significant differences between trials were as a direct result of the treatment.

Experiment 1

There was no difference in exercise performance between the two conditions (2213 – 2272 m; Table I). There was no difference in heart rate between conditions and pre-exercise rates were achieved after the 1-h recovery periods. The maximum heart rate (197 ± 1.6 beats · min^{-1}) achieved during the intermittent exercise was the same between conditions. There were no differences in ratings of perceived soreness between conditions. Moreover, the ratings were relatively stable, especially in the intervention group, throughout the trials. There were no differences in RPE immediately after each bout of exercise between conditions. On the comfort questionnaire, mean scores of 6 – 8 (moderate to high) were reported by the participants for "comfort" and "tightness". Furthermore, mean values of ~2 were reported for "pain".

Experiment 2

Run times for the 10 km-GCS and 10 km-CON trials were similar (44.7 and 45.0 min, respectively; $P = 0.15$) (Figure 2). However, it should be noted that 10 of the 14 participants ran faster in the stockings trial with one participant running exactly the same time. There was a tendency for heart rate to be higher during the 10 km-CON trials but this was not statistically significant ($P = 0.15$) (Figure 3). There was no difference in RPE between trials and the ratings of "comfort", "tightness", and "pain" were similar to those in Experiment 1 (Table II).

Ratings of soreness 24 h after exercise were significantly higher in the 10 km-CON condition (interaction of treatment × time, 3 ± 0.6 vs. 5 ± 0.4, $P < 0.05$) (Figure 4). Figure 5, constructed using methods described previously (Thompson *et al.*, 1999), shows the frequency and location of perceived soreness during the 10-km trials. In the control condition, 11 and 13 of the 14 participants reported soreness in the left and right calves respectively, while only 2 participants reported the same in the 10 km-GCS trial. Furthermore, there were reduced frequency reports for the knee flexors in the 10 km-GCS trial.

Discussion

The aim of this study was to examine the effectiveness of graduated compression stockings on physiological and perceptual responses during and after intermittent and continuous running. The main finding was a reduction in muscle soreness 24 h after

Table I. Performance, physiological, and perceptual data from Experiment 1.

		MFST 1		MFST 2			
Distance run (m)	INT-GCS	2213 ± 77		2247 ± 84			
	INT-CON	2272 ± 75		2225 ± 67			
		Pre-ex	Mean	Pre-ex	Mean	1 h post	24 h post
Heart rate (beats · min^{-1})	INT-GCS	85 ± 1	164 ± 3	79 ± 3	171 ± 3	81 ± 3	
	INT-CON	73 ± 4	165 ± 3	74 ± 3	169 ± 3	79 ± 4	
Perceived soreness	INT-GCS	3 ± 0.5		3 ± 0.4		3 ± 0.6	3 ± 0.5
	INT-CON	2 ± 0.2		3 ± 0.4		4 ± 0.5	3 ± 0.7
RPE	INT-GCS		17 ± 0.5		17 ± 0.4		
	INT-CON		17 ± 0.4		17 ± 0.4		
Comfort and feel ratings (INT-GCS)	Comfort	7 ± 0.4	6 ± 0.5		7 ± 0.4		
	Tightness	8 ± 0.3	6 ± 0.5		6 ± 0.4		
	Pain	2 ± 0.2	3 ± 0.5		2 ± 0.5		

Note: MFST = multi-stage fitness shuttle running test; RPE = ratings of perceived exertion; INT-GCS = intermittent exercise experimental trial; INT-CON = intermittent exercise control trial.

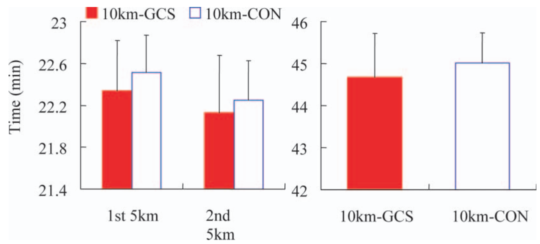

Figure 2. Mean time to complete 10 km during the continuous running trials. 10 km-GCS = continuous exercise experimental trial; 10 km-CON = continuous exercise control trial.

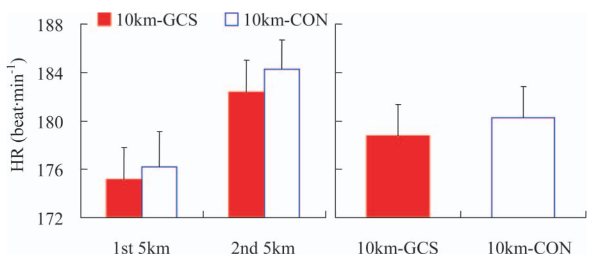

Figure 3. Mean heart rate (HR) during the continuous running trials. 10 km-GCS = continuous exercise experimental trial; 10 km-CON = continuous exercise control trial.

Table II. Ratings of perceived exertion (RPE) and comfort, tightness, and pain ratings from Experiment 2.

	Pre-exercise	Post-exercise
RPE		
10 km-GCS		17 ± 0.5
10 km-CON		17 ± 0.5
Comfort and feel ratings (10 km-GCS only)		
Comfort	8 ± 0.5	8 ± 0.3
Tightness	6 ± 0.3	6 ± 0.5
Pain	1 ± 0.3	2 ± 0.4

Note: 10 km-GCS = continuous exercise experimental trial; 10 km-CON = continuous exercise control trial.

a bout of high-intensity continuous road-running while wearing the stockings.

Experiment 1

There were no significant differences in any of the experimental variables between conditions. After exercise, there was no increase in perceived muscle soreness above baseline values (Table I). Thus, the exercise protocol was insufficient to promote myofibrillar damage or was not of long enough duration to highlight any possible benefits of wearing graduated compression stockings. Future research should investigate the efficacy of graduated compression stockings during an intermittent protocol that is longer in duration and has previously been shown to induce delayed-onset muscle soreness (Thompson *et al.*, 1999).

Experiment 2

During the continuous exercise trials, participants were required to complete 10 km at a fast, controlled pace. We used this exercise protocol not for performance reasons but to provide an exercise stressor that was consistent between conditions, with the main aim of examining the effects of wearing graduated compression stockings on subsequent recovery. Despite the measures taken to ensure consistency in running pace between experimental conditions, there was a trend ($P = 0.15$) for participants to perform the distance slightly quicker in the 10 km-GCS trial (Figure 2). Indeed, 10 of the 14 participants ran faster (mean of 20 s faster) in the experimental condition. Utilizing a treadmill protocol would have alleviated this issue but we wanted to assess the effect of wearing graduated compression stockings in an athlete's natural environment and so maintain a high degree of ecological validity. Future studies should be conducted to assess the impact of wearing the stockings during exercise on a treadmill to maintain consistency between trials.

Heart rate was used as a surrogate measure of venous return during this study (based on the assumption that increased venous return will improve end-diastolic volume and stroke volume, thus eliciting a reduced heart rate response to maintain similar cardiac output). This is a crude method of assessing venous return but one we consider worthy of note. Although not statistically significant ($P = 0.15$), heart rate tended to be lower in the 10 km-GCS trial even though run times tended to be quicker. Based on previous research (albeit mainly in the clinical setting), this would make intuitive sense. Lewis *et al.* (1976) reported an enhanced clearance of stagnant blood from behind venous valves due to improved valve function. Furthermore, using various indirect methods, compression garments have been shown to increase deep vein blood velocity by up to 80% relative to control conditions (Benko, Kalik, & Chetty, 1999; Lawrence & Kakkar, 1980). Therefore, compression stockings do appear to improve venous return but rigorous studies, in more controlled settings and using more sophisticated techniques, are required.

There are two generally recognized types of muscle soreness after exercise: *immediate-onset soreness*, which is characterized by pain during and immediately after exercise, and *delayed-onset muscle soreness*, which increases in intensity for the first 24–48 h after exercise and then declines during the next few days (Plowman & Smith, 2003). Figure 4 shows the ratings of perceived soreness during the

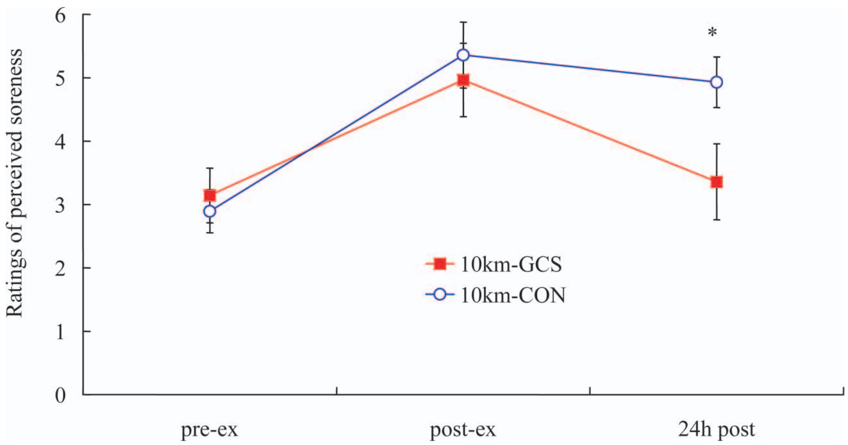

Figure 4. Ratings of perceived whole-body soreness during the continuous running trials. *Significantly higher in the 10 km-CON trial, $P<0.05$. 10 km-GCS = continuous exercise experimental trial; 10 km-CON = continuous exercise control trial.

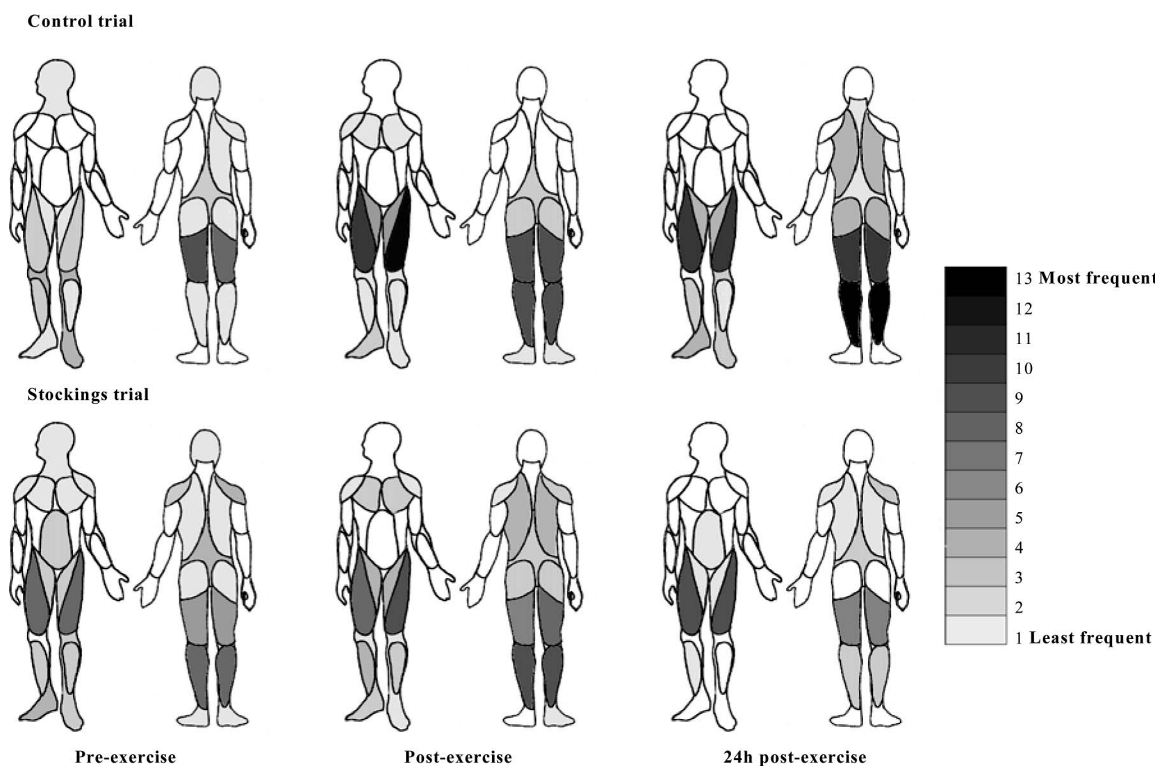

Figure 5. Location and frequency of soreness during the continuous running trials.

continuous exercise trials. There was no difference in immediate-onset soreness between conditions but there was a reduction in perceived soreness 24 h after exercise in the 10 km-GCS trial ($P<0.05$). Additionally, there was a marked difference in the frequency of reported soreness 24 h after exercise, especially in the lower extremities (Figure 5). As there was no "placebo" condition, it could be argued that this finding is a result of the participants' intuition of expected findings. However, as there was no difference in soreness ratings during the intermittent trials (Experiment 1), this is unlikely to have occurred. Future research might consider using graduated compression stockings exhibiting different compression levels; this approach would also enable the investigators to incorporate a placebo garment in the study design.

Wearing graduated compression stockings during running appears to reduce delayed-onset muscle soreness after exercise. This could have important implications not only for elite or semi-elite runners, but also for individuals who wish to embark on exercise regimes but may be deterred due to the associated pain following exercise.

Armstrong (1984) suggested that the mechanisms responsible for delayed-onset muscle soreness are related to mechanical trauma – that is, mechanical forces in the contractile or elastic tissue results in structural damage to the cells. Damage to the sarcolemma then leads to a disruption of calcium homeostasis and cell necrosis follows. Thereafter, the presence of immune cells and cellular debris leads to inflammation and swelling that results in delayed-onset muscle soreness. In the current study, the stockings might have had the effect of compressing the muscle tissue to such an extent that less structural damage occurred. Although not measured in the present study, Kraemer *et al.* (1998) did report reduced oscillations of muscle when LycraPower tights were worn, and noted also a reduction in creatine kinase activity. Future investigations with graduated compression stockings would also benefit from using blood markers, such as creatine kinase activity and myoglobin concentration, and use of a pressure algometer to quantify the extent of muscle damage and soreness after exercise.

In summary, wearing graduated compression stockings during fast-paced, continuous road running reduces muscular soreness of the lower limbs after exercise. The mechanism by which this reduction is achieved remains uncertain, although a reduction in muscle soreness may result from reduced structural damage and/or reduced localized ischaemia. In physically active young men, at least, graduated compression stockings are perceived to be comfortable to wear and heighten perceptual feelings during and after exercise. We were unable to confirm whether there was an improved venous return during exercise, although a trend towards reduced heart rate during continuous road running suggests that this is possible and thus warrants further research. Furthermore, there is a need for research investigating whether graduated compression stockings can benefit other user groups including untrained participants, female and older athletes.

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